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MERRIMACK RIVER

ANADROMOUS FISHERIES INVESTIGATION

1978

Prepared for

PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE
Manchester, New Hampshire

by

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I. INTRODUCTION

A. HISTORICAL SHAD FISHERIES OF NEW HAMPSHIRE

Although American shad presently are not abundant in New Hampshire waters, they were historically abundant in both the Merrimack and Connecticut Rivers. The following account of the Merrimack River shad fishery has been excerpted primarily from Mansueti and Kolb (1953). The early history of shad in New Hampshire has also been presented by McDonald (1887), Bailey (1938) and Marston and Gordon (1938).

Dams in the Merrimack River have prevented shad from entering the watershed since 1847 when the river was crossed at Lawrence, Massachusetts, by a 9.75 m dam equipped with a wooden fishway at the southern end. Twelve miles upstream at Lowell, a 9.1 m dam was constructed in 1830 and enlarged in 1876. Four other dams were subsequently located upstream of Lowell at Manchester (constructed in 1871), Hooksett, Garvins Falls and Sewalls Falls, New Hampshire. In addition, seven dams were constructed on the Winnipesaukee River.

Prior to construction of these dams, large quantities of shad ascended the Merrimack River to Lake Winnipesaukee. Stevenson (1899) estimated that 830,000 shad were harvested from the Merrimack River in 1789; catches decreased to 50,000 per year in 1865, and to less than 1,000 by 1882. Marston and Gordon (1938), describing the early shad runs in New Hampshire wrote:

> The shad ascended the river mostly in May and June and soon deposited their spawn, selecting for that purpose bodies of water larger and of higher temperature than the spawning places of the salmon. The spring run of shad usually coincided with the appearance of the apple blossoms and the arrival of the shad fly. Their eggs were hatched out in a few weeks and the young fish were ready to return to the sea early in the autumn. The old shad returned to the sea in August and were very poor and not considered worth catching. The young ones migrating in September were only three or four inches long.

After completion of the Lowell Dam in 1847, migratory fish could no longer ascend the river. Fishways were constructed at several of the dams in 1866, 1867 and 1868, but the designs were faulty and did not permit migratory fish passage. Subsequent remodeling of the fishways through 1877 permitted alewives and lampreys to ascend the river. By 1880 alewives again appeared at Amoskeag Falls in Manchester, New Hampshire; alewives have been observed at Amoskeag Falls as recently as 1971 (Wightman and Newell, 1971). Restoration of the American shad, however, was more difficult. Live adult shad were transported from the Merrimack below the Lawrence Dam to reaches farther upstream during 1867. Coincidently, Connecticut, Vermont and New Hampshire jointly funded a juvenile shad rearing program for stocking in the Merrimack and Connecticut Rivers. In July 1867, approximately one million eggs were released into the Merrimack River at Concord, and several thousand fry were released into Lake Winnipesaukee. Many shad were hatched in the Merrimack River and Lake Winnipesaukee during 1869, but none of the shad returned to spawn naturally, probably because the fishways had not been reconstructed at that time. In 1875 the State of Massachusetts released more than 800,000 young shad in the river above Lowell, and, as a result, more adult shad were observed in the lower reaches of the river. However, ice damage to the fishways during 1877 and destruction of many juvenile shad by commercial menhaden fishing in the Merrimack estuary severely depleted the shad stocks. Although New Hampshire introduced 170,000 juvenile shad into the Merrimack below Hooksett Falls in 1886, adult American shad never returned to the Merrimack system.

B. PROJECT BACKGROUND

The Merrimack River has again been selected for restoration of Atlantic salmon (*Salmo salar*) and American shad (*Alosa sapidissima*) through the cooperative efforts of New Hampshire and Massachusetts state agencies and the U.S. Fish and Wildlife Service. Recent Merrimack River shad stocking began in 1969 with the release of fertilized eggs of Connecticut River origin into Hooksett Pond, Bow, New Hampshire. Egg releases have continued on an annual basis; eggs were released above the Sewalls Falls Dam at Franklin, New Hampshire from 1970 to 1974, in the Essex Pool, Lawrence, Massachusetts during 1975, in Hooksett Pond during 1976, and in Pawtucket Pool, Lowell, Massachusetts during 1977 (Technical Committee for Fisheries Management of the Merrimack River Basin, 1978).

Representatives of the agencies involved in the restoration program are concerned that the Public Service Company of New Hampshire's (PSCoNH) 470 megawatt Merrimack Generating Station, located on the Hooksett Pond reach of the Merrimack River may interfere with the successful reintroduction of salmon and shad to the river. Primary concerns include effects such as thermal blockage of upstream and downstream migrations, entrapment of juveniles on the travelling screens, and the entrainment of eggs and larvae in the station's cooling system and in the thermal plume. In 1975, the Public Service Company's NPDES Permit No. NH0001465 was modified such that cold-water stream standards would be enforced unless specific research could show that less stringent standards would adequately protect the potential anadromous fishery resources. As a result, Normandeau Associates, Inc. (NAI) was contracted by Public Service Company to design and implement studies necessary for this research.

In conjunction with river monitoring studies, NAI completed American shad studies during 1975 and 1976 that (1) delineated current velocities near the plant intake structures and discharge canal as well as temperature distributions throughout Hooksett Pond; (2) numerically modeled current velocities throughout Hooksett Pond; (3) determined downstream transport characteristics of developing eggs; (4) characterized several aspects of early larval behavior including their apparent ability to withstand downstream transport; (5) determined egg and larvae tolerance to rapid temperature increases through laboratory bioassay, *in situ* bioassay, and literature review; and (6) synthesized this information into an assessment of potential pump entrainment and thermal shock mortality for American shad eggs and larvae should the restoration of a spawning adult population to Hooksett Pond be successful. Results of these studies were contained in two reports submitted to PSCoNH in May 1976 and February 1977 (NAI, 1976b; 1977b), and are summarized as follows:

Based on physical data, laboratory observations and existing entrainment sampling programs at other powerplants, the probability of entraining significant numbers of American shad eggs directly in the Merrimack Station cooling water is extremely low. Near-bottom velocities are generally insufficient to remove eggs from shelter at low river discharge levels, when the power plant cooling water volume represents a substantial proportion of total river volume. At discharge levels high enough to remove eggs from shelter, the intake's zone of influence is small in terms of cross-stream distance and the proportional volume of the cooling water flow; therefore, the likelihood of entrainment is also small. The probability of egg entrainment in the thermal plume is also low; near-bottom velocities are insufficient to effect the suspended-load transport necessary for eggs to be elevated into the warmest water layers. Furthermore, temperatures even in the warmest regions of the Merrimack Station discharge are not warm enough to be lethal over the short exposure periods which typically would be experienced by the few eggs which might be entrained.

Larval entrainment is considerably more difficult to assess than egg entrainment. Potential pump and momentum entrainment rates depend on downstream transport rates which are, in turn, dependent upon larval responses to environmental variables which have not yet been adequately described. Data from existing powerplants suggest that larval pump entrainment is not likely to be significant. Entrainment, however, cannot be dismissed entirely, due to the apparent surface and streamside orientation of the larvae. Similarly, momentum entrainment may be experienced by larvae undergoing downstream transport. Water temperatures within the thermal plume's warmest areas are generally less than the lethal levels determined for larvae; however, lethal levels may be approached should unusually warm and dry periods occur during late June and early July.

Although proposed in 1976, a radio telemetry study to determine the responses of juvenile shad to the thermal discharge was not conducted because juveniles were not captured. Despite stocking 4.3 million fertilized shad eggs in Hooksett Pond during May and June 1976, intensive seining from late August through October failed to capture any juvenile shad. However, it is likely that the unseasonably high river discharge levels and low water temperatures, resulting from heavy precipitation during early August, induced the downstream migration of any juvenile shad present in Hooksett Pond prior to the initiation of seining.

C. OBJECTIVES

The agencies involved in shad restoration believed that the inability to collect juvenile shad from Hooksett Pond in 1976 left some question as to the effects of the Merrimack Generating Station on successful rearing of American shad in Hooksett Pond. Therefore, to meet permit requirements and agency requests, Normandeau Associates, Inc. conducted further studies for PSCoNH during 1978 to determine whether the Merrimack Station and its thermal discharge will have detrimental effects on American shad survival in Hooksett Pond. This objective was fulfilled by introducing both fertilized eggs and gravid adults into Hooksett Pond during 1978 in sufficient numbers so that larvae and/or juveniles could be subsequently captured or observed within Hooksett or Amoskeag Ponds before migrating downstream.

D. STUDY AREA

1. Physical Description

Hooksett Pond is a 9.3 km section of the Merrimack River, New Hampshire, bounded on the southern, downstream end by Hooksett Dam at river kilometer 130.4 and on the northern, upstream end by Garvins Falls Dam at river kilometer 139.7 (Figure 1; Appendix I, Figure 1). Both dams are low-head (4.6 and 10.1 m, respectively), run-of-river type peaking hydropower units; neither has significant storage capacity. Garvins Falls is currently operated by PSCoNH for peaking power, and river flow varies according to power demand with a minimum required discharge of approximately 14.2 m^3/s (cms). Hooksett Dam is maintained by PSCoNH to maintain suitable head for the cooling system at Merrimack Station, to generate hydroelectric power, and to regulate river flow for Amoskeag Dam, located 12.6 km downstream.

Physically, Hooksett Pond is fairly homogeneous. The reach from Garvins Falls downstream to the Soucook River (Figure 1) changes quickly from a rapidly-flowing tailrace and spillway area to a broad, shallow reach typified by a sand bottom with several extensive shoals and sandbars. A short distance below the Soucook River confluence the river becomes somewhat constricted. Current in this reach is stronger and, as a result, the substrate grades from sand to cobble. Eddies are present except for an area between Stations N-8 and N-9. In this region, several macrophyte beds are noticeable late in the growing season.

The river is fairly uniform below Merrimack Station southward to the confluence of the Suncook River (Figure 1). This reach is characterized by sediment ranging from sand to cobble with macrophyte beds along the banks. Southward from the Suncook River, the Merrimack becomes progressively wider and deeper, with more varied substrate. Under low-flow conditions, impoundment by Hooksett Pond is evident upstream to the vicinity of Station S-19, at other times, the entire reach is riverine.

Garvins Falls discharge varies from a low of about 14.2 cms to a maximum of over 850 cms during an annual cycle (Appendix I, Figure 2). Annual discharge maxima due to snowmelt usually occur during April and early May while minima occur from late July through September. During late May and June, when shad passage and spawning in Hooksett Pond would most likely occur, flow is usually between 42.5 and 226.5 cms with a minimum of approximately 28.3 and occasional spates of over 283.2 cms.

Ambient Hooksett Pond temperatures during May and June typically average about 12.8 and 19.4°C, respectively and range from 5.6 to 25.6°C.

Sampling stations have been established and marked at transects north and south of the discharge canal mouth. These are numbered N-1 to N-10 and S-1 to S-24, respectively (Figure 1). Stations N-1 through N-6 are 152 m apart; N-6 to N-10 are 305 m apart. Stations south of the discharge canal (S-1 to S-24) are located at 152 m intervals. The north stations, particularly N-10, are used to characterize ambient river conditions as contrasted with the thermally affected zone south of the discharge canal.

2. Indigenous Biota

Hooksett Pond supports a diverse, productive aquatic community as revealed by past monitoring studies. Most notable is the indigenous warm-water fish community supporting a high-quality sport fishery, especially for smallmouth bass (*Micropterus dolomieui*). Additional warm-water game species include largemouth bass (*M. salmoides*), pickerel (*Esox niger*), yellow perch (*Perca flavescens*), pumpkinseed and redbreast sunfish (*Lepomis gibbosus* and *L. auritus*) and white perch (*Morone americana*). A complete list of indigenous and introduced fish species is contained in Appendix I, Table 1.

3. Merrimack Station

Merrimack Station is situated at river kilometer 135, approximately midway between the Hooksett and Garvins Falls Dams. Two units of 120 and 350 MW require a total water volume of 12.6 cms for once-through condenser cooling with a designed maximum temperature increase (Δt) of 12.8°C. Cooling water is drawn through two intake structures on the river's west bank at Station N-5 (Figure 1a): each is equipped with a 9.5 mm mesh travelling screen. Water velocities in the Unit I and II intake structures average 45.7 cm/sec.

After passing through the station, cooling water is circulated through a 1189 m discharge canal equipped with 54 banks of 4 (216 total) power spray cooling modules (psm). The thermal plume assumes the form of a warmwater surface lens upon entering the Merrimack River. This surface lens is generally confined to the west bank during high-flow periods, but crosses to the east bank when water levels are low. The plume cools rapidly through mixing as it progresses downstream, with the immediate area of thermal influence generally extending as far south as the confluence of the Suncook River. Southward to Hooksett Dam mixing occurs progressively such that waters exiting the pond at Hooksett Dam are fully mixed with a 2.3°C maximum ΔT.

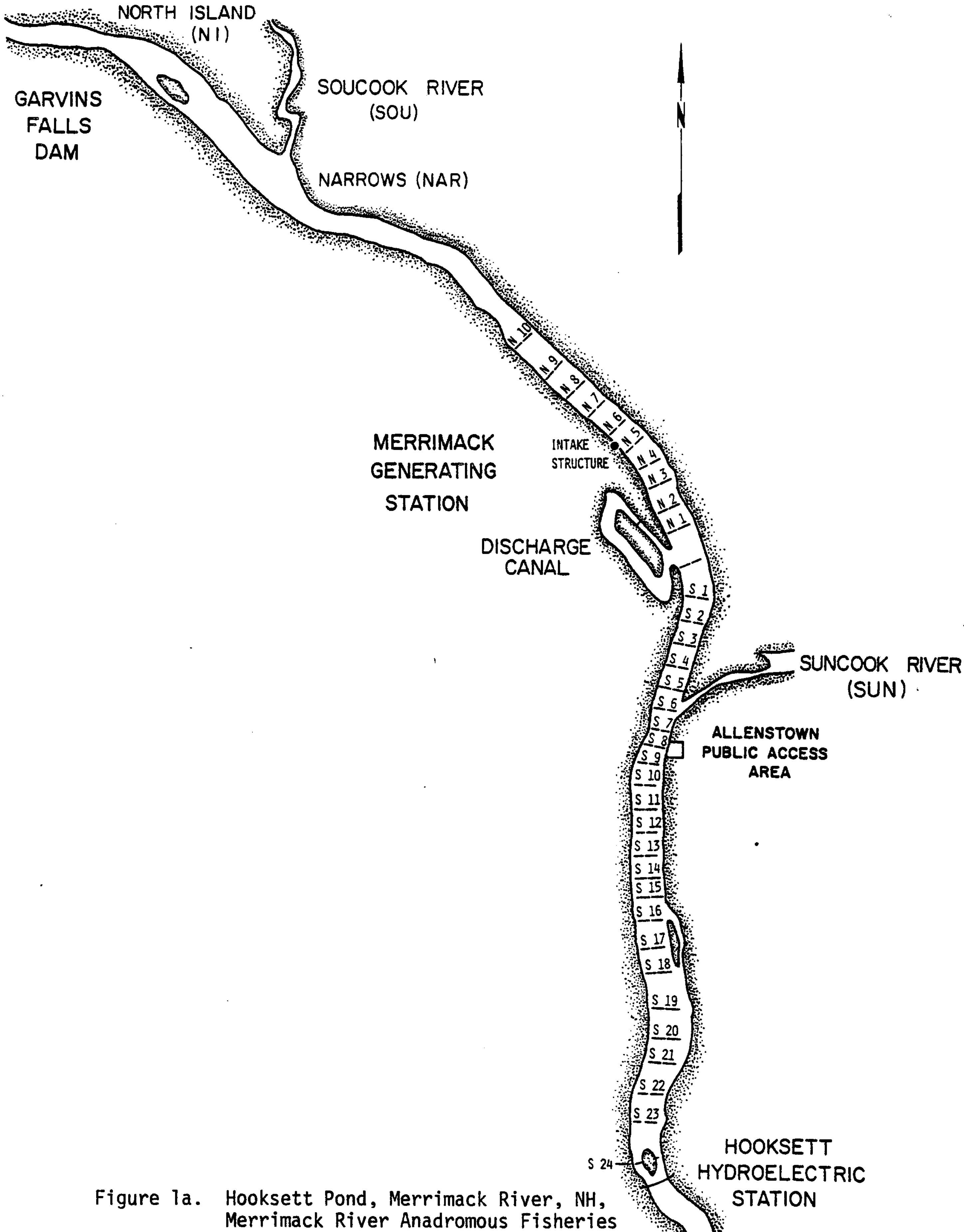

Figure 1a. Hooksett Pond, Merrimack River, NH, Merrimack River Anadromous Fisheries Investigation, 1978.

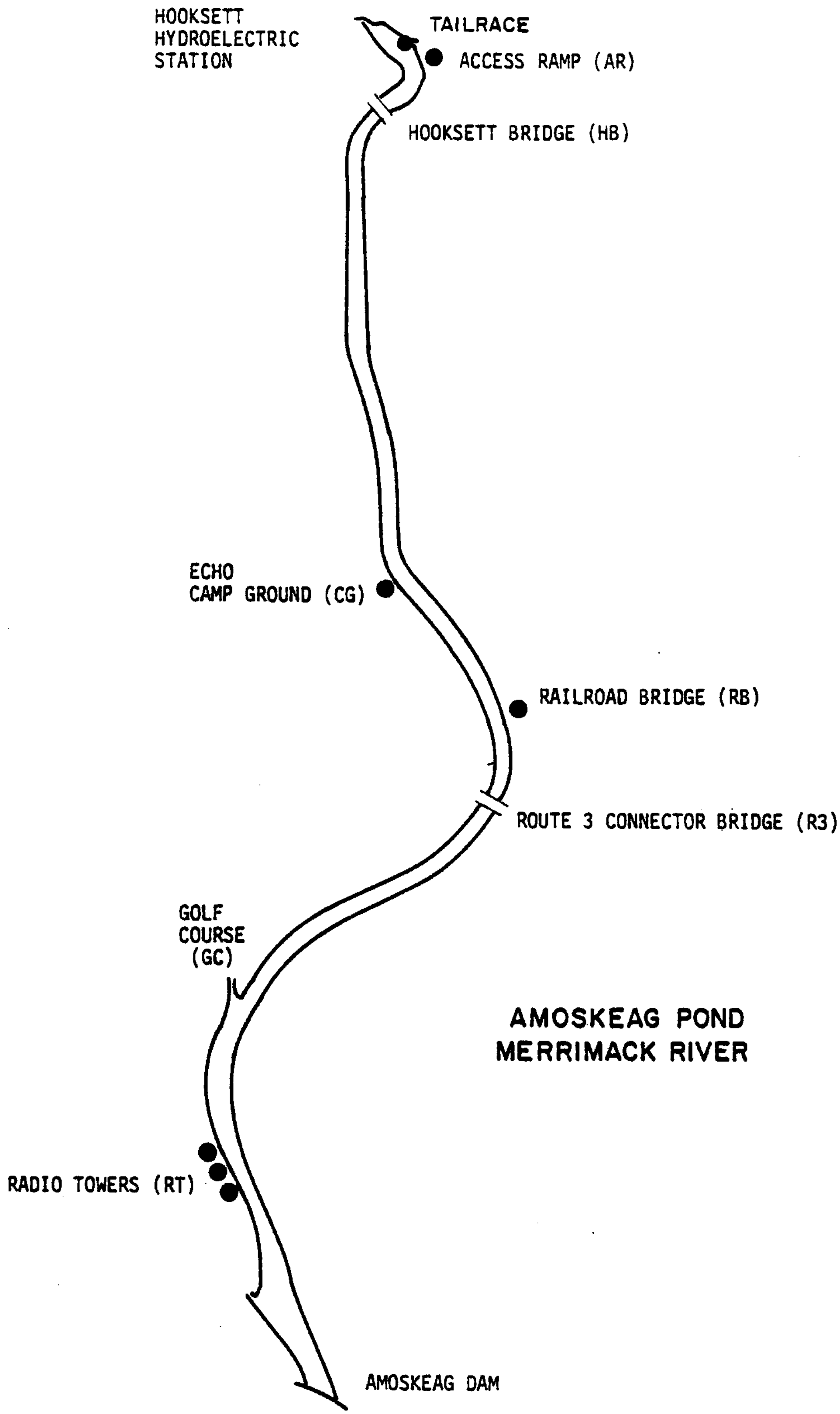

Figure 1b. Amoskeag Pond and designated landmarks for identifying seining stations. Merrimack River Anadromous Fisheries Investigation, 1978.

II. METHODS

A. SHAD INTRODUCTION

Because American shad do not presently ascend the Merrimack River beyond Lawrence, Massachusetts, it was necessary to introduce shad from the Connecticut River. On June 9, 1978, 780,000 fertilized shad eggs were obtained by stripping ripe female shad gill netted from the Connecticut River below the Holyoke Dam. These eggs were artifically inseminated between 2100 and 2400 hours, water hardened and transported to Hooksett Pond. A sample of approximately 1300 fertilized eggs was removed for viability testing, and the remainder were released into Hooksett Pond upstream of the Soucook River confluence at 0430 hours, June 10. The eggs saved for viability determinations were separated into three batches and placed into three hatching boxes (Carlson, 1966; NAI, 1977b) anchored at the egg release site. Each evening all dead eggs were removed, samples were taken for egg staging, and the number of live eggs and/or larvae remaining was recorded. All egg and larvae samples were preserved in 5% buffered formalin, and returned to the laboratory where all eggs were counted and staged to estimate development rates. Shad eggs were classified into three developmental stages: 1) early stage, used to denote that period from spawning until the forming embryo is visible but its outline is indistinct from the surrounding cells, 2) mid-stage, from the time that the embryo outline is distinct until tail bud separation, and 3) the late stage, denoting all eggs from tail bud separation until hatching.

In addition to stocking eggs, adult American shad were transported from the Holyoke Dam on the Connecticut River to Hooksett Pond. Fish and wildlife agencies from Massachusetts and Rhode Island transported the shad in trucks specially constructed for that purpose. These vehicles have a cylindrical 5677.5 liter (1500 gal) tank with a closed-cycle water circulation and aeration system (O'Brien and Stolgitis, 1976). The shad were introduced into Hooksett Pond at the Allenstown, New Hampshire public access area just downstream of the Suncook River confluence (Figure 1). The number of fish, sex-ratio and percent mortality during transportation were recorded for each truckload.

Prior to releasing the shad from the truck, four or five shad were removed by dip-netting and tagged with a radio frequency tag. These 30.000 to 30.300 MHz transmitters with 30-day batteries were attached externally behind the dorsal fin by inserting two 10-lb test monofilament lines through the epaxial muscles via #15 hypodermic needles, and tying the ends together. After being tagged, the shad were placed in a 2.4 x 2.4 x 1.2 m (12 mm bar mesh) live car anchored in the littoral zone at Station S-8-E. All shad swimming vigorously and appearing to be in good condition after one hour were released into the Merrimack River through a gate in the live car wall. In each case at least four shad were released simultaneously.

A 12-channel receiver with loop antenna was used to locate each of the tagged fish. A tracking crew actively followed the tagged fish for 48 hours following their release. Thereafter, a crew surveyed the entire reach from Hooksett Dam to Garvins Falls Dam between 1600 and 2200 hr each evening to locate the tagged shad. During these evening trackings, crew members also looked for surface splashing that is typical of shad spawning activity in an attempt to locate spawning regions.

Drift nets were set daily from 2000 to 2200 hr at various locations throughout the Pond to capture recently spawned eggs still drifting in the water column. These 1/2 meter, 505 μm mesh nets were set just above the river substrate as illustrated in Figure 2a. While the drift nets were set, a benthic trawl (100 cm wide by 50 cm high) with a 505 μm mesh was towed along the substrate to collect eggs that had settled out of the water column. These tows were not standardized as to distance or time of towing, but were intended to provide a qualitative idea of egg distribution. All eggs collected were preserved in 5% buffered formalin.

River temperatures were recorded on an event basis during sampling for shad eggs, larvae and juveniles, and upon release of adult shad into the river. In addition, the temperature distribution within Hooksett Pond was mapped on May 31. Cross-sectional thermal profiles were measured at Stations N-10, N-5, N-1, Zero, S-2, S-4, S-6, S-8, S-10, S-14, S-18, S-22 and S-24 using a calibrated NAI field thermistor unit. Each transect consisted of six equidistant locations across the river; temperature was measured at 0.34 m depth intervals at each location.

B. LARVAL SHAD MONITORING

To assess the presence of larval American shad, larval seining was begun on June 22, and continued until July 24. Throughout this period, seining was conducted three days per week for a total of 16 days. On each day, from eight to sixteen stations throughout Hooksett Pond were seined with a 12.2 x 1.2 m bag seine containing 6 mm mesh wings and 515 μm mesh bag. This seine was dragged parallel to the shore at each station for at least 30.5 m, and then pulled into shallow water. Juvenile fish were examined and released. Larvae within the net were examined in the field, and a representative sample was preserved in 5% buffered formalin for identification. These samples were later examined in the laboratory and American shad larvae were enumerated.

In addition to seining, the resident fish population was sampled beginning on June 14 for gut-content analysis to determine if shad larvae were being consumed, thus indicating their successful survival within Hooksett Pond. Fyke netting and seining were used to capture resident species for gut content analysis. Fyke nets were set at Stations N-10 and S-4 one week per month as part of the Merrimack River Monitoring Program (NAI, 1978a). These nets were set for 2 nights, twice per week and tended at dawn or dusk. Fyke nets were also set at N-10 and S-4 two additional nights per month, and tended every morning or evening. Two roving fyke nets were set for two nights per week at various locations throughout Hooksett and Amoskeag Ponds, with the fishing effort divided equally between these regions. These nets were set for two continuous days and tended each morning or evening.

Resident predator species were also collected by seining each week at Stations N-10, Zero, S-4 and S-17 as part of the Merrimack River Monitoring Program, and at four additional stations throughout Hooksett Pond. All seining was performed at dusk or dawn to obtain stomach contents subjected to a minimum amount of digestion.

After collecting the predators by the methods described, all smallmouth bass, largemouth bass, pumpkinseed, redbreast sunfish, pickerel, white perch and yellow perch caught were held in water containing MS-222 in quantities specified in manufacturer's instructions. Each anesthetized fish was removed from the bath, and its stomach contents were pumped out using a modification of the pulsed gastric lavage technique (Foster, 1977). Gut contents were preserved in 5% buffered formalin and returned to the laboratory for sorting and identification of the eggs and larvae.

To determine the potential pump entrainment susceptibility of larval American shad, the water flowing into Unit I was sampled on a diel basis three days per week from June 1 to July 27. A recessed-impeller trash pump rated at a maximum 41,000 gph with 4" suction and discharge pipes was used to sample water from three depths (Figure 3). Every 24 hrs the pump was calibrated by recording the time required to fill a 208 l (55 gal) drum. The pump was run at a constant speed throughout the subsequent 24-hour sampling period; total run time multiplied by the calibration figure (gallons per unit time) gave an estimate of total water volume filtered. Water from the three intake pipes was pumped into a 505 μm mesh 1/2 meter net suspended in a 208 l drum. Suspending the net in water helped prevent mutilation of the larvae against the mesh. Sample nets were changed every four hours; samples were washed from the net into a 1.9 l bottle and preserved in 10% buffered formalin. All larvae were hand sorted from the sample debris in the lab and represerved in 5% buffered formalin prior to identification and enumeration.

From June 17 through June 26 the ichthyoplankton pump system was not operated because of maintenance problems. On scheduled sampling evenings during this period a gang-net was set approximately 3 m upstream of the Unit I intake to capture any larval shad drifting toward the intake. These nets were set from 1930 to 2230 hours because previous pumping had indicated maximum larval drift during that period of the day. The gang-net was similar to the drift nets used to capture eggs, but contained two 1/2 meter nets tethered onto the same float line (Figure 2). One net was suspended just below the surface, and the other was suspended 1/3 of the water column depth above the substrate. All gang-net samples were processed the same as the ichthyoplankton pump samples.

No ichthyoplankton entrainment samples were obtained from July 10 to 20 because of dredging operations at the Unit I intake and maintenance of the ichthyoplankton pump.

C. JUVENILE SHAD MONITORING

Juvenile shad in Hooksett and Amoskeag Ponds were monitored by seining, visual observations, predator stomach-content sampling, and trapping downstream migrants.

Seining for juvenile shad was conducted in Hooksett Pond two days per week during August, and one day per week during September and October using a 45.7 x 3.7 m bag seine (6 mm bar mesh). Juvenile shad seining was also conducted from August through October in Amoskeag Pond one day per week. On both ponds the daily effort was expended throughout the river reach. Once shad were collected in one portion of the river, the remainder of the day would be spent in other areas to document juvenile shad distribution.

Visual observations of shad movement or feeding activity during seining activities were also recorded. In addition, the forebay of Hooksett Hydroelectric Generating Station was checked randomly several days per week during August, and daily during September, October and November. Water temperature at the forebay was also measured during these observation periods. The forebays of Amoskeag Hydroelectric Station were also observed for juvenile shad several days per week from September through November.

Resident piscivores were seined one day per week during September and October in Amoskeag and Hooksett Ponds. The stomach contents of all predators large enough to feed on juvenile shad were sampled to determine whether or not resident populations were utilizing the introduced forage source. Gut contents were sampled using the pulsed gastric lavage technique.

Downstream migrating juveniles were sampled using a custom-made trap net in the tail race of Hooksett Hydroelectric Station. The dimensions and placement of this net are illustrated in Figures 4 and 5. Most of the water flowing from Hooksett Pond into Amoskeag Pond passed through the Hooksett Power House; the only exception to this was occasional water that was spilled through the trash gate. By designing the trap net such that its mouth occupied 50% of the cross-sectional area of the tail race, approximately 50% of the water volume moving downstream from Hooksett Pond into Amoskeag Pond was sampled by the trap net.

The net was installed on August 16, and sampling was conducted three days per week from August 21 to September 29. Thereafter until November 10, the trap was fished five days per week. Because the generating station did not release water at night, the trap net was normally fished between dawn and dusk. To collect a sample, the removable cod end was installed for four-hour intervals. At the end of this period, the fish were removed from the cod end and preserved in 10% buffered formalin. In the laboratory, the juvenile shad were measured (total length, mm) and weighed (total weight, grams). Length-weight relationships of shad from Hooksett Pond (including the Hooksett tail race trap samples) and Amoskeag Pond were calculated separately using the formula:

$$\text{total weight} = a\ (\text{total length})^{n}$$

where a and n are calculated constants.

To determine the potential entrapment susceptibility of juvenile shad on the intake screens at Merrimack Station, screen wash samples were collected for 48 continuous hours each week from July 31 through September 11. Entrapment samples were not collected during the weeks of August 28, September 26 and October 10 and 30. Screen wash samples were collected for only 8 to 24 hr per week from September 18 through October 23. The screen washings were sorted, all fish were identified, measured (total length), and discarded. Entrapment monitoring alternated on successive weeks between Units I and II while both units were operating.

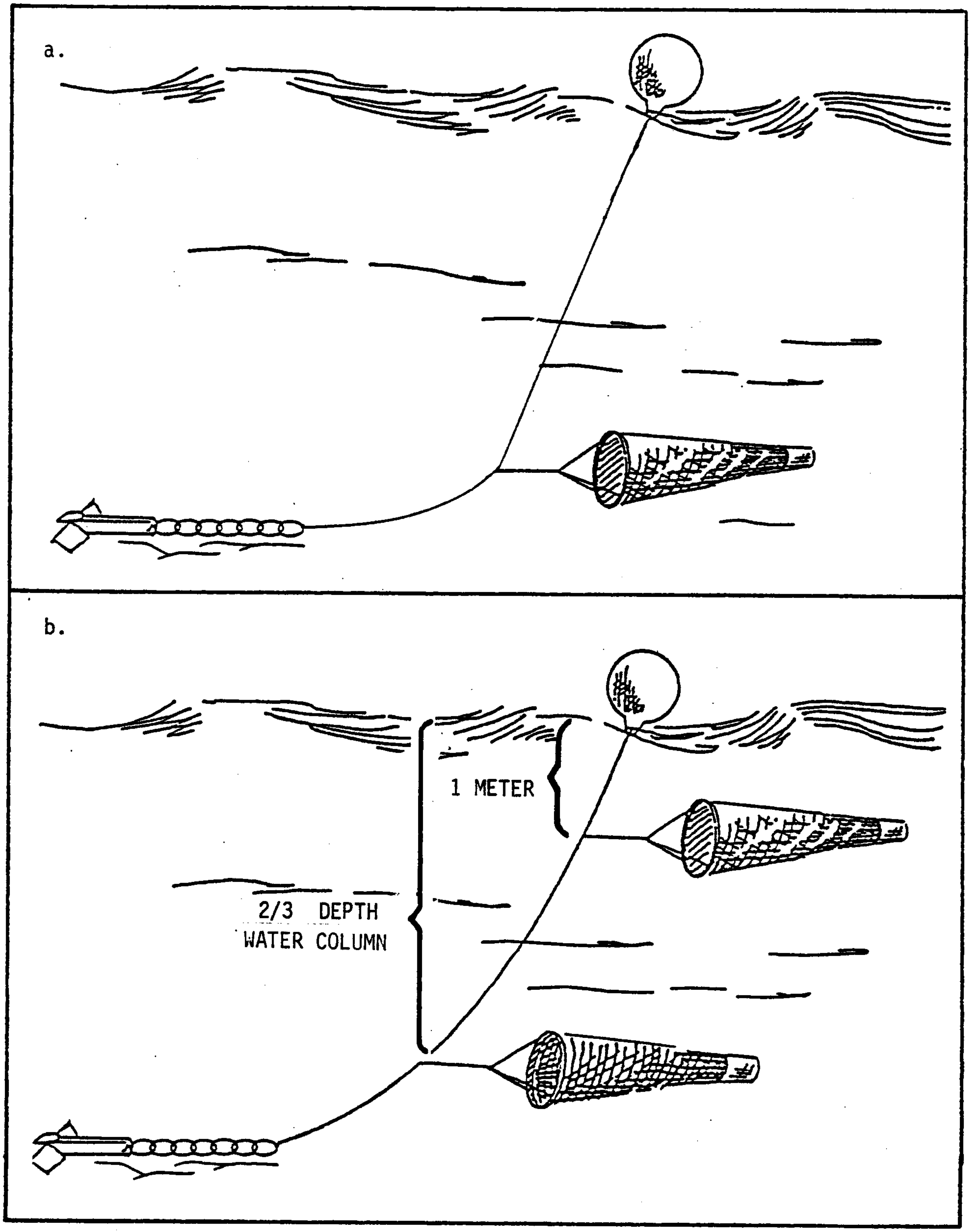

Figure 2. Plankton net arrangement for (a) detecting egg drift and (b) egg and larvae entrainment. Merrimack River Anadromous Fisheries Investigation, 1978.

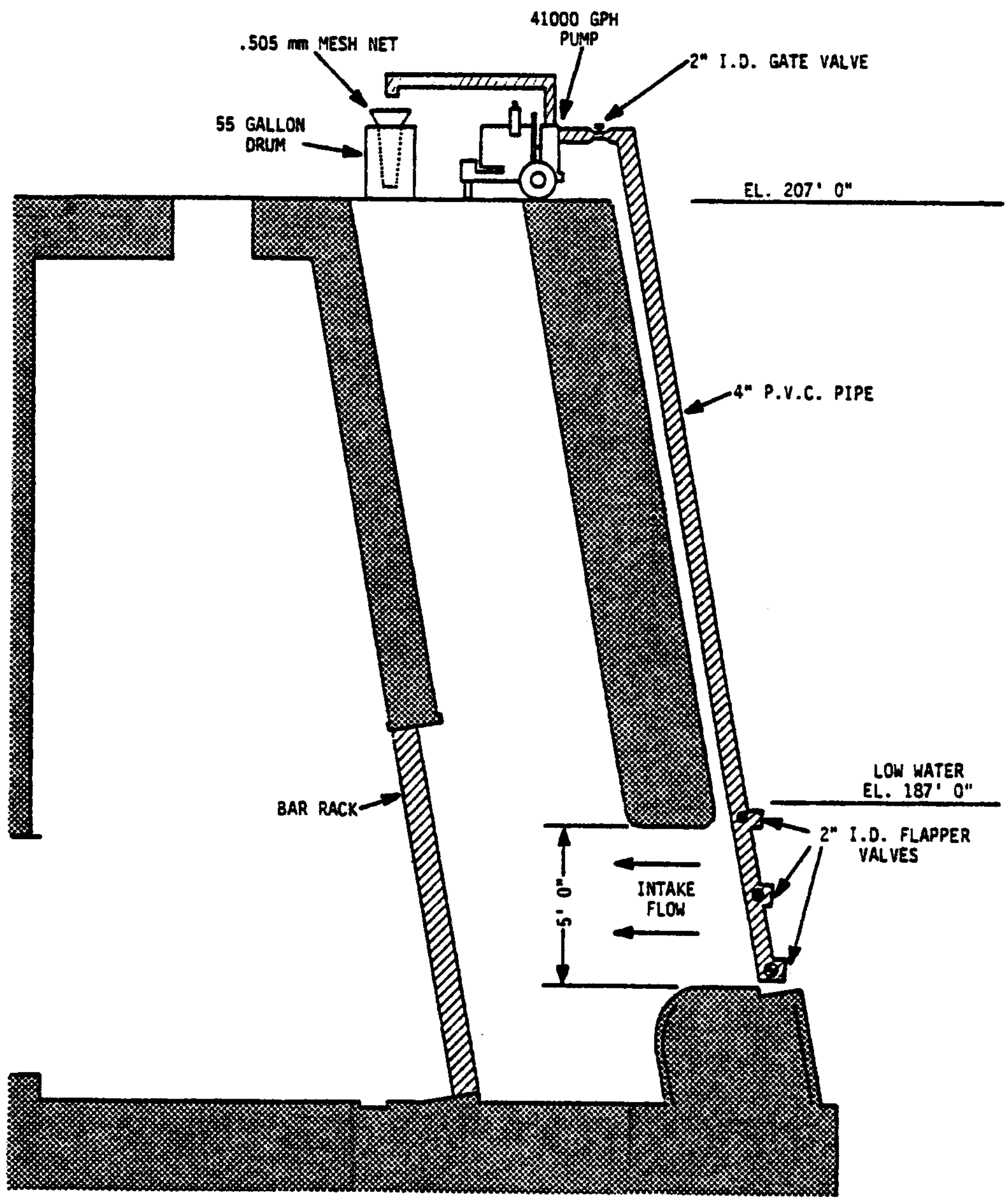

Figure 3. Diagram of ichthyoplankton entrainment sampling equipment. Merrimack River Anadromous Fisheries Investigation, 1978.

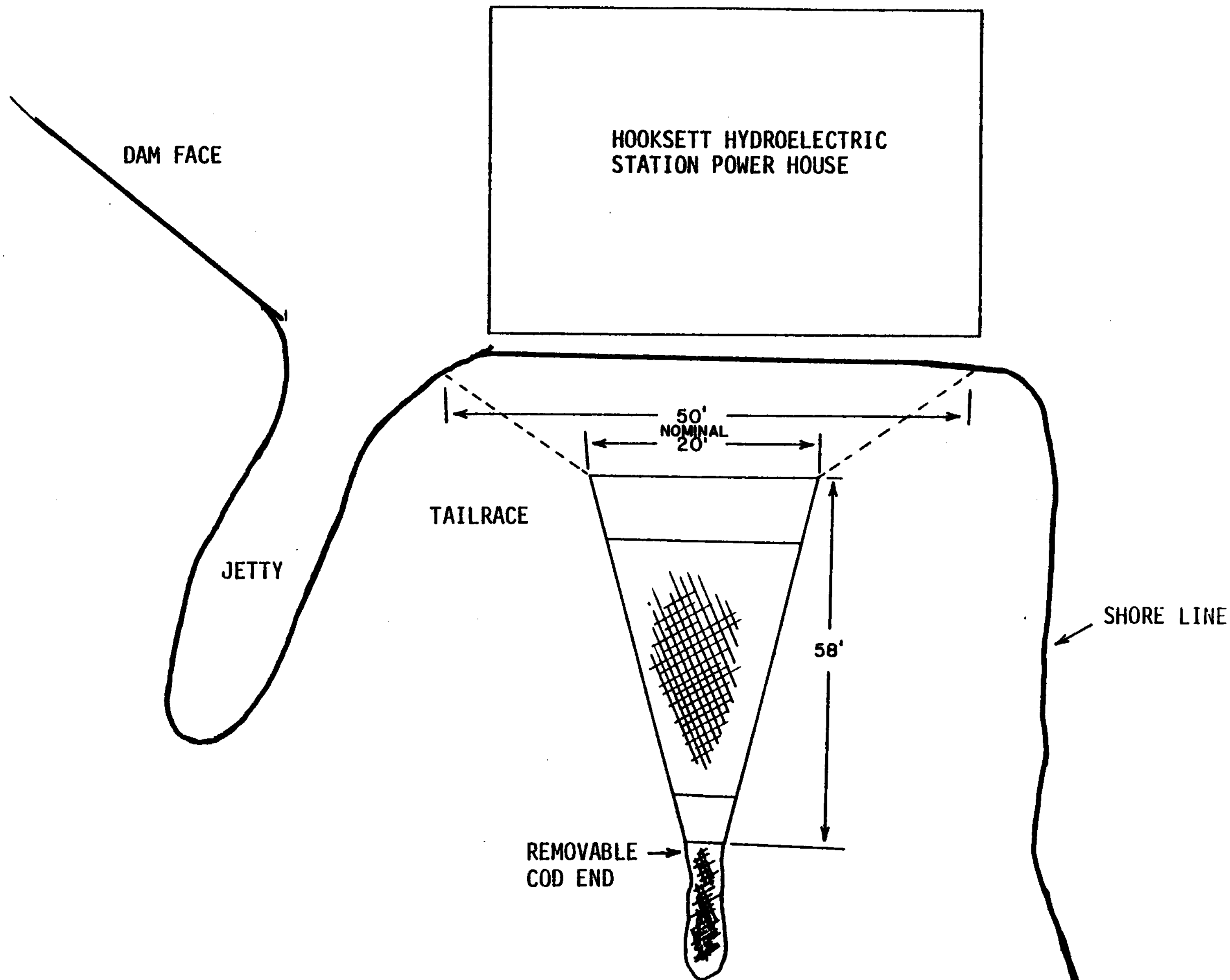

Figure 4. Diagrammatic top view of fish trap used to capture juvenile shad migrating downriver at Hooksett Hydroelectric Station. Merrimack River Anadromous Fisheries Investigation, 1978.

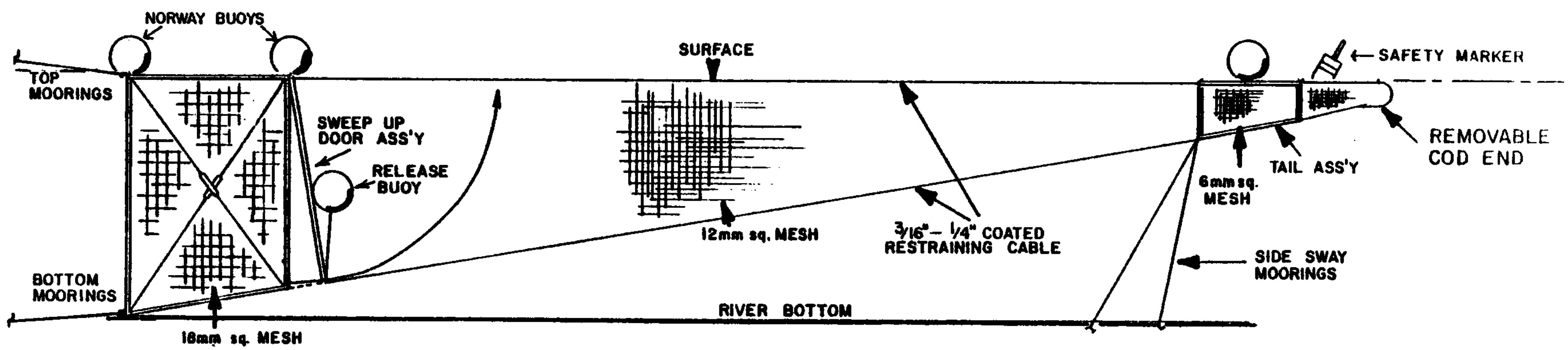

Figure 5. Diagrammatic side view of fish trap in the tailrace of Hooksett Hydroelectric Station. Merrimack River Anadromous Fisheries Investigation, 1978.

III. RESULTS AND DISCUSSION

A. SHAD INTRODUCTION

1. Fertilized Eggs

On June 10, 780,000 fertilized shad eggs were released into Hooksett Pond upstream of the Soucook River confluence. Three samples were retained for *in situ* culture at the release station. Hatching success of the cultured eggs was 64.8 to 88.6% giving an expected hatching rate of 77.8% (606,800 larvae) for the eggs released (Table 1). Most eggs hatched within five to seven days (120 to 168 hrs) after fertilization. Thus, all eggs released into Hooksett Pond should have hatched on or before June 17.

Wightman and Newell (1971) reported an incubation period of 60 to 74 hours from fertilization to hatching for American shad eggs in the Merrimack River at water temperatures varying between 18.3° to 22.8°C. Based on Watson's (1968) regression equation describing the rate of development as a function of water temperature, Marcy (1972) calculated a development time of 103 hrs at 22°C and 217 hrs at 14.8°C for Connecticut River shad eggs in 1967 and 1968. Water temperatures on the Merrimack River ranged from 16.7 to 18.4°C during the seven-day period following introduction of fertilized eggs. At these temperatures, an incubation period of 159 to 186 hours (7 to 8 days) would be expected based on Watson's regression equation, hrs = 729.06 - 8.75(°F). This estimate is slightly higher than the observed incubation period of 5 to 7 days.

In 1976, 4.43 million American shad eggs were released in Hooksett Pond. Hatching success was lower than in 1978, ranging from 51 to 66%. Hatching success of artificially fertilized eggs released into the Merrimack River from 1969 through 1977 has ranged from 0% to 94%, but typically fell within the range of 50% to 80% (TCFMMRB, 1978).

2. Adult Shad Transportation

On June 1 and 2, 690 adult American shad were transported from the Holyoke Dam on the Connecticut River to Hooksett Pond. Mean mortality in the six truckloads during transportation was 9.6%, resulting in a total of 624 live shad released into the Merrimack River (Table 2). Males dominated the spawning population in early June at the rate of 1.7 males per female. Because the shad that died in transit were not sexed, a sex-independent mortality rate was assumed. Dividing 624 shad by the 1.7:1 ratio yielded an estimate of 393 males and 231 females released into Hooksett Pond.

Shad fecundity in New England rivers varies between approximately 150,000 and 450,000 eggs per female depending on the population and its age composition (Walburg and Nichols, 1967; Leggett, 1969; Lehman, 1953). Based on this range, the 231 females introduced into Hooksett Pond had the potential for spawning 34 to 104 million eggs.

Water temperatures at the time of shad release varied from 22.5 to 25.2°C at the release point; these temperatures were typically 2 to 3°C higher than Connecticut River temperatures.

Trucking adult shad has been successfully used to introduce American shad stocks into the Susquehanna River (Whitney, 1961) and from the Connecticut River into the Pawcatuck River, Rhode Island (O'Brien and Stolgitis, 1976), and the Charles River, Massachusetts (DiCarlo, pers. comm.). However, this was the first re-introduction of adult shad to the Merrimack River since 1867. Fertilized shad eggs have been stocked in the Merrimack River each year since 1969, but adults had not been released prior to 1978.

3. Adult Shad Movement

On June 2, fourteen shad were netted from the transportation trucks for radio-frequency tagging (Table 3). Five shad, designated as

Fish A through E, were tagged at 1300 hrs. By 1430 hours all five shad (3 males, 1 female, 1 unsexed) appeared to be in excellent condition and were released. River temperature was 23.7°C on the surface and 22.3°C near the substrate at the release point. Shad A, C, D and E initially moved upstream, while Shad B remained near the release location for approximately one hour (Appendix II, Figures 1 through 5).

Two male and two female shad, designated as Shad F through I, were tagged at 1445. By 1530 all were actively swimming within the holding pen, and were released. Shad F remained near the release station for approximately one hour before moving downstream (Appendix II, Figure 6). Shad G was released, but never subsequently relocated with the tracking equipment. Shad H moved immediately downstream, and Shad I moved immediately upstream.

At 1530 five more shad (3 males, 1 female, 1 unsexed) were tagged (Shad J through N). By 1620 four of the five shad were in good condition and actively swimming throughout the holding net. They were released at 1620, but Shad L was dying, and its tag was removed. Shad J and M were never located after being released. Shad K moved immediately downstream, and Shad N swam directly upstream (Appendix II, Figures 11 and 13).

Of the 13 shad released, three (G, J, M) were never relocated, four (B, F, H, K) moved downstream without ever ascending north of the release point, two (E, I) swam upstream a short distance before they were lost, and four (A, C, D, N), all of which were males, ascended the river past the Merrimack Generating Station. Shad A and C swam from S-8 to N-3 within 3 hours after being released; surface water temperature at O-M was 22.2°C when these shad moved past the discharge canal. Both shad subsequently turned around and descended to the Hooksett Dam during the evening. Shad A remained just above the dam for approximately 40 hours (Appendix II, Figure 1), but Shad C was observed in this region only until the afternoon of June 3. Shad N also ascended from S-8 to N-3 within 3 hours of release. However, this fish was not located again until 1805 on June 4 when it was observed just above Hooksett Dam (Appendix I, Figure 13). Shad D exhibited a complex series of movements throughout Hooksett Pond (Appendix II, Figure 4). Initially Shad D swam upstream to Station S-4 within one hour of release (1530), but subsequently descended to Station S-23 by midnight where it remained at least until 0415 on June 3. This fish again moved upstream and was found at Station N-2 at 1240. It swam upstream past the generating station intake structures (N-5) at 1340, and reached N-8 by midnight. This fish subsequently moved downstream and was last observed just above Hooksett Dam at 1740 on June 4. When Shad D initially ascended to S-4 and started to move downstream, the water temperature at 0-M was 22.2°C throughout the water column. During its subsequent travel upstream past the discharge canal on June 3, river temperatures at 0-M were 25.3°C on the surface and 22.1°C near the substrate. The thermal conditions at that time did not prevent upstream movement of this shad.

On May 31, two days before the adult shad were tagged, the temperature distribution of Hooksett Pond was mapped (Appendix I, Figure 3). Mean daily river discharge was 118.2 cms, and ambient river temperature was approximately 22°C. Water temperatures at the discharge canal mouth reached 33.2°C, but thermal stratification caused a maximum plume depth of 2 meters. There was a clear "zone of passage" in which the water temperature did not exceed ambient levels downstream from the discharge canal. Behavior of Shad A, C, D and N indicate that those adults moving upstream through the mixing zone did not experience thermal blockage to migration, and successfully ascended past the discharge canal and into ambient river conditions. Monitoring of Hooksett Pond temperatures since 1968 (NAI, 1969; 1971; 1972; 1973; 1974; 1975; 1976; 1977a; 1978a; 1978b; Wightman, 1971) has indicated that the cooling water discharged from Merrimack Station generally forms a surface plume 1 to 2 m deep. Beneath this layer, ambient river temperatures generally prevail. Thus, this ambient zone of passage is typically present throughout the mixing zone.

Similar conditions were reported at the Connecticut Yankee Atomic Plant (CYAP) by Leggett (1976). Discharge water approximately 9°C warmer than ambient is released into the Connecticut River. This heated water overlies the cooler river water and is seldom in contact with the substrate except in the immediate vicinity of the discharge canal. Tracking of 27 shad through the discharge area indicated no elevation in temperature along the path followed by 33% of the shad, largely because the fish ascended along the river bank opposite the thermal plume. Eighteen other shad migrated upstream in the vicinity of the plume, but it was not determined whether the shad swam through the plume or under it in the underlying ambient water. Seven of these 18 shad made direct upstream migration with no alterations of orientation or swimming speed. The remainder exhibited some meandering near the discharge before moving upstream. Generally, Leggett (1976) indicated that no thermal blockage to upstream or downstream migration of adult shad exists at CYAP. This results from 1) the location of the river channel along the bank opposite the thermal discharge, and 2) thermal stratification which restricts the plume to the upper 2 m of the water column, providing a pathway under the plume.

Two shad (A and F) were observed to remain immediately above Hooksett Dam for 40 to 57 hours, respectively, before they could no longer be located. Both shad were active, moving throughout the entire river width. This river section is comparatively deep, up to 7.5 m. Layzer (1976) reported that shad preferred remaining in deeper river sections between periods of active upriver migration. The only shad actually tracked over Hooksett Dam was Shad K. This fish descended into the rapid water just below the dam at 0415 on June 3, and remained in that region for at least 3 hours. Searching of Amoskeag Pond, emphasizing the upper reaches, on June 4 failed to locate this shad or any of the other fish that may also have descended into Amoskeag Pond.

Leggett (1976) reported that American shad tagged in the Connecticut River also made initial downstream movements after tagging. When the shad were externally tagged, downstream movements resulted from a combination of active downstream migration and passive drift. These fish were subsequently observed farther upstream. When internal tags were used, a higher proportion of tracked shad moved upstream after release, although some actively travelled downriver. Similarly, Carlson (1966) reported that six sonic tagged adult shad released in the Conowingo Reservoir on the Susquehanna River during 1964, moved generally downstream although upstream movement of tagged shad was observed during 1965. Based on these observations, the initial downstream movements of five of the thirteen American shad introduced into Hooksett Pond are not surprising. Leggett (1976) attributed the high frequency of initial downriver movement by tagged shad to physiological shock and disorientation related to capture and tagging. Shad released into the Merrimack River were subjected to the additional stress of transportation from the Connecticut River. Therefore, downstream movement of adult shad may have been due to the above mentioned factors and not an avoidance of specific factors such as the Merrimack Station thermal plume.

Although no tagged shad were located after June 5, there were additional sightings of untagged adult shad. Conversations with local fishermen indicated that some of the adult shad entered the Suncook River on June 3 and 4, although searching of this area throughout the following week gave no evidence of tagged shad in that region. On July 3, a school of nine adult shad were observed over the sandy flats (approximately 1.2 m deep) between N-2 and N-10. These shad appeared to be unstressed and exhibited normal behavior. Water temperature in this region was 23°C when the shad were seen. Shad were observed in the same region for approximately 2 weeks following the original sighting.

On July 6, one dead adult shad was found on the intake screens of Merrimack Generating Station Unit II. Another dead shad was found at Station S-1-E the following day. On July 12 an additional dead shad was observed at Station N-1-E. This mortality is not unusual, nor is it a sign of adverse environmental conditions. Even though many adults successfully return to the ocean after spawning, many die while in freshwater. Chittenden (1976) reported a large mortality of shad upstream near the spawning grounds on the Delaware River near the end of the 1963 and 1964 spawning periods. That author also indicated that some shad may die before being completely spent.

A conversation with Leon Brooks (PSCoNH, pers. comm.) and other personnel at Amoskeag Hydroelectric Station indicated that adult shad were observed regularly in the station's headworks for several weeks in late July and early August. A school of approximately 15 shad swam back and forth in front of the trash racks as long as the hydroelectric station was drawing water for generation. When the trash gate was opened, the shad moved into the stronger flow, but were not observed moving downstream through the trash gate. During periods when the flow through the generating station was stopped, the shad moved away from the dam and were not seen. Sightings of the shad at Amoskeag were rare between August 11 and October 10 because reduced river discharges prevented hydroelectric generation most of the time. However, adult shad were observed by NAI biologists fairly consistently above Amoskeag Dam's headworks from October 10 through November 16 (Table 8). This is surprising since no other adult shad had been seen since early August, and most research indicates that adult shad migrate downstream in late summer, typically two months after the upstream migration (Chittenden, 1976).

4. Location and Duration of Spawning

a. Field Observations

Field crews searched Hooksett Pond throughout June for surface activity that has been reported to be indicative of shad spawning (Layzer, 1974), but none was observed anywhere in Hooksett Pond. However, the adult shad that were introduced into the Merrimack River did spawn, as indicated by the eggs captured throughout June in drift net collections (Table 4). Although fertilized eggs were released upstream of the

Soucook River confluence on June 10, most eggs should have developed into larvae by June 17. Thus, only the four early-stage eggs captured at Station O-E on June 11, and the two late-stage eggs captured on June 14 (Table 4) could have come from the fertilized egg stocks. Therefore, it is assumed that the other 65 eggs collected were spawned by the introduced adults.

Although the drift nets were set throughout Hooksett Pond, most of the shad eggs were collected at Stations 0-E and S-8-E. In addition, most eggs collected were in the early stages of development, indicating that they had been recently spawned. According to the staging method used, the early stage pertained to eggs within the first 24 to 36 hours of development. Several mid and late stage eggs were also collected in the drift nets, but these were likely resuspended in the water column after initially settling to the substrate. Drift nets set at 0-E and S-8-E were located in regions where the river channel curves and most of the river volume is contained within a relatively narrow cross-sectional area of the river. This increased the chances of capturing shad eggs because eggs that may be spawned across the entire river width tend to be captured in highest numbers at mid and bottom depths within and near the river channel (Gilmore, 1975).

The relatively high numbers of eggs captured at 0-E and S-8-E and the paucity of eggs collected upstream of N-5 indicate that much of the shad spawning in Hooksett Pond occurred between N-1 and S-8. Assuming a mean sinking rate for water-hardened shad eggs of 1.25 cm/sec (NAI, 1977b) and a water column depth of 3.35 and 2.44 m at Station 0-E and S-8-E, the time required for shad eggs to sink and be captured by the drift nets was 268 and 196 seconds, respectively, at these stations. A hydrographic model of Hooksett Pond developed in 1976 (NAI, 1977b) indicated that, at river discharge conditions existing during June 1978, water velocities were typically 36 to 50 cm/sec at 0-E, and 36 to 47 cm/sec at S-8-E. Thus, shad eggs collected at these locations were likely spawned 97 to 135 m upstream of Station Zero (N-1), and 70 to 92 m upstream of S-8 (S-7). The river reach from Station Zero to N-4 is primarily shallow flats (1-2 m deep) with a sand and cobble substrate. The river is deeper below Station Zero with a coarse sand substrate.

Leggett (1976) states that shad prefer to spawn in areas dominated by broad flats or shallow water with moderate currents (see also Smith, 1907; Bigelow and Welsh, 1925; Massman, 1952; Marcy, 1972). Shad in Hooksett Pond appeared to spawn in the deeper region south of the discharge canal as well as the shallow water just north of the discharge.

b. Thermal Influences on Spawning

The time of spawning as well as the survival of eggs and larvae are dependent on water temperatures. Mansueti and Kolb (1953), in a review of North American shad fisheries, have reported that shad typically spawn at water temperatures of 12.7 to 23.9°C. Talbot (1954) collected shad eggs in the Hudson River at temperatures of 13.8 to 20.0°C. Marcy (1972; 1976b) reported peak spawning in the Connecticut River at water temperatures of 22°C in 1967 and 14.8°C in 1968. Leggett and Whitney (1972), Massman (1952) and Walburg (1960) have reported median shad spawning temperatures between 16 and 20°C. Stira and Smith (1976) report that no shad eggs were collected in the Hudson River after the mean weekly water temperature had risen to 20°C. On the Merrimack River, ambient temperatures ranged from approximately 16 to 24°C, while mixing zone temperatures ranged between 16.7 and 25.3°C (mean = 20.0°C) during June, the period through which eggs were collected. This constitutes thermal conditions conducive to shad spawning throughout the month based on egg collections as well as the literature.

c. Thermal Sensititivity and Entrainment of Shad Eggs

Leim (1924) and Bradford *et al.* (1966) have indicated that maximum shad hatch and survival of both eggs and larvae occurred between 15.5 and 26.5°C. Temperatures below 16.0°C prolong the time of hatching and reduce survival (Leim, 1924; Leach, 1925; Mansueti and Kolb, 1953; Bradford *et al.*, 1966; Leggett and Whitney, 1972). Ambient Hooksett Pond temperatures during June varied from a low of 16°C to a maximum of

25°C, although surface temperatures at the discharge canal reached 31°C. Thus, water temperatures during this period were optimal for shad egg and larvae survival based on the above literature.

Surface temperatures within the thermal plume probably were not detrimental to shad eggs, considering both maximum plume temperatures and the drift characteristics of the eggs. Koo (1976), reviewing his own work as well as that of Schubel and Auld (1972a, 1972b, 1974), Schubel (1974, 1975), and Schubel and Koo (1976) indicated that 29 to 31°C is the boundary between the zones of thermal tolerance and the zone of thermal resistance (see Fry *et al.*, 1946) for late embryo stages. This means that late embryo stages subjected to temperatures up to 30°C will exhibit no significant temperature effects regardless of length of exposure up to 60 min. At temperatures above 30°C, significant effects are functions of both temperature and time of exposure. Schubel (1973) conducted laboratory experiments on time-temperature exposure histories of fish eggs of some sensitive species including American shad, and concluded that Δt's of up to 10°C during the time of year that these species spawn are not detrimental to egg development or hatching success.

NAI (1977b) conducted a series of laboratory bioassays to determine thermal tolerance of American shad eggs. Eggs in varying stages of development from 14 to 110 hrs were subjected to Δt's of up to 28°C (ambient temperature = 16.6 to 20.6°C) with exposure periods of ten to thirty minutes. In these tests, shad egg survival was not significantly influenced by exposure to temperatures below 33.9°C or to $\Delta t \leq$ 13.9°C. Eggs exposed to temperatures above 33.9°C and $\Delta t >$ 13.9°C exhibited greater mortality than control groups when exposed for 30 minutes, but not for 20 minutes. These results corroborated the apparent insensitivity of shad eggs reported by the previously cited authors to temperatures < 30°C for up to 60 minutes. These data, combined with the results of a field-bioassay exposing shad eggs to water temperatures $\leq$ 32.2°C demonstrating no distinct temperature-related mortality, indicate that eggs spawned during June 1978 in Hooksett Pond would not have been exposed to lethal thermal conditions, even if entrained directly in the thermal plume. Furthermore, the likelihood of momentum entrainment within the thermal plume is extremely low at the discharge canal mouth because flows are typically less than those required to resuspend shad eggs in the water column. As indicated by NAI (1977b), lethal conditions do not exist within the Merrimack Station thermal plume under typical late-spawning period conditions (ambient water = 25°C; maximum discharge temperature = 32.7°C; river discharge = 53.8 cms).

No American shad eggs were collected during normal ichthyoplankton entrainment sampling. However, one shad egg was captured in the gang-net set just upstream of Unit I (Station N-5-W) on June 22 (Table 4). This egg was in an early stage of development, and was drifting near the substrate.

Although most shad spawning in Hooksett Pond occurred downstream of the generating station intake structures as indicated by the drift net studies, some spawning did occur upstream of Merrimack Station, and 750,000 fertilized eggs were released above the plant. Thus, the absence of shad eggs or larvae collected at Unit I indicates the low entrainment potential of this species.

Using physical parameters such as current velocities, shad egg fall velocity, river depth, and station cooling water volume, NAI (1977b) calculated that the probability of directly entraining shad eggs in the Merrimack Station cooling water flow is extremely low. The transport characteristics of the eggs make it unlikely that any eggs will be in suspension near the intakes at discharge levels typical of the spawning season (<226.5 cms); the small lateral component of the near-bottom currents makes it further unlikely that any bed-load eggs will be entrained. Some direct egg entrainment is possible if shad spawn in an area extending approximately 25 m offshore and 120 m upstream of the intake. This requires that the shad select this particular 3000 m^2 area adjacent to the west bank, which represents approximately 0.4% of the total area between Merrimack Station and Garvins Falls, in which to spawn. Considering the conservative assumptions utilized, direct egg entrainment is a remote possibility.

(Text continued on page 42)

TABLE 1. DEVELOPMENT AND HATCHING SUCCESS OF ARTIFICIALLY FERTILIZED AMERICAN SHAD EGGS CULTURED IN RIVER HATCHING BOXES, JUNE 10 TO JUNE 17, 1978. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

		HATCHING BOX #1			HATCHING BOX #2			HATCHING BOX #3		
DATE	MAXIMUM SURFACE TEMP. (°C)	EGGS # LIVE	EGGS # DEAD	LARVAE # LIVE	EGGS # LIVE	EGGS # DEAD	LARVAE # LIVE	EGGS # LIVE	EGGS # DEAD	LARVAE # LIVE
June 10	16.7	607 eggs stocked			456 eggs stocked			585 eggs stocked		
10	16.7	570	37	0	403	53	0	511	74	0
11	17.6	545	25	0	371	32	0	389	122	0
12	18.7	540	5	0	365	6	0	380	9	0
13	18.2	531	2	1	365	0	0	379	1	0
14	17.5	230	0	≈300†	365	0	0	226	0	5
15	17.9	55	0	≈475†	135	0	≈230†	75	0	≈150†
16	17.7	0	0	61	30	0	≈330†	16	0	≈75
17	18.4	0	0	1	0	0	17	0	0	23
Hatching Success = $\frac{\text{Total Eggs - Dead Eggs}}{\text{Total Eggs}}$		$\frac{538}{607}$ = 88.6%			$\frac{365}{456}$ = 80.0%			$\frac{379}{585}$ = 64.8%		

† Too many larvae to count *in situ*; this number was reconstructed by adding the number of eggs hatched during previous day to the number of existing larvae. Actual count was probably lower due to larval mortality.

TABLE 2. ADULT SHAD STOCKING SUMMARY. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

			NUMBER OF SHAD TRANSPORTED					
DATE	TIME	TRUCK LOAD	MALES	FEMALES	TOTAL	NUMBER DEAD IN TRANSIT	TOTAL NUMBER STOCKED	PERCENT MORTALITY
6/1/78	1530	1	80	40	120	15	105	12.5
	1615	2	81	38	119	7	112	5.9
	1645	3	54	37	91	13	78	14.2
6/2/78	1305	1	82	42	124	10	114	8.1
	1445	2	82	50	132	7	125	5.3
	1515	3	57	47	104	14	90	7.4
TOTAL			436	254	690	66	624	9.6

$$\text{Sex Ratio} = \frac{\text{\# Males}}{\text{\# Females}} = \frac{436}{254} = \frac{1.7}{1}$$

$$\frac{624 \text{ stocked shad}}{2.7} = 231 \text{ stocked females}$$

2.31 x 1.7 = 393 stocked males

TABLE 3. ADULT SHAD TAGGING SUMMARY, JUNE 2, 1978. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

FISH IDENTIFICATION	SEX	TAG FREQUENCY (+30.000 MHz)	TIME RELEASED
A	M	.010	1300
B	Unknown	.030	1300
C	M	.120	1300
D	M	.165	1300
E	F	.080	1300
F	M	.180	1520
G	F	.135	1520
H	M	.165*	1520
I	F	.220*	1520
J	M	.220	1620
K	M	.235	1620
L	Unknown	Died before release	
M	F	.250	1620
N	M	.150	1620

* Internal tags, inserted via mouth; slower pulse rate than external tags

TABLE 4. SUMMARY OF SHAD EGGS AND LARVAE CAPTURED IN DRIFT NETS AND TUCKER TRAWLS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1978.

				NUMBER SHAD CAPTURED	
DATE	STATION	TIME	GEAR*	EGGS (STAGE)	LARVAE
6/1	S-8-E	1930-2145	Net	4 (early)	0
6/3	0-E	2000-2330	Net	14 (early)	0
6/4	N-8-W	1800-2130	Net	0	0
	S-15-W	1800-2130	Net	0	0
6/5	N-6-W	1930-2200	Net	0	0
	S-23-W	1940-2210	Net	0	0
6/6	Narrows	2000-2150	Net	0	0
	N-3-E	2040-2200	Net	0	0
	0-E	2040-2200	Net	2 (early)	0
	S-4-E	2050-2210	Net	0	0
6/7	N-9-E	2000-2200	Net	0	0
	0-E	2000-2240	Net	0	0
	S-8-E	2000-2200	Net	1 (early)	0
	S-22-E	2000-2200	Net	0	0
6/8	0-E	2010-2210	Net	7 (early)	0
				1 (late)	0
	S-8-E	2010-2210	Net	10 (early)	0
6/9	SOU-E	2115-2125	Trawl	0	0
	Narrows	2100-2110	Trawl	7 (early)	0
				1 (late)	0
	N-6 to N-8	2050-2055	Trawl	0	0
	N-5 to N-6	2035-2045	Trawl	0	0
	0-E	1945-2150	Net	0	0
	S-8-E	1950-2200	Net	0	0
6/11	SOU-W	2010-2200	Net	0	0
	Narrows	2000-2210	Net	0	0
	0-E	1950-2230	Net	4 (early)	0
	S-8-E	1945-2225	Net	0	0
6/14	SOU-W	2015-2215	Net	0	0
	Narrows	2010-2215	Net	0	0
	0-E	1955-2200	Net	1 (early)	0
				2 (late)	0
	S-8-E	1945-2155	Net	0	0
	0-E	2100-2110	Trawl	2 (early)	0
	S-8-E	2130-2140	Trawl	3 (early)	0
6/16	SOU-W	2000-2200	Trawl	0	0
	Narrows	2000-2200	Trawl	0	0
	0-E	2000-2200	Net	1 (early)	0

(Continued)

TABLE 4. (Continued)

				NUMBER SHAD CAPTURED	
DATE	STATION	TIME	GEAR*	EGGS (STAGE)	LARVAE
	S-8-E	2000-2200	Net	0	0
6/18	Narrows	1955-2205	Net	0	0
	O-E	1945-2215	Net	0	0
	S-8-E	1940-2225	Net	0	0
	Narrows	2030-2045	Trawl	0	0
	SOU-W	2100-2115	Trawl	0	0
6/19	SOU-W	2020-2155	Net	0	0
	Narrows	2105-2205	Net	0	0
	O-E	2005-2215	Net	0	0
	S-8-E	2000-2225	Net	0	0
	SOU-W	2030-2045	Trawl	0	0
	N-10 to Narrows	2100-2115	Trawl	0	0
6/20	N-5-W(surf)	2000-2200	Net	0	0
	N-5-W(btm)	2000-2200	Net	0	0
	O-E	1955-2115	Net	1 (early)	0
				1 (late)	0
	S-8-E	1950-2150	Net	0	0
6/21	N-5-W(surf)	1955-2205	Net	0	0
	N-5-W(btm)	1955-2205	Net	0	0
	O-W	1945-2155	Net	0	0
	O-E	1950-2200	Net	0	0
	S-3-E	2030	Trawl	0	0
	S-7-W	2100	Trawl	0	0
6/22	N-5-W(surf)	2000-2200	Net	0	0
	N-5-W(btm)	2000-2200	Net	1 (early)	0
	O-W	1955-2155	Net	0	0
	O-E	1955-2155	Net	2 (mid)	0
	N-7	2050-2105	Trawl	0	0
	SOU-W	2010-2025	Trawl	0	0
6/23	N-5-W(surf)	2000-2200	Net	0	0
	N-5-W(btm)	2000-2200	Net	0	0
	O-E	2000-2200	Net	0	0
	S-3-E	2000-2200	Net	0	0
6/24	N-5-W(surf)	2000-2200	Net	0	0
	N-5-W(btm)	2000-2200	Net	0	0
	O-E	2000-2200	Net	1 (mid)	0
	S-4-E	1955-2155	Net	0	0
6/25	N-5-W(surf)	2000-2215	Net	0	0
	N-5-W(btm)	2000-2215	Net	0	0
	O-E	1955-2205	Net	2 (early)	0
	S-4-E	1950-2155	Net	0	0

(Continued)

TABLE 4. (Continued)

				NUMBER SHAD CAPTURED	
DATE	STATION	TIME	GEAR*	EGGS (STAGE)	LARVAE
6/26	N-5-W(surf)	1940-2225	Net	0	0
	N-5-W(btm)	1940-2205	Net	0	0
	N-2-E	1935-2200	Net	0	0
	0-E	1935-2155	Net	0	0
6/28	0-W	1930-2200	Net	0	0
	0-E	1930-2200	Net	0	0
6/30	N-5-W(surf)	2000-2207	Net	0	0
	N-5-W(btm)	2000-2207	Net	0	0
	0-E	1951-2153	Net	0	0
	S-3-E	1947-2143	Net	0	0
7/2	N-5-W(surf)	1945-2200	Net	0	0
	N-5-W(btm)	1945-2200	Net	0	0
	0-E	1950-2200	Net	1 (late)	1
	0-W	1955-2200	Net	0	0
7/5	0-E	2000-2220	Net	0	0
	S-3-E	2000-2225	Net	0	0
7/6	N-2-E	1955-2240	Net	0	0
	0-E	1950-2200	Net	0	0

* Net = 0.5 m plankton net, 505 μm mesh

Trawl = modified Tucker trawl, 505 μm mesh

TABLE 5. ICHTHYOPLANKTON ENTRAINMENT SUMMARY. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

DATE	TIME		WATER TEMPERATURE (°C)		VOLUME OF WATER FILTERED (THOUSANDS OF LITERS)	LARVAE CAPTURED	
	START	END	SURFACE	BOTTOM		QUANTITY	SPECIES
6/1	0005	0400	20.1	20.1	146.8	10	Golden shiner
	0405	0800	19.9	19.9	146.8	0	
	0800	1200	23.2	23.0	149.9	1	Johnny darter
6/8	0850	1215	18.7	18.5	128.0	0	
	1215	1605	19.2	19.1	143.6	0	
	1610	2000	18.8	18.8	143.6	0	
	2000	2400	18.8	18.8	149.9	17	*Notropis* spp.
						10	Golden shiner
						3	Johnny darter
						2	White sucker
6/9	0000	0430	18.3	18.0	149.9	11	Golden shiner
						1	*Notropis* spp.
	0435	0730	18.0	17.6	109.3	0	
	2000	2400	NA	NA	149.9	1	Golden shiner
6/13	0830	1155	17.9	17.9	128.0	0	
	1200	1600	18.2	18.2	149.9	0	
	1600	1955	17.2	17.2	146.8	0	
	2000	2400	16.9	17.0	149.9	6	Golden shiner
6/14	0005	0400	16.3	16.5	146.8	23	Golden shiner
						3	Unidentifiable
						1	*Notropis* sp.
	0400	0815	17.5	17.5	140.5	3	Golden shiner
6/15	0900	1200	17.0	17.0	17.8	0	
	1200	1600	17.9	17.9	20.3	0	
	1600	2000	17.5	17.5	20.7	0	
	2000	2400	16.7	16.7	20.7	0	

(Continued)

TABLE 5. (Continued)

DATE	TIME		WATER TEMPERATURE		VOLUME OF WATER FILTERED (THOUSANDS OF LITERS)	LARVAE CAPTURED	
	START	END	SURFACE	BOTTOM		QUANTITY	SPECIES
6/16	0000	0400	16.3	16.3	20.7	1	Golden shiner
	0400	0600	16.3	16.3	5.2	0	
6/28	0900	1200	25.2	25.1	116.4	0	
	1200	1600	25.3	25.3	199.5	0	
	1600	2000	24.4	24.3	119.5	0	
	2000	2400	24.3	24.4	119.5	0	
6/29	0000	0400	23.6	23.6	119.5	2	*Lepomis* spp.
						1	Golden shiner
	0400	0800	23.8	23.8	119.5	0	
	0800	1200	25.7	25.6	119.5	0	
	1200	1600	25.9	25.9	119.5	14	*Lepomis* spp.
	1600	2000	24.9	24.8	192.9	3	*Lepomis* spp.
	2000	2400	24.2	24.2	192.9	1	*Lepomis* spp.
6/30	0000	0400	23.3	23.3	192.9	2	*Lepomis* spp.
						2	Golden shiner
						1	*Notropis* sp.
						1	Unidentifiable
	0400	0800	23.4	23.4	192.9	1	Largemouth bass
7/5	0900	1200	22.4	22.3	160.2	0	
	1200	1600	23.9	23.9	213.6	6	*Lepomis* spp.
	1600	2000	22.1	22.1	213.6	0	
	2000	2400	21.5	21.5	213.6	2	*Lepomis* spp.
						1	Golden shiner
7/6	0000	0400	20.9	20.9	213.6	0	
	0400	0800	21.5	21.4	213.6	1	Golden shiner
	0800	1200	23.0	23.0	216.1	0	
	1200	1600	24.9	24.7	230.6	0	
	1600	2000	23.9	23.9	230.6	0	
	2000	2400	23.5	23.5	230.6	0	

(Continued)

TABLE 5. (Continued)

DATE	TIME		WATER TEMPERATURE		VOLUME OF WATER FILTERED (THOUSANDS OF LITERS)	LARVAE CAPTURED	
	START	END	SURFACE	BOTTOM		QUANTITY	SPECIES
7/7	0000	0400	23.1	23.1	230.6	0	
	0400	0800	22.7	22.7	230.6	4	*Lepomis* sp.
7/10	0850	1200	24.7	24.7	141.3	0	
7/21	0845	1600	28.0	28.0	605.2	0	
	1600	2000	26.9	27.1	230.6	0	
	2000	2400	26.5	26.6	230.6	0	
7/22	0000	0400	26.5	26.6	230.6	0	
	0400	0800	26.7	26.8	230.6	0	
7/25	1745	2000	27.4	27.5	140.4	0	
	2000	2400	26.4	26.4	249.6	0	
7/26	0000	0400	23.8	23.8	249.6	1	Margined madtom
	0400	0800	25.2	25.2	249.6	0	
	0955	1200	26.4	26.4	130.0	0	
	1200	1600	26.8	26.8	249.6	0	
	1600	2000	26.3	26.3	249.6	0	
	2030	2400	25.9	25.9	218.4	0	
7/27	0000	0400	25.5	25.5	249.6	0	
	0400	0900	25.4	25.4	312.0	0	
	0930	1200	23.4	23.4	218.4	0	
	1200	1600	26.6	26.5	249.6	0	
	1630	2000	25.8	25.7	161.2	0	
	2000	2400	25.6	25.6	249.6	0	

NA indicates that water temperatures are not available

Marcy (1976b) estimated a total of 81,000 shad eggs entrained at Connecticut Yankee Atomic Plant (CYAP) during 1968, and 131,000 during 1969. Using Leggett's (1969) estimate that one mature adult shad is produced per 100,000 eggs spawned, Marcy concluded that entrainment at the estimated 1968 and 1969 rate would result in the loss of only one adult shad per year. The number of shad eggs lost was considered to be minimal when compared with either the number of potential adults lost or the total egg production of the Connecticut River's major spawning areas.

Marcy (1976a) found that although clupeids (*Alosa* spp.) made up 97.6% of the eggs and larvae entrained at CYAP during 1971 and 1972, less than 1% were contributed by American shad. In addition, both shad eggs and larvae were present in plankton tows at a station directly upstream of the intake. These observations tend to reinforce the entrainment probability calculations and subsequent field observations at Merrimack Station indicating that pump entrainment of shad eggs is minimal.

B. LARVAL SHAD MONITORING

1. Larval Shad Distribution

The distribution of larval shad throughout Hooksett Pond was investigated by seining the littoral zone from June 22 through July 24. During this period 16 days of seining were expended, typically twice per week during June, and three or four times per week during July. Although various habitats of Hooksett Pond from the confluence of the Soucook River to S-24 were seined at water temperatures of 21 to 30°C, no shad larvae were collected. Larvae of resident fish species were abundant in these samples. Seining for larval shad was ended on July 25 when juvenile shad were first collected.

One shad larvae was collected, however, in a drift net set at Station 0-E on July 2. This was the only shad larvae captured during this study.

Marcy (1976a, b) captured American shad larvae in the lower Connecticut River from May through August, 1965 to 1969. Although most shad larvae were captured at water temperatures of 21.0 to 22.9°C, some larvae were collected throughout the temperature range of 9.7 to 30.0°C. In addition, shad larvae were more abundant in the surface waters than near the substrate, becoming more pelagic in the downstream areas. Marcy (1976a) used 0.5 m plankton nets to collect shad larvae. Similarly, Stira and Smith (1976) used open-water larval trawls and an epibenthic sled to capture American shad larvae in the Hudson River estuary. Most yolk-sac and post-yolk-sac larvae in that survey were collected at water temperatures of 10 to 20°C. However, G. Kuzmeskus (pers. comm.) conducted a study for the Massachusetts Cooperative Fisheries Research Unit to determine the distribution of larval shad in the Connecticut River and the best method for collecting the larvae. After sampling littoral and limnetic habitats using an epibenthic sled, towed 0.5 m plankton nets, an otter trawl with a larval liner, and a larval beach seine, Kuzmeskus concluded that shad larvae were most abundant in littoral zones, particularly in eddies, and that the larval seine was the most effective gear type for sampling the larvae. Building on this study, Cave (1978) studied the horizontal distribution of shad larvae in the Connecticut River's Holyoke Pool. Although metered 1/2 m nets, epibenthic sleds and larval beach seines were used throughout the study area, seining accounted for most of the larvae collected. Cave also concluded that eddies appeared to be areas of shad larvae concentration although he was unable to statistically prove this because of the extreme variation in larval abundance among the eddies.

It is not known why larval shad were not captured in Hooksett Pond. The collection method used was appropriate, the field crews were experienced in shad seining, and larvae were present somewhere in Hooksett Pond by virtue of the subsequent presence of juveniles in this pool.

The stomach contents of resident Hooksett Pond fish were examined from 14 June through 14 July because these predators could be more efficient than fishery biologists at locating and utilizing the larval shad population. Although four chain pickerel, 63 largemouth bass, 20 smallmouth bass, 94 pumpkinseed, 27 redbreast sunfish, 46 yellow perch, 7 bullhead, 18 white suckers, 4 fallfish and 3 white perch were collected at dusk or dawn (typically periods of greatest feeding intensity), no shad larvae were observed in any of the fish stomachs sampled. One reason may be the soft nature of the larvae; many insects which possess relatively hard exoskeletons were observed in the stomachs. Larvae, however, contain no hard body parts and are easily mutilated. In retrospect, this method would be more applicable for juvenile fish which would not be so easily mutilated and would require longer time to digest.

2. Thermal Sensitivity of Shad Larvae

Bioassays conducted by NAI (1977b) revealed that exposure of shad larvae to temperatures below 33.3°C and Δt's less than 12.8°C for up to 30 min caused no significant mortality differences between control and treatment groups (acclimation temperatures = 17.2 to 21.1°C). Regression analysis showed that mortality was directly related to larval age; younger larvae showed a higher thermal resistance than the older groups. Overall, exposure to temperatures above 34.4°C or Δt's greater than 11.1°C for 10 min were required to significantly influence mortality in shad larvae older than 200 hr; more extreme conditions (temperature > 35°C and Δt > 15°C) were necessary to effect the same results in younger larvae.

Both the Merrimack (NAI, 1977b) and Maryland (Schubel and Koo, 1975) investigations indicated a maximum temperature effect which is more evident than the Δt response. Schubel and Koo (1975), for example, found that exposure to Δt = 10°C increased mortality significantly at base temperature of 27°C and maximum exposure temperature of 37°C. At base temperature = 17°C, exposure to Δt = 14.5°C (maximum temperature = 31.5) produced significant mortality only at the highest exposure temperatures and longest durations. The same trends were evident for the Merrimack River larvae bioassays (NAI, 1977b).

3. Momentum Entrainment of Shad Larvae

Shad larvae may be vulnerable to the thermal discharge during their "upward swimming" stage immediately following hatching, or later in life should they be displaced from northern pond reaches downstream along the river bank. Ambient Hooksett Pond temperatures during June and July 1978 ranged from 16 to 28°C, well within the thermal tolerance of larval shad. At the discharge canal mouth, plume temperatures reached a maximum of 29°C during July, indicating that larvae subjected to momentum entrainment within the plume would not have experienced lethal temperature conditions. However, Merrimack Unit II was not in operation from June 24 until early autumn. When both units are operating, summer discharge temperatures are typically less than 34°C, but have been recorded as high as 36.4°C. Therefore, lethal conditions could exist within the thermal plume during periods of high ambient temperatures, low flows and maximum power generation. The effects of the potential lethality to shad larvae were not assessed during 1978 because of the extended shut-down of Unit II and consequently lower discharge temperatures.

4. Pump Entrainment of Shad Larvae

The likelihood of entraining shad larvae in the Merrimack Station Unit I cooling system was examined during June and July. The volume of water filtered, surface and bottom water temperatures, and the quantity of larvae collected are presented in Table 5. Golden shiners, other shiners (*Notropis* spp.), and sunfish (*Lepomis* spp.) larvae were the most commonly collected fish larvae. Most larvae were collected between the hours of 2000 and 0800, or during the periods of darkness; few larvae were collected during the day. Marcy (1973) found that fish larvae are more abundant near the bottom during the day, and between the surface and mid-water at night. This would make the larvae most vulnerable to drift and entrainment during the hours of darkness.

No American shad larvae were collected during entrainment sampling. As mentioned earlier, Marcy (1976a) found that although river herring (*Alosa* spp.) together made up 97% of the entrained egg and larvae at Connecticut Yankee Plant, American shad eggs and larvae represented less than 1% of the total. American shad ranked ninth in overall ichthyoplankton abundance in the river adjacent to the plant, with both eggs and larvae were present in plankton tows directly upstream of the intake, yet few were entrained. Similarly, studies funded by the Central Hudson Gas and Electric Company on ichthyoplankton entrainment in the Hudson River near Poughkeepsie, New York demonstrated the presence and entrainment of many *Alosa* spp. larvae, but relatively few American shad eggs and larvae (QLM, 1974).

The potential for shad larvae entrainment at Merrimack Station is dependent upon many aspects of larval ecology, especially behavioral ecology, which are poorly understood at the present time. Experiments conducted during 1976 and Connecticut River field observations (NAI, 1977b) together have produced some additional insight into previously unknown distributional and feeding aspects.

Newly-hatched shad larvae, originating at or near the bottom from either stationary, sheltered eggs or moving eggs undergoing bed-load transport, will swim upward in short activity bursts and settle back downward between periods of activity. This behavior was observed early by fish culturists, who noted that the newly-hatched sac-fry would eventually swim upward and out of hatching jars (Leach, 1925). Larvae cultured at Avery Point and in the Merrimack Station field laboratory (NAI, 1977b) displayed this behavior pattern uniformly for their first one to two days of life, with the bursts becoming progressively longer and the settling periods shorter with age. Additionally, the young larvae displayed an obvious negative tactile response upon substrate contact, swimming rapidly upward as soon as they touched bottom. Thus, shad larvae are in a periodically active state characterized by a net upward movement during the first day or so after hatching. At the end of this initial period, sac-fry in the laboratory were observed swimming continuously at the surface oriented towards the current. However, current speeds as low as 3 cm/sec were capable of displacing these individuals.

After the first day or two, laboratory larvae became progressively more adept at maintaining position within flowing water. Observations indicated that they were able to detect and orient to currents of less than 3 cm/sec. During this stage they tended to seek areas of minimal current, a trait which remained consistent throughout approximately 3 weeks of laboratory observations. These observations are consistent with Connecticut River field studies that successfully seined larvae from eddies and backwaters. Cave (1978) has reported that eddies were the most productive stations in the Holyoke Pool for shad larvae, although the larval abundance between eddies varied greatly.

These laboratory and field observations (NAI, 1977b) offer plausible explanations for the apparent invulnerability of shad larvae to conventional ichthyoplankton sampling equipment and power plant cooling water intakes. Laboratory observations indicate that initial post-hatching movement is upward to the extent that some larvae were observed at the surface within several hours of hatching. This appears to be followed by a general shoreward movement. Both activities tend to move the larvae into the relatively low-velocity regions of a typical free-flow stream; surface tension and boundary friction cause velocities to be lower in the extreme surface layers and, in places, near zero along the lateral boundaries. These perimeter refugia are always available, even under high-flow conditions. If the larvae behave in the field as they do in the test flume, they are vulnerable in the free-stream region only from the period immediately after hatching until they reach and complete their shoreward movement. Because power plant intake structures located along the river banks generally draw most of their water from the mid-water layers, they are largely ineffective at capturing the surface-oriented larvae. Even though located along the banks, power plant intakes are essentially passive devices requiring downstream larval movement to effect capture.

Test flume observations (NAI, 1977b) clearly indicated some downstream larval transport even under low-velocity conditions. In addition, Cave (1978) observed downstream shad larval drift for a distance of 1.5 to 2.0 km in the Holyoke Pool, Connecticut River, although the rate of drift was not estimated. The obvious implication regarding Merrimack Station is that larvae hatched upstream which are being transported downstream along Hooksett Pond's west bank will be potentially entrainable. The rate of downstream larval movement, and hence the magnitude of entrainment is therefore dependent on both physical and behavioral factors.

On the Connecticut River, the 26 mile Holyoke Pool reach has currents comparable to those of Hooksett Pond. In the Montague, Massachusetts reach of this pool, currents average 30 to 45 cm/sec under typical daily discharge conditions, but diurnal fluctuations are much more severe due to Turner's Falls power releases. Larvae and juveniles are captured regularly throughout the reach despite these tremendous fluctuations, indicating some operational retention mechanism. Similarly, the lack of an entrainment problem at Connecticut Yankee despite a major shad spawning area only 13 km upstream further implies that the larvae are adept at minimizing downstream transport.

Theoretically, even without the highly regulated, temporally varying discharge regime presently characteristic of most New England rivers, a large coastal river during May, June and July represents a relatively unstable environment. Water level and temperature may change rapidly from day to day, and the river itself is geologically dynamic in that its substrate and morphology are in continuous flux.

Ecologically, it is difficult to imagine that a species depending on such a varying environment for its reproductive success could survive if its larvae were not able to retain themselves in suitable nursery areas under normal late spring conditions.

C. JUVENILE SHAD MONITORING

1. Juvenile Shad Distribution

The distribution of juvenile shad throughout Hooksett Pond as indicated by seining catches and visual observations, is contained in Tables 6 and 8. Shad juveniles were first collected on July 25; they were not captured earlier because most of the seining effort prior to July 25 was spent using a larval seine which the juveniles could avoid. After juveniles were initially found, all seining was done with a 45.7 x 3.7 m (6 mm bar mesh) seine.

Throughout July and August, juveniles were collected regularly, but rarely in large quantities. Juveniles were found predominantly in the river reach between the discharge canal mouth (0-W) and the lower end of the mixing zone (S-4) at water temperatures of 23.0 to 27.3°C. Occasionally, juveniles were also collected from the northern and southern ends of Hooksett Pond. Abundance decreased during September and October, largely resulting from the onset of downstream migration. Seining and visual observations in Hooksett Pond indicated no preponderance of juveniles in or near the discharge canal as river temperatures decreased throughout the autumn.

Juveniles were first seen in the Hooksett Hydroelectric Station forebay on October 9, although some juveniles had been captured moving downstream through the hydroelectric station as early as September 12, suggesting that the bulk of the juveniles reared in Hooksett Pond did not migrate downstream as far as Hooksett Dam until early October. Water temperatures at this time were approximately 12°C.

Juvenile shad were observed regularly in the Hooksett Dam forebay from October 10 through November 7; during this period, water temperatures ranged between 9.6 and 15.1°C.

Generally, more juveniles were captured and observed in Amoskeag Pond than in Hooksett Pond (Tables 7 and 8). During August and September, most juvenile shad in Amoskeag Pond were collected between Hooksett Dam and the Hooksett Bridge at water temperatures of 16.7 to 21.5°C. However, visual observations as early as September 14 indicated that juvenile shad were present in Amoskeag Pond as far south as the golf course (Figure 1b). On this evening, thousands of juvenile shad were observed jumping out of the water in apparent feeding behavior. Several of these shad were collected for positive identification. This feeding behavior was evident across the entire river and downstream for a distance of approximately 500 meters. Similar activity was seen on subsequent days during the late afternoon and evening throughout Amoskeag Pond, but was never observed in Hooksett Pond upstream of the Hooksett Dam forebay. Juvenile shad were last observed in Amoskeag Pond on November 10 at an approximate water temperature of 10°C.

No resident predator fish containing juvenile shad were captured in either Hooksett or Amoskeag Ponds from August through October. One problem encountered was capturing piscivores that were large enough to consume the juvenile shad. Most shad were 50 to 120 mm TL, which is too large for effective utilization by the abundant pumpkinseeds. Therefore, largemouth bass, smallmouth bass, and pickerel were the only species large enough to prey on the shad during September and October. While seining for these species, only 9 smallmouth bass and 12 pickerel of sufficient size to prey on the juvenile shad were collected; none contained shad. Utilization of the shad population by resident species cannot be determined due to this small sample size.

2. Entrapment of Juvenile Shad

Entrapment sampling from July 31 through October 31 indicated a low occurrence of significant juvenile shad impingement (Table 9). Only one juvenile shad was observed in the 48 hour-per-week screen washings. This 91 mm specimen was captured at Unit II on October 31 when the mean daily water temperature was 8.6°C. This was during the last week that juvenile shad were observed anywhere in Hooksett Pond. Because only one juvenile was captured, no projections of the total number of shad possibly entrained throughout the sampling period were calculated.

3. Juvenile Shad Growth

Growth curves for juvenile shad collected from Hooksett and Amoskeag Ponds from July 25 through November 7 are presented in Figures 6 and 7. Length of juveniles caught in the Hooksett shad trap are included in the Hooksett Pond data set.

The total length (TL) range observed in each sample was large (3 to 39 mm), reflecting the prolonged duration of spawning. When first observed during late July, the juveniles averaged 52 mm TL. From that time until emigration in November, the growth rate for juveniles in Amoskeag and Hooksett Ponds were similar, as shown by the linear regression of total length on date (Table 10; Figures 6 and 7). The logarithmic growth equations most accurately describe the curvilinear nature of shad growth through time, and therefore express instantaneous length values. In comparison, the slope of the linear equations are used to estimate growth throughout the season and to provide a per diem (daily) growth rate (Watson, 1968; 1970; Marcy, 1967b).

Daily growth rates for Hooksett and Amoskeag Pond shad were 0.60 and 0.52 mm, respectively (Table 10). Growth rates of 0.77 mm to 1.18 mm per day have been calculated for Connecticut River shad by Watson (1968; 1970). Marcy (1976b) reported daily growth of 0.69 to

0.92 mm for shad collected from 1966 to 1972 on the Connecticut River. Fastest growth rates were observed during years when juvenile abundance was lowest, while slowest rates were observed when juvenile shad were most plentiful. Whether or not the lower growth rates observed in the Merrimack River during 1978 are the result of higher competition than present in the Connecticut River is not known. There is no quantitative estimate of the number of juveniles produced in the Merrimack during 1978, and there are no other years of shad production with which the 1978 growth rates can be compared.

The mean total length of the Merrimack River shad just before emigration was approximately 110 mm. Marcy (1976b) observed a mean total length of 96.2 mm for Connecticut River shad during October, 1966 to 1972. Watson (1970) collected juveniles up to 182 mm at the Holyoke Dam in 1968, and reported a mean total length of 120 mm for shad during mid-October, 1967. Stira and Smith (1976) reported that the mean length of juvenile shad in the Cornwall region of the Hudson River during late October was 86 to 90 mm. Thus, juvenile shad from the Merrimack River were within the range of lengths reported in the literature.

Length-weight relationships for Hooksett and Amoskeag Ponds were similar to those calculated for Connecticut River shad by Watson (1968) and Marcy (1976b), indicating a normal pattern of weight increase throughout the summer (Table 10; Figures 8 and 9). Juveniles reared in Hooksett Pond appear to be somewhat more robust than those collected from Amoskeag Pond, based on the slope of the length-weight equations.

4. Downstream Migration

Juvenile shad were first observed migrating downstream on September 12 at a water temperature of 17°C. Between 0800 and 1200 hours, five shad (77 to 83 mm T.L.) moved downstream through Hooksett Hydroelectric Station, and were caught in the tailrace trap net (Table

11). That afternoon, 39 more shad were captured moving downstream (77 to 92 mm T.L.). From September 12 through October 20, juveniles moved downstream sporadically, although large quantities were not collected in the trap net. During this period, many juvenile shad were observed congregating in the Hooksett Hydroelectric Station forebay (Table 8). One reason that shad may not have been collected in the trap throughout this period is that the trash gate, which opens onto the forebay and spills water from the forebay surface into the river below the dam, was periodically opened. Flow from this gate does not enter the tailrace and was therefore not subject to sampling by the trap net. No shad were observed moving into the trash gate, but it is possible that some juveniles utilized this path to move down into Amoskeag Pond. Throughout the entire downstream migration, Hooksett Pond water levels were lower than the boards across Hooksett Dam, and shad could not move downstream directly over the dam. All downstream migration was limited to movement either through the trash gate (which was reported to be closed during normal operation) or through the hydroelectric power house.

Another large downstream movement of juvenile shad occurred on October 24. Between 0930 and 1730 hours, 220 juveniles (85 to 123 mm T.L.) were captured in the trap net at a water temperature of 10.4°C. Most of these shad (121) moved downstream between 0930 and 1300 hours, and only 20 were captured between 1600 and 1730 (Table 11). This observation suggests that on a daily basis, juveniles moved most heavily during midday. This may reflect the normal circadian rhythms of juvenile shad. Katz (1978) showed that juvenile shad under a circadian day/night regime have a daily swimming rhythm. Schooling begins and swimming speed increases with light onset, while reduced swimming speed and breakup of schooling both appear with the beginning of darkness. As the light regime is shifted, so are initiation of schooling and increased swimming speed. Night-time sampling of migration from Hooksett Pond was not possible because Hooksett Hydroelectric Station typically did not generate during the night. Therefore, no comparison of downstream migration rates during day and night were possible.

Migration at Hooksett Dam continued through November 7 when water temperatures were approximately 10.4°C. Leggett and Whitney (1972) reported that downstream migration of the juveniles is triggered by temperature, citing the work of Sykes and Lehman (1957) who indicated that downstream migration of Delaware River juvenile shad commences in early September at a water temperature of 20.5°C, but peaks at temperatures of 15.5°C. Chittenden (1969) reported that all juvenile shad left the non-tidal portion of the Delaware River before water temperatures dropped to a daily minimum of 8 to 9°C in the fall.

Marcy (1976b) observed downriver migration at somewhat higher temperatures in the Connecticut River. Juveniles began moving downstream by the middle of August at temperatures of 23 to 26°C. Most of the population emigrated from September through early October at temperatures of 17.8 to 23°C. A smaller portion of the population moved out of the river between 10.9 and 17.8°C during the mid-October to early November period. No juveniles could be found in the Connecticut by the end of November when water temperatures dropped below 6.6°C. Marcy (1976b) reported that this final emigration from the river was associated with high river flows and low temperatures.

During 1970, the New Hampshire Fish and Game Department introduced 457,000 fertilized shad eggs into the Franklin, New Hampshire section of the Merrimack River (Wightman and Newell, 1971). Survival of those eggs to the juvenile stage was documented when juvenile shad were observed at Garvins Falls Dam. Those juveniles migrated downstream during late September and October when water temperatures were 17.8 to 20.6°C. Subsequently, shad were observed migrating downstream at Hooksett Hydroelectric Station from October 21 through 24 at water temperatures of 13.4°C. Juveniles were also seen at Amoskeag Dam from October 23 through 30. Water temperatures were 10.0°C on the date of last shad sightings.

These observations of juvenile migration in the Merrimack, Connecticut, and Delaware Rivers essentially are identical to those for

Hooksett and Amoskeag Ponds during 1978. Juveniles began moving downstream as river temperatures dropped below 18°C, and continued into November when water temperatures reached 9 to 10°C.

Seining and visual observations gave no evidence that migration was delayed by the heated discharge from Merrimack Station, or that juveniles tended to remain in the warmer regions of the river instead of migrating downstream. Moss (1970) has shown that captive juvenile American shad will avoid rapid temperature increases of 4°C, although responses to 1°C increases were inconsistent. He concluded that young shad are capable of avoiding potentially lethal temperatures. Marcy (1976b) tested the reactions of juvenile shad to the heated effluent of the CYAP by observing them in submerged cages. Juveniles showed no depth or temperature preference at ambient temperatures or effluent temperatures less than 30°C. As the water temperature exceeded 30°C, the shad moved deeper in the water column. Marcy concluded that young shad will avoid potentially lethal temperatures (>30°C), and are capable of avoiding the CYAP heated effluent during their downstream migration. Wightman and Newell (1971) documented the successful downstream migration of juvenile shad past Merrimack Station's thermal plume in late October 1970. At that time, both generating units were in operation, but the present, cooling canal with power spray modules had not been installed. Thus, thermal conditions at that time were likely to have been more adverse than would exist presently. From these observations, juvenile shad in the Merrimack River have the ability to sense and avoid potentially lethal temperatures and utilize the cooler waters below the surface plume as a safe zone of passage downstream.

Size of the juvenile shad can also influence the timing of migration. Both Watson (1970) and Marcy (1976b) have suggested that the larger individuals move downstream prior to the time when river temperatures become critical. This can be seen in Marcy's data as a decrease in mean fish size from October into November, indicating that the larger individuals left the river before the latter samples were collected. A similar decrease in mean total length is not present in the 1978 Hooksett or Amoskeag Pond data (Figures 6 and 7), nor do the two large downstream migrant samples indicate a higher mean length than corresponding river samples.

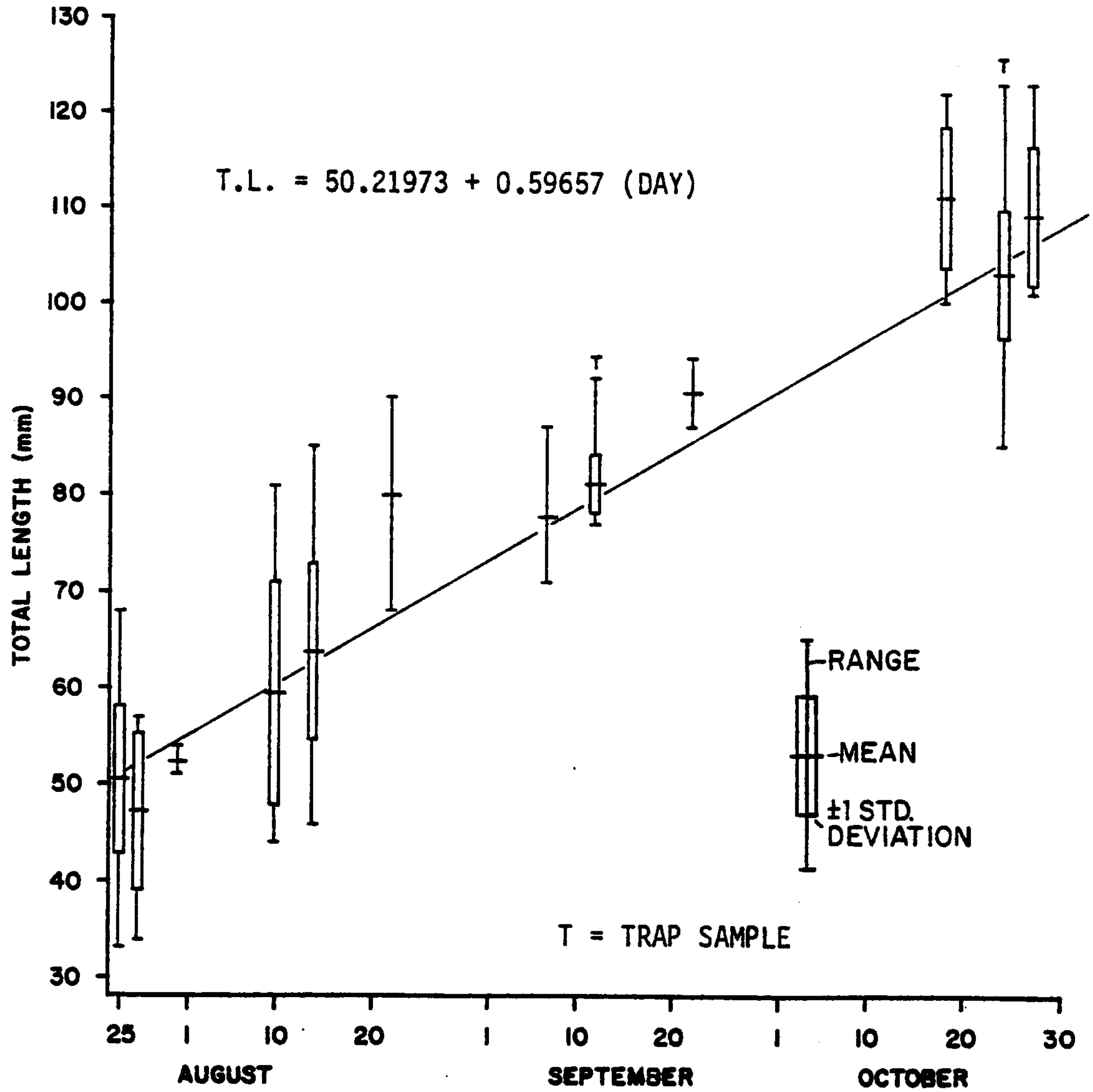

Figure 6. Total length of juvenile American shad captured in Hooksett Pond and in the Hooksett Hydroelectric shad trap. Merrimack River Anadromous Fisheries Investigation, 1978.

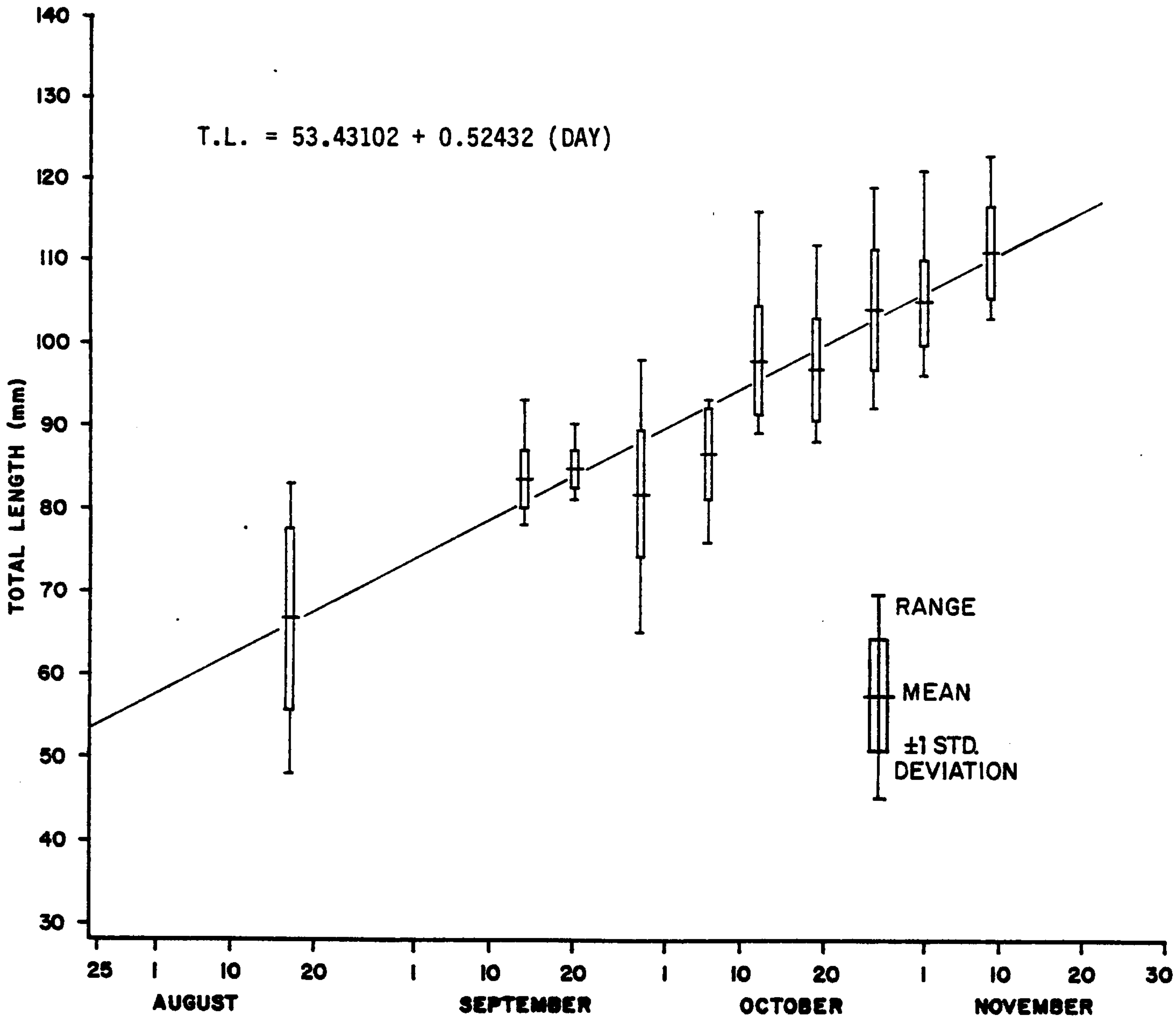

Figure 7. Total length of juvenile American shad captured in Amoskeag Pond, Merrimack River, 1978. Merrimack River Anadromous Fisheries Investigation, 1978.

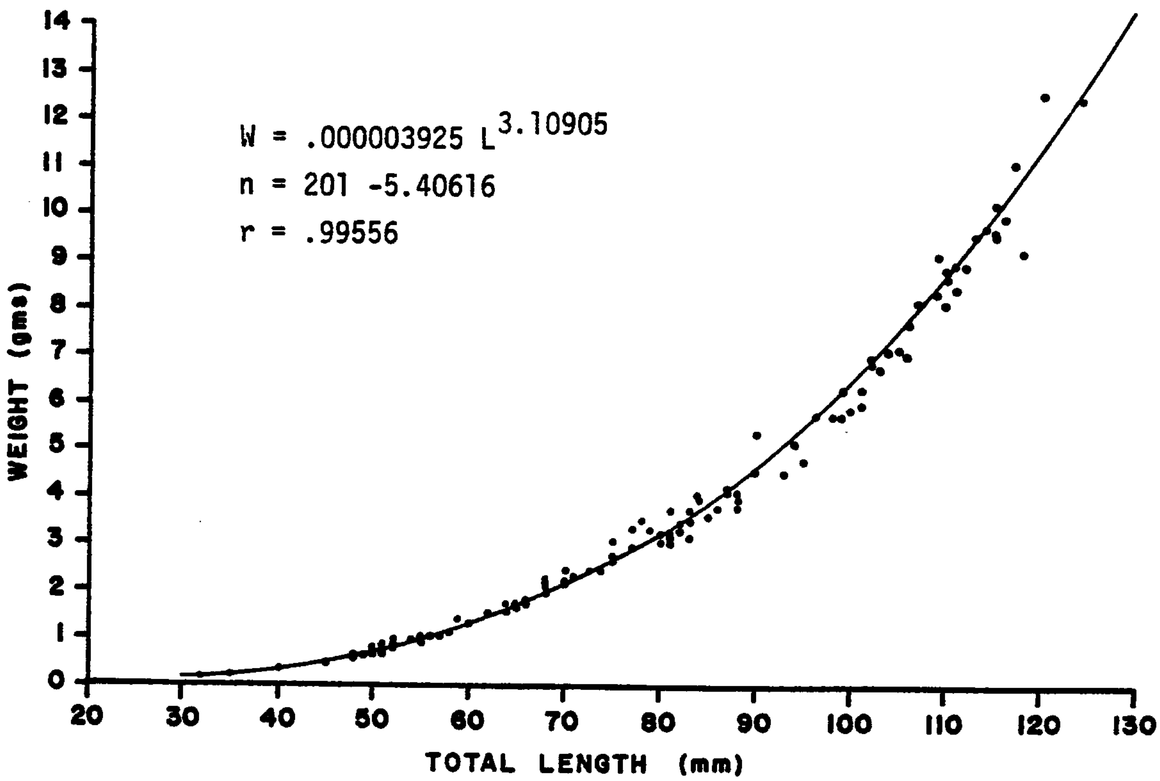

Figure 8. Length-weight relationship for juvenile shad collected in Hooksett Pond. Merrimack River Anadromous Fisheries Investigation, 1978.

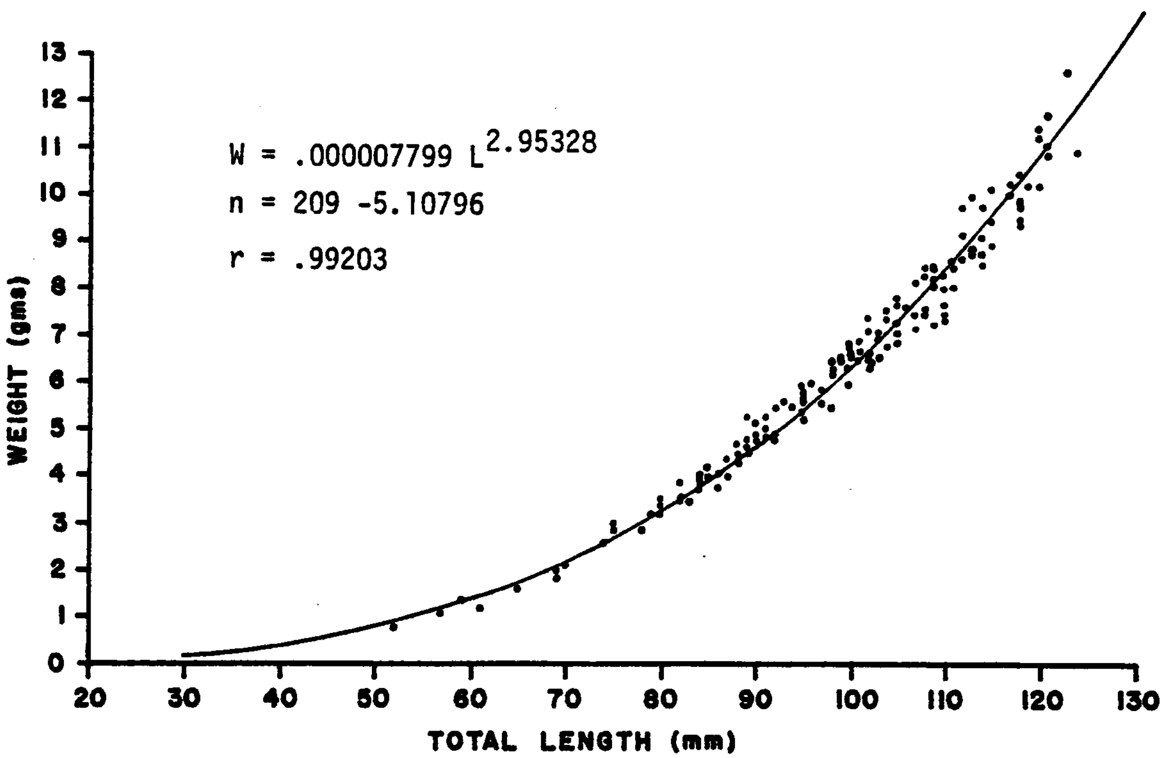

Figure 9. Length-weight relationship for juvenile shad collected in Amoskeag Pond. Merrimack River Anadromous Fisheries Investigation, 1978.

TABLE 6. JUVENILE SHAD SEINING DATES AND STATIONS, WITH THE NUMBER AND LENGTH RANGE FOR SHAD COLLECTED. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

DATE	STATION	SURFACE WATER TEMPERATURE (°C)	NUMBER OF SHAD COLLECTED	NUMBER OF SHAD MEASURED	TOTAL LENGTH RANGE (mm)
7/25/78	O-W	28.2	2	2	33-37
	S-4-E	27.8	15	15	48-68
7/26/78	O-W	26.6	0	0	
	S-3-E	N/A	0	0	
7/27/78	O-W	27.6	12	2	52-57
	S-3-E	26.5	1	0	
7/28/78	O-W	27.6	21	3	34-50
	S-4-E	N/A	0	0	
7/31/78	NI-W	23.4	9	2	52
	SOU-W	23.7	0	0	
	SOU-E	23.1	0	0	
	N-12-E	23.3	0	0	
	N-4-E	23.2	0	0	
	N-2-E	23.0	2	2	51-54
8/2/78	N-1-E	22.6	0	0	
	N-1-W	21.8	0	0	
	O-W	25.4	0	0	
	S-3-E	23.9	1	1	51
	S-8-E	22.7	0	0	
	S-17-E	22.8	0	0	
	S-19-E	23.0	0	0	
	S-21-E	23.1	0	0	
8/8/78	NI-E	22.9	0	0	
	NI-W	22.8	0	0	
	SOU-W	22.8	0	0	
	N-7-E	22.7	0	0	
	N-1-E	26.6	0	0	
	O-W	27.3	0	0	
	S-3-E	25.0	0	0	
	S-19-E	25.6	0	0	
8/14/78	NI-S	NA	0	0	
	SOU-W	NA	0	0	
	NAR-E	NA	0	0	
	O-E	NA	130	13	46-72
	S-3-E	27.3	73	28	54-85
	S-4-E	26.6	0	0	
	S-19-E	26.5	0	0	
	S-21-E	28.0	0		
8/22/78	NI-S	24.6	0	0	
	SOU-W	25.5	0	0	
	NAR	24.7	0	0	
	N-2-E	25.0	0	0	
	O-E	27.9	5	5	68-90
	O-W	27.4	0	0	
	S-3-E	27.6	14	2	68-90
8/29/78	N-2-E	22.2	0	0	
	O-E	23.1	0	0	
	O-W	25.8	0	0	
	S-3-E	23.1	1	1	85
	S-19-E	23.8	0	0	

Continued

TABLE 6. (Continued)

DATE	STATION	SURFACE WATER TEMPERATURE (°C)	NUMBER OF SHAD COLLECTED	NUMBER OF SHAD COLLECTED	TOTAL LENGTH RANGE (mm)
9/8/78	NI	20.8	1	1	98
	NAR-E	21.7	0	0	
	N-2-E	21.2	0	0	
	O-E	21.1	0	0	
	S-3-E	20.5	4	2	71-75
9/12/78	NI	NA	0	0	
	SOU-W	NA	0	0	
	NAR-W	NA	0	0	
	N-10-E	NA	2	2	75-81
	N-1-E	NA	0	0	
	O-W	NA	0	0	
	O-W	NA	0	0	
	S-3-E	NA	0	0	
	S-19-E	NA	0	0	
	S-23-E	NA	0	0	
9/22/78	N-I	18.8	0	0	
	N-2-E	19.8	0	0	
	S-3-E	20.5	0	0	
	S-8-E	NA	0	0	
9/26/78	NI	16.1	0	0	
	SOU	16.0	0	0	
	N-11-E	15.6	0	0	
	N-2-E	16.5	0	0	
	S-3-E	19.3	0	0	
	S-19-E	16.9	0	0	
10/3/78	NI	14.7	0	0	
	NI-W	15.3	0	0	
	N-5-E	16.4	0	0	
	N-4-E	15.6	0	0	
	N-3-E	15.0	0	0	
	O-E	16.3	0	0	
	O-W	17.0	0	0	
	S-1-W	15.4	0	0	
	S-3-E	16.4	0	0	
	S-4-E	16.2	0	0	
	S-6-E	15.8	0	0	
	S-7-W	16.7	0	0	
10/10/78	S-1-W	16.3	0	0	
	S-3-E	18.7	0	0	
	S-3-E	18.6	0	0	
	S-4-E	18.6	0	0	
	S-24-E	14.9	0	0	
	S-24-E	14.3	0	0	
	S-24-M	14.8	0	0	
	S-24-W	14.8	0	0	
	S-24-E	14.5	0	0	
10/17/78	N-3-E	10.3	0	0	
	O-E	18.8	0	0	
	S-3-E	17.0	0	0	
	S-19-E	11.8	0	0	
10/18/78	Hooksett Forebay *	11.2	9	9	104-122
10/27/78	Hooksett Forebay *	NA	8	8	101-113
11/2/78	Canal	18.6	0	0	
	O-W	18.2	0	0	
	Hooksett Forebay *	NA	2	2	100-104
11/8/78	O-W	17.1	0	0	
	S-3-E	14.4	1	1	98
	S-4-E	13.3	0	0	
	S-3-E	14.0	0	0	
	Canal	NA	0	0	
	O-E	15.3	0	0	

* Electrofished

TABLE 7. JUVENILE SHAD SEINING CATCHES AND WATER TEMPERATURES IN AMOSKEAG POND. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

DATE	STATION*	SURFACE WATER TEMPERATURE (°C)	NUMBER OF SHAD COLLECTED	NUMBER OF SHAD MEASURED	TOTAL LENGTH RANGE (mm)
8/4/78	AR-E	23.2	0	0	
	AR-E	23.2	0	0	
8/17/78	50-S-AR-E	NA	8	8	58-83
	HB-E	NA	0	0	
	100-S-HB-W	NA	1	1	58
	200-S-HB-E	NA	4	4	48-70
	300-3-HB-W	NA	0	0	
	600-S-HB-E	NA	0	0	
	600-S-HB-W	NA	0	0	
8/31/78	20-N-AR-E	21.5	280	2	70
	50-S-AR-E	22.1	0	0	
	100-S-AR-E	22.1	0	0	
	50-S-HB-E	22.0	0	0	
	400-S-HB-W	22.0	0	0	
9/14/78	HB-E	18.8	37	17	78-85
	R3-W	18.5	0	0	
9/20/78	AR-E	19.2	≈500	12	81-89
	300-S-HB-E	19.5	0	0	
	800-S-HB-W	18.8	0	0	
	1200N-R3-E	18.5	0	0	
	800N-R3-E	19.1	0	0	
9/28/78	AR-E	16.7	17	17	65-98
	HB-W	16.3	0	0	
	CG-W	15.3	0	0	
	500-N-R3-W	15.3	0	0	
	500-N-R3-E	15.3	0	0	
	500-S-R3-W	16.1	0	0	
	300-N-GC-E	16.0	0	0	
	GC-E	16.4	0	0	
	GC-W	16.3	0	0	
	R3-E	16.3	0	0	
	1000-N-AD-E	16.6	0	0	
10/5/78	100-N-AR-W	14.8	0	0	
	50-N-AR-E	15.1	7	7	76-93
	1000-3-HB-W	14.9	0	0	
	100-N-RB-E	15.0	0	0	
	50-N-RB-E	15.0	0	0	
10/12/78	50-N-AR-E	13.6	5	5	92-116
	100-N-RB-E	14.1	3	3	91-104
	50-N-RB-E	14.1	0	0	
	500-S-RB-W	14.3	0	0	
	GC-E	13.9	0	0	
	RT-E	13.7	0	0	
	RT-E	13.3	0	0	
	30-N-AD-E	13.0	9	9	89-102
10/19/78	AR-E	11.1	16	16	88-110
	100-N-RB-E	11.2	0	0	
	50-N-RB-W	11.2	0	0	
	500-S-R3-W	11.3	0	0	
	RT-E	11.8	0	0	
	30-N-AD-W	11.5	22	22	89-112
10/26/78	AR-E	13.2	3	3	88-101
	EC-W	11.1	0	0	
	100-N-RB-E	10.8	0	0	
	30-N-AD-W	11.2	355	55	92-119
11/1/78	N-AR-E	10.9	0	0	
	N-AR-E	10.9	4	4	108-117
	100-N-RB-E	9.8	0	0	
	50-N-RB-E	9.8	0	0	
	50-S-R3-W	10.4	0	0	
	30-N-AD-W	10.4	140	60	96-121
11/9/78	N-AR-E	10.5	0	0	
	S-AR-E	10.4	0	0	
	CG-W	10.1	0	0	
	75-N-RB-E	10.5	0	0	
	500-S-R3-W	10.7	0	0	
	30-N-AD-W	10.2	16	16	103-123

* Stations on Amoskeag Pond are coded as follows:
Number-Letter-Station code-Bank

Where:
Number = distance in meters from landmark designated in the station code
Letter = north or south from landmark
Station code = two letter code for each landmark shown in Figure 1B
Bank = E or W = east or west bank

TABLE 8. VISUAL OBSERVATIONS OF SHAD ACTIVITY IN HOOKSETT AND AMOSKEAG PONDS DURING SEPTEMBER, OCTOBER AND NOVEMBER. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

DATE	LOCATION	TIME	WATER TEMPERATURE (°C)	COMMENTS AND OBSERVATIONS*
9/14/78	N. of Rt. 3 Conn. bridge	1915	18.3	many shad jumping; activity extends south to golf course
9/19/78	Tailrace	0900	18.4	≈2000 shad
		1200	NA	≈2000 shad
9/20/78	N. of Rt. 3 Conn. Bridge	1700	19.1	few shad
	Tailrace	1915	18.8	shad very active; hundreds seen
	N. of Rt. 3 Conn. Bridge to Tailrace	1720-1820	NA	no shad seen
9/22/78	Tailrace	0645	19.8	shad active on surface
9/26/78	Tailrace	0830	16.0	no shad seen
		1200	16.1	no shad seen
		1600	17.1	no shad seen
9/28/78	Tailrace	1230	16.6	no shad seen
	Tailrace	1420	16.6	no shad seen
	Amoskeag Dam	1140	NA	no shad seen
	Hooksett Dam	0810	16.4	no shad seen
9/27/78	Amoskeag Dam	0800	NA	no shad seen
9/29/78	Amoskeag Dam	0945	NA	no shad seen
10/2/78	Tailrace	0900	15.4	no shad seen
	Tailrace	1200	16.0	no shad seen
	Tailrace	1600	16.2	no shad seen
10/3/78	Amoskeag Dam	0830	NA	no shad seen
	Hooksett Forebay	0855	14.7	no shad seen
	Hooksett Forebay	1610	15.4	no shad seen
10/4/78	Tailrace	0645	14.6	no shad seen
	Tailrace	1200	14.7	no shad seen
	Tailrace	1830	14.4	no shad seen
10/5/78	Tailrace	1300	15.6	shad active
	400 meters S. of Rt. 3 to RB	1345	14.6	shad active mid-stream
10/6/78	Tailrace	1330	15.6	shad active
10/9/78	Amoskeag Forebays	0930	NA	shad active
	Hooksett Forebay	0940	12.1	no shad
	Hooksett Forebay	1600	12.5	many shad
10/10/78	Tailrace	1745	14.8	many shad
	Hooksett Forebay	0945	13.5	no shad
	Hooksett Forebay	1350	14.2	no shad
	Hooksett Forebay	1610	14.5	6 shad
	Hooksett Forebay	1800	14.8	large school of shad
	Amoskeag Forebays	0915	NA	11 adult shad; many shad*
	Hooksett Forebay	1820	14.8	shad feeding
10/11/78	Amoskeag Forebays	0745	NA	no shad seen
	Hooksett Forebay	0800	12.3	no shad seen
	Tailrace	1600	15.6	shad active
10/12/78	Amoskeag Forebays	1010	NA	17 adult shad; shad active
	Hooksett Forebay	1410	13.2	many shad
	N. of RB	1700	14.0	shad active
	RB to 400 meters S. of R3	1710-1745	NA	shad sparse and widely distributed
	N. of Amoskeag Forebays	1200	13.1	many (2-3000) shad seen
	Hooksett Forebay	1800	13.5	many shad; very active
10/13/78	Amoskeag Forebays	0945	NA	few shad seen jumping
	Amoskeag Forebays	1545	NA	no shad seen
	Hooksett Forebay	0910	14.2	shad lightly active
	Hooksett Forebay	1605	15.1	shad moderately active
10/16/78	Amoskeag Forebays	0910	NA	shad lightly active
	Hooksett Forebay	0930	12.5	shad moderately active
10/17/78	Hooksett Forebay	1055-1635	11.7	many shad
	Amoskeag Forebays	0950	NA	11 adult shad; moderately active
	Hooksett Forebay	0920	11.7	shad moderately active
	Hooksett Forebay	1710	12.0	shad lightly active

Continued

TABLE 8. (Continued)

DATE	LOCATION	TIME	WATER TEMPERATURE (°C)	COMMENTS AND OBSERVATIONS
10/18/78	Amoskeag Forebays	0930	NA	1 shad seen
	Hooksett Forebay	0950	10.7	shad lightly active; ≈1000 shad above trash gate
	Hooksett Forebay	1410	11.4	shad near trash racks (trash gate opening at 1300 appears to have reduced shad in that area)
10/19/78	Amoskeag Forebays	1020	NA	no shad
	Amoskeag Forebays	1115	11.5	12 shad observed above trash racks
	Amoskeag Forebays	1205	11.6	few shad in area; occasional small school observed
	N. of RB	1315	11.2	shad active; small numbers
	Hooksett Forebay	1410	11.3	shad moderately active
10/20/78	Amoskeag Forebays	0900	NA	shad lightly active
	Hooksett Forebay	0915	11.6	shad lightly active
	Hooksett Forebay	1545	11.7	500+ shad seen; moderately active
10/23/78	Amoskeag Forebays	1030	NA	shad moderately active
	Hooksett Forebay	1100	12.9	shad lightly active
	Tailrace	1600	12.4	shad seen
10/24/78	Amoskeag Forebays	0900	NA	no shad seen
	Hooksett Forebay	0920	10.5	shad lightly active
	Hooksett Forebay	1745	10.7	shad heavily active
10/25/78	Hooksett Forebay	0840	9.6	shad lightly active
	Hooksett Forebay	1615	10.8	many shad seen
	Amoskeag Forebays	0830	NA	no shad seen
10/26/78	Amoskeag Forebays	0930	NA	shad activity seen
	Hooksett Forebay	1000	12.7	shad heavily active
10/27/78	Amoskeag Forebays	0920	NA	no shad seen
	Hooksett Forebay	0940	13.0	shad lightly active
10/30/78	Amoskeag Forebays	1015	NA	10 adult shad; shad lightly active
	Hooksett Forebay	1045	11.1	shad lightly active
	Hooksett Forebay	1600	11.7	shad heavily active
10/31/78	Amoskeag Forebays	0910	NA	15 adults; 2 shad*
	Hooksett Forebay	0945	10.1	no shad seen (water going through trash gate
	Hooksett Forebay	1230	10.1	500+ shad near trash racks (water going through trash gate)
	Hooksett Forebay	1600	10.0	shad lightly active
11/1/78	Amoskeag Forebays	0945	NA	21 adult shad; no juveniles
	Hooksett Forebay	1205	10.4	500+ shad
11/2/78	Amoskeag Forebays	0915	NA	12 adult shad
	Hooksett Forebay	0930	10.1	large school juveniles
	Hooksett Forebay	1545	10.3	some shad; trash gate open
11/3/78	Amoskeag Forebays	0945	NA	20 adult shad
	Hooksett Forebay	1600	10.7	shad; water going through trash gate
11/6/78	Amoskeag Forebays	0915	NA	20 adult shad
	Hooksett Forebay	1015	10.5	no shad
	Hooksett Forebay	1600	10.9	shad present
11/7/78	Amoskeag Forebays	0845	NA	no shad seen
	Hooksett Forebay	0915	11.3	no shad seen
	Hooksett Forebay	1605	10.4	2-3 shad
11/8/78	Amoskeag Forebays	0900	NA	9 adult shad
	Hooksett Forebay	0940	10.5	no shad seen
	Hooksett Forebay	1545	10.2	no shad seen
11/9/78	Amoskeag Forebays	0900	NA	16 adult shad
	Hooksett Forebay	0945	9.6	no shad seen
11/10/78	Canal	1030	NA	no shad seen
	Amoskeag Forebays	0845	NA	19 adult shad; 50 shad
	Hooksett Forebay	0915	9.8	no shad seen
	Hooksett Forebay	1530	10.0	no shad seen
11/14/78	Amoskeag Forebays	1530	NA	5 adult shad
11/16/78	Amoskeag Forebays	1130	NA	13 adult shad
11/20/78	Amoskeag Forebays	1315	NA	no shad seen
	Hooksett Forebay	1335	NA	no shad seen

* All references to shad in this table indicate juveniles unless specified as adults

+ Tailrace indicates the tailrace of Hooksett Dam below the Power House

TABLE 9. SUMMARY OF FISH ENTRAPMENT MONITORING FOR UNITS I AND II, MERRIMACK STATION, 1978. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

	JUNE		AUGUST		SEPTEMBER		OCTOBER	
	NO.	LENGTH RANGE (mm)	NO.	LENGTH RANGE (mm)	NO.	LENGTH RANGE (mm)	NO.	LENGTH RANGE (mm)
Golden Shiner	3	71-86	0		0		1	130
Common Shiner	2	55-95	0		0		0	
Spottail Shiner	0		0		0		0	
Fallfish	3	100-200	1	87	0		0	
White Sucker	1	461	0		0		0	
Yellow Bullhead	1	170	0		0		0	
Brown Bullhead	10	71-204	6	145-170	0		0	
Margined Madtom	1	151	0		0		0	
Pumpkinseed	1	59	0		1	43	1	31
Smallmouth Bass	1	280	0		0		0	
Largemouth Bass	1	28	1	78	0		0	
Yellow Perch	2	260-281	2	194-243	0		0	
American Shad	0		0		0		1	91

TABLE 10. GROWTH AND LENGTH-WEIGHT EQUATIONS FOR MERRIMACK RIVER JUVENILE SHAD. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

GROWTH EQUATIONS

INSTANTANEOUS GROWTH	PER DIEM GROWTH	LENGTH INCREASE PER DAY (mm)	RIVER SECTION
Log Y = 1.5400 + 0.2261 Log X (0.84)*	Y = 50.2197 + 0.5966x(0.94)	0.60	Hooksett Pond
Log Y = 1.3005 + 0.3591 Log X (0.86)	Y = 53.4310 + 0.5243x(0.86)	0.52	Amoskeag Pond

Y = Total length in mm   X = Time in days; day 1 = July 25, 1978

LENGTH-WEIGHT EQUATIONS

EQUATION	RIVER SECTION	AUTHOR
Log Y = -5.4062 + 3.1091 Log X (0.99)*	Hooksett Pond	This study
Log Y = -5.1080 + 2.9533 Log X (0.99)	Amoskeag Pond	This study
Log Y = -5.230 + 3.1094 Log X (0.98)	Connecticut River	Marcy, 1976b
Log Y = -5.2152 + 3.0879 Log X	Connecticut River	Watson, 1968

Y = Total weight in grams   X = Total length in mm

* Numbers in parentheses are correlation coefficients.

TABLE 11. SUMMARY OF FISH CAPTURED IN THE HOOKSETT HYDROELECTRIC STATION TAILRACE USING A DOWNSTREAM-MIGRANT TRAP NET. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

DATE	TIME	WATER TEMPERATURE (°C)	FISH CAPTURED	TOTAL LENGTH RANGE (mm)
8/21/78	1000-1200	25.6	0	
	1200-1400	25.9	0	
	1400-1600	26.2	0	
8/23/78	0530-0700	25.2	0	
	0700-0900	25.2	0	
	0900-1100	25.1	0	
	1100-1300	25.2	0	
8/25/78	1600-1800	24.0	0	
	1800-2000	24.0	2 common shiner 1 brown bullhead	
	2000-2200	23.8	0	
	2200-2400	23.6	0	
8/29/78	0830-1200	21.8	0	
	1200-1600	23.0	0	
8/31/78	0600-1000	22.0	1 brown bullhead	
	1000-1400	21.7	0	
9/6/78	0600-1000	21.8	0	
	1000-1400	22.7	0	
9/12/78	0800-1200		5 shad 2 largemouth bass	77-83
	1200-1600		39 shad 1 largemouth bass	77-89
9/13/78	0800-1200	18.4	0	
	1200-1600	18.9	0	
9/15/78	0830-1200	18.0	1 shad 1 Atlantic salmon smolt 6 largemouth bass	83
	1200-1600	18.0	2 largemouth bass	
9/19/78	0900-1200	18.5	0	
	1200-1600	19.9	0	

(Continued)

TABLE 11. (Continued)

DATE	TIME	WATER TEMPERATURE (°C)	FISH CAPTURED	TOTAL LENGTH RANGE (mm)
9/20/78	1220-1600	19.6	2 largemouth bass 1 smallmouth bass	
	1600-2000	18.8	1 largemouth bass 1 white sucker	
9/22/78	0645-1030	19.8	0	
	1030-1350	19.2	1 largemouth bass 1 redbreast sunfish 1 brown bullhead	
9/26/78	0830-1200	16.0	1 brown bullhead 1 eel	
	1200-1600	17.1	0	
9/27/78	0900-1200	16.3	0	
	1200-1600	16.8	3 largemouth bass	
9/28/78	1230-1600	16.6	3 largemouth bass	
	1600-2000	15.8	2 largemouth bass 1 eel	
9/29/78	1000-1230	15.2	1 largemouth bass 1 shad	89
	1230-1600	15.6	0	
10/2/78	0900-1200	16.0	0	
	1200-1600	16.2	0	
10/3/78	0900-1200	15.3	10 largemouth bass 1 pumpkinseed	
	1200-1600	15.4	7 largemouth bass 1 pumpkinseed	
10/4/78	0645-1200	14.7	10 largemouth bass	
	1200-1830	14.4	6 largemouth bass 1 brown bullhead 1 shad	89
10/5/78	1100-1300	15.6	0	
	1300-1600	15.6	1 largemouth bass	
10/6/78	0930-1330	15.8	1 brown bullhead 8 largemouth bass	
	1330-1530	15.8	24 largemouth bass	

(Continued)

TABLE 11. (Continued)

DATE	TIME	WATER TEMPERATURE (°C)	FISH CAPTURED	TOTAL LENGTH RANGE (mm)
10/9/78	1000-1230	12.4	3 largemouth bass 2 largemouth bass	
	1230-1600	10.5	1 shad	91
10/10/78	0950-1215	14.2	1 largemouth bass	
	1215-1400	14.4	1 largemouth bass	
	1400-1600	14.5	6 largemouth bass 1 brown bullhead	
	1600-1745	14.8	1 common shiner	
10/11/78	0800-1200	14.3	1 largemouth bass	
	1200-1600	15.6	8 largemouth bass	
10/12/78	1115-1400	13.2	0	
	1400-1745	13.6	1 spottail shiner	
10/13/78	0915-1600	15.1	3 spottail shiner 1 yellow perch 1 golden shiner 1 brown bullhead 1 fallfish 1 largemouth bass 2 common shiner	
10/16/78	0945-1200	13.0	1 shad 2 largemouth bass 1 yellow perch	120
	1200-1400	13.5	5 largemouth bass 2 yellow perch	
	1400-1600	14.0	1 largemouth bass 1 golden shiner	
10/17/78	0930-1200	11.7	5 largemouth bass	
	1200-1700	12.0	7 largemouth bass 6 yellow perch 1 white perch	
10/18/78	1000-1300	11.5	2 shad 2 largemouth bass 1 yellow perch	101-116
	1300-1500	11.4	1 largemouth bass	
	1500-1615	11.1	10 largemouth bass	

(Continued)

TABLE 11. (Continued)

DATE	TIME	WATER TEMPERATURE (°C)	FISH CAPTURED	TOTAL LENGTH RANGE (mm)
10/19/78	1045-1330	11.3	1 largemouth bass 2 yellow perch	
	1330-1500	11.3	1 largemouth bass 5 yellow perch	
	1500-1800	11.2	1 pumpkinseed 5 yellow perch	
10/20/78	0930-1540	11.6	1 largemouth bass 1 shad 5 yellow perch 1 white sucker	107
10/23/78	1100-1300	12.9	0	
	1300-1600	12.4	3 yellow perch 2 fallfish	
10/24/78	0930-1300	10.4	121 shad 2 largemouth bass 1 yellow perch	89-123
	1300-1600	10.1	79 shad	91-123
	1600-1730	10.7	20 shad	95-112
10/25/78	845-1215	10.6	1 largemouth bass 1 yellow perch	
	1215-1600	10.8	2 largemouth bass 1 spottail shiner	
10/26/78	1030-1200	13.2	0	
	1200-1315	13.3	1 yellow perch 2 largemouth bass	
	1315-1600	12.2	2 yellow perch	
10/27/78	0950-1200	13.0	1 largemouth bass	
	1200-1400	13.2	1 shad 1 largemouth bass	101
	1400-1600	13.2	0	
10/30-78	1100-1300	11.6	0	
	1300-1600	11.7	3 largemouth bass 1 common shiner	
10/31/78	1000-1200	10.1	0	
	1200-1330	9.9	1 white perch	
	1330-1600	10.0	0	

(Continued)

TABLE 11. (Continued)

DATE	TIME	WATER TEMPERATURE (°C)	FISH CAPTURED	TOTAL LENGTH RANGE (mm)
11/1/78	1000-1200	10.4	2 largemouth bass 1 yellow perch	
	1200-1400	10.9	2 shad 1 largemouth bass 1 spottail shiner	108-110
	1400-1600	0.9	2 yellow perch 1 largemouth bass 1 spottail shiner	
11/2/78	1000-1200	10.3	0	
	1200-1400	10.3	4 yellow perch	
	1400-1600	10.3	1 shad	119
11/3/78	1000-1345	10.6	6 yellow perch 2 largemouth bass 1 spottail shiner	
11/6/78	0930-1545	10.9	6 yellow perch 1 largemouth bass	
11/7/78	0930-1600	10.4	6 yellow perch	
11/8/78	0945-1230	10.1	2 largemouth bass 1 yellow perch	
	1230-1600	10.2	3 yellow perch	
11/9/78	1000-1200	9.9	0	
	1200-1400	10.5	0	
11/10/78	0930-1545	10.0	13 spottail shiners 1 yellow perch 1 golden shiner	

Total number shad collected = 276

Total number hours fished = 310.6 hrs

IV. SUMMARY

During 1978, 780,000 fertilized eggs and 624 adult American shad were introduced into Hooksett Pond, Merrimack River, to determine if the Merrimack Generating Station and its thermal discharge would have any adverse effects on either the movement and spawning of adult shad or the survival of shad eggs, larvae or juveniles.

Survival of the fertilized eggs to hatching was estimated to be 64.8 to 88.6%, with a hatching time of five to seven days. Thus, approximately 607,000 larvae should have been produced from these eggs.

The sex-ratio of the introduced adults was 1.7 males per female, resulting in an estimated 393 males and 231 females released into Hooksett Pond. Assuming a potential fecundity range of 150 to 450 thousand eggs per female, there was a potential for 34 to 104 million eggs to be spawned in Hooksett Pond during 1978.

Thirteen shad were radio-tagged, released downstream of the Merrimack Station thermal discharge, and tracked for a period of five days. Of these thirteen, four ascended the river past the thermal discharge; behavior of these shad indicated no thermal blockage to migration within the mixing zone. Thermal surveys have shown that an ambient zone of passage is typically present throughout the mixing zone. Untagged adult shad were observed in Hooksett Pond through mid-July, and in Amoskeag Pond until November 16.

The introduced adult shad successfully spawned in Hooksett Pond, although the surface activity that is normally indicative of shad spawning was not observed. Drift nets set throughout Hooksett Pond collected drifting shad eggs from June 3 through July 2; most eggs were collected along the east river bank opposite the discharge canal and 1.2 km south of the canal mouth. Relatively few eggs were collected upstream of the generating station. Although some of the eggs collected may have come from the fertilized eggs that were stocked, most had been spawned by the adults.

Larval shad were not collected in Hooksett Pond despite extensive seining effort and predator stomach sampling during June and July. One shad larvae was collected in a drift net set at Station 0-E on July 2.

Entrainment susceptibility of shad eggs and larvae in Merrimack Station's cooling system appears to be low. No American shad eggs or larvae were collected in entrainment samples from June 1 through July 27. This supports the conclusions of previous studies that shad egg and larval transport characteristics reduce the probability of entrainment in the cooling water system. Similarly, momentum entrainment in the thermal plume should not be lethal to shad eggs. The effects of larval drift through the discharge were not assessed during 1978 because no larvae were collected. Previous studies indicated that plume temperatures may be lethal to American shad only during periods of maximum power generation and low river flows. The extended shut-down of Merrimack Unit II during the critical mid-June to mid-July period precluded any assessment of maximum power generation on larval survival within the discharge plume during 1978.

Juvenile shad were observed in Hooksett and Amoskeag Ponds from July 25 through November 10. Although the young shad ranged throughout this river section, they were collected most consistently within the mixing zone of the Merrimack Station and immediately downstream of the Hooksett Hydroelectric Station tailrace. Shad grew normally in both ponds and appeared to be healthy. Downstream migration began in early September as water temperatures approached 17°C, but most juveniles moved downriver during early October when water temperatures were approximately 12°C. Migration out of Hooksett Pond was complete by November 7, and out of Amoskeag Pond by November 10. Juvenile shad did not tend to congregate near the discharge canal as river temperatures decreased throughout the fall. In addition, there was no evidence of thermal blockage to downstream migration.

Entrapment sampling from August through October indicated a low probability of juvenile shad impingement. Only one juvenile was impinged during a total of 336 hours of screen sampling.

V. CONCLUSIONS

Observations during three years of shad study indicate that the thermal discharge of Merrimack Station would not adversely affect the successful restoration of American shad in the Merrimack River. Thermal blockage should not occur to either the upstream migrating adults or the juveniles moving downstream during the fall. Water temperatures in Hooksett Pond typically are conducive to shad spawning and development of the eggs into the larval and juvenile stages. In addition, pump entrainment of eggs and larvae and entrapment of juveniles should be minimal. Once Hooksett Pond is utilized by a restored anadromous American shad population, the effects of maximum power generation on larval drift past Merrimack Station should be appraised in relationship to the total shad production of this river section.

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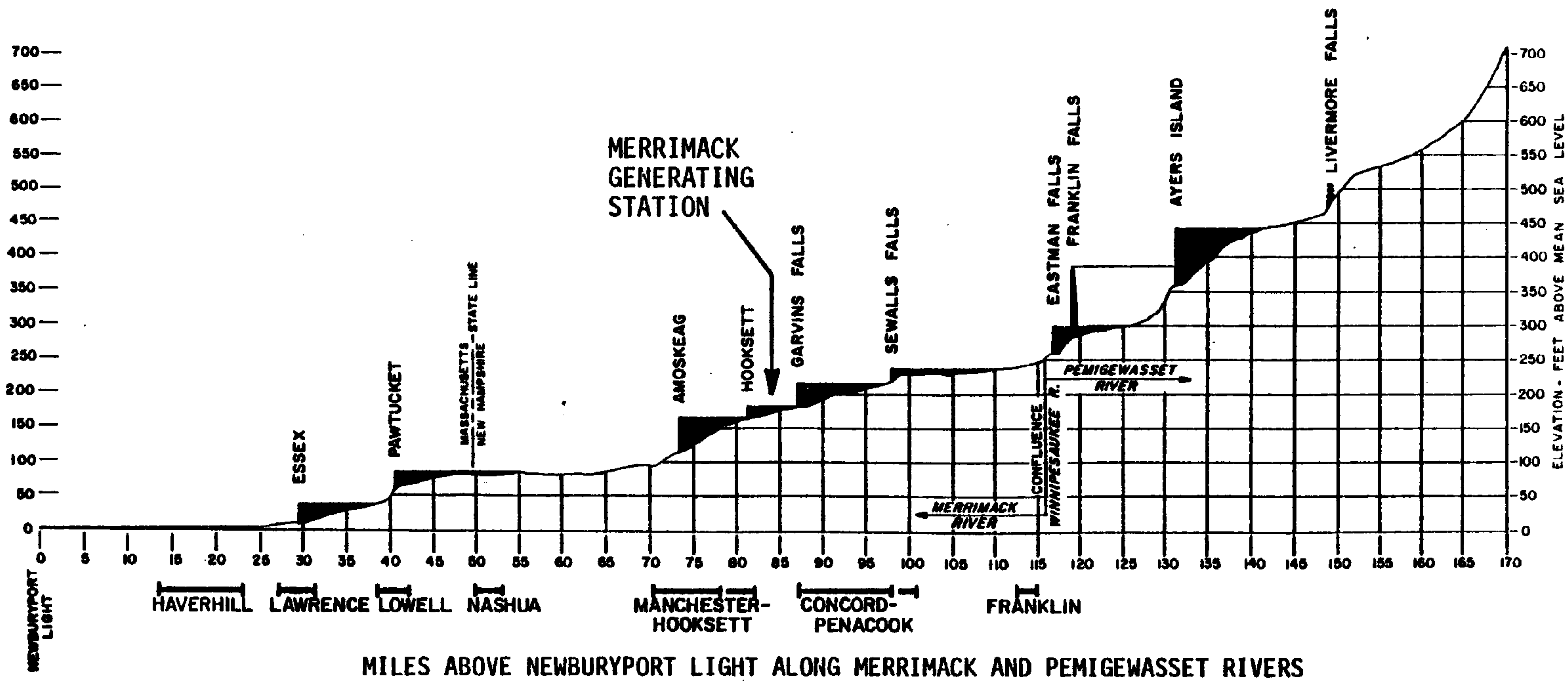
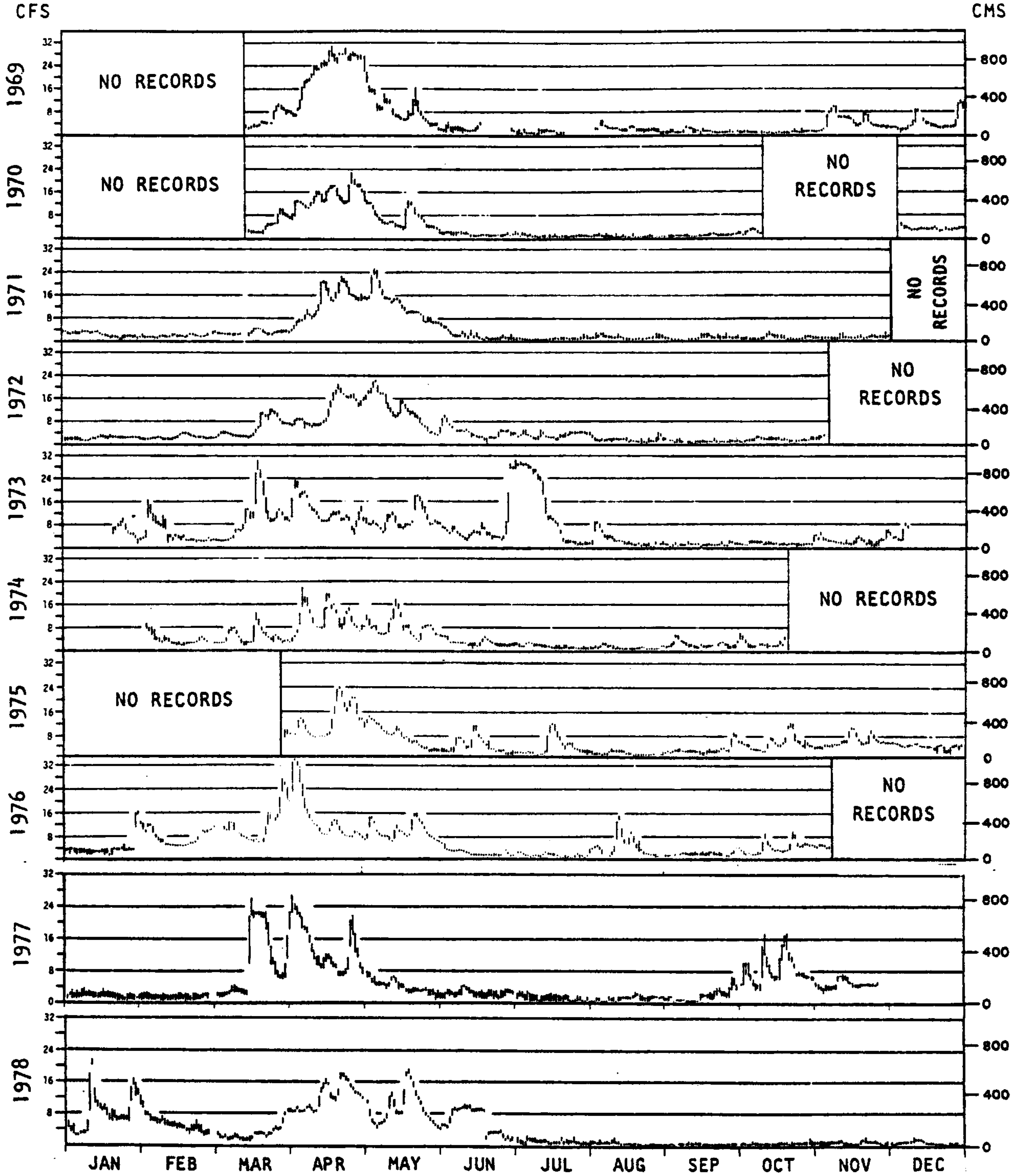
APPENDIX I.

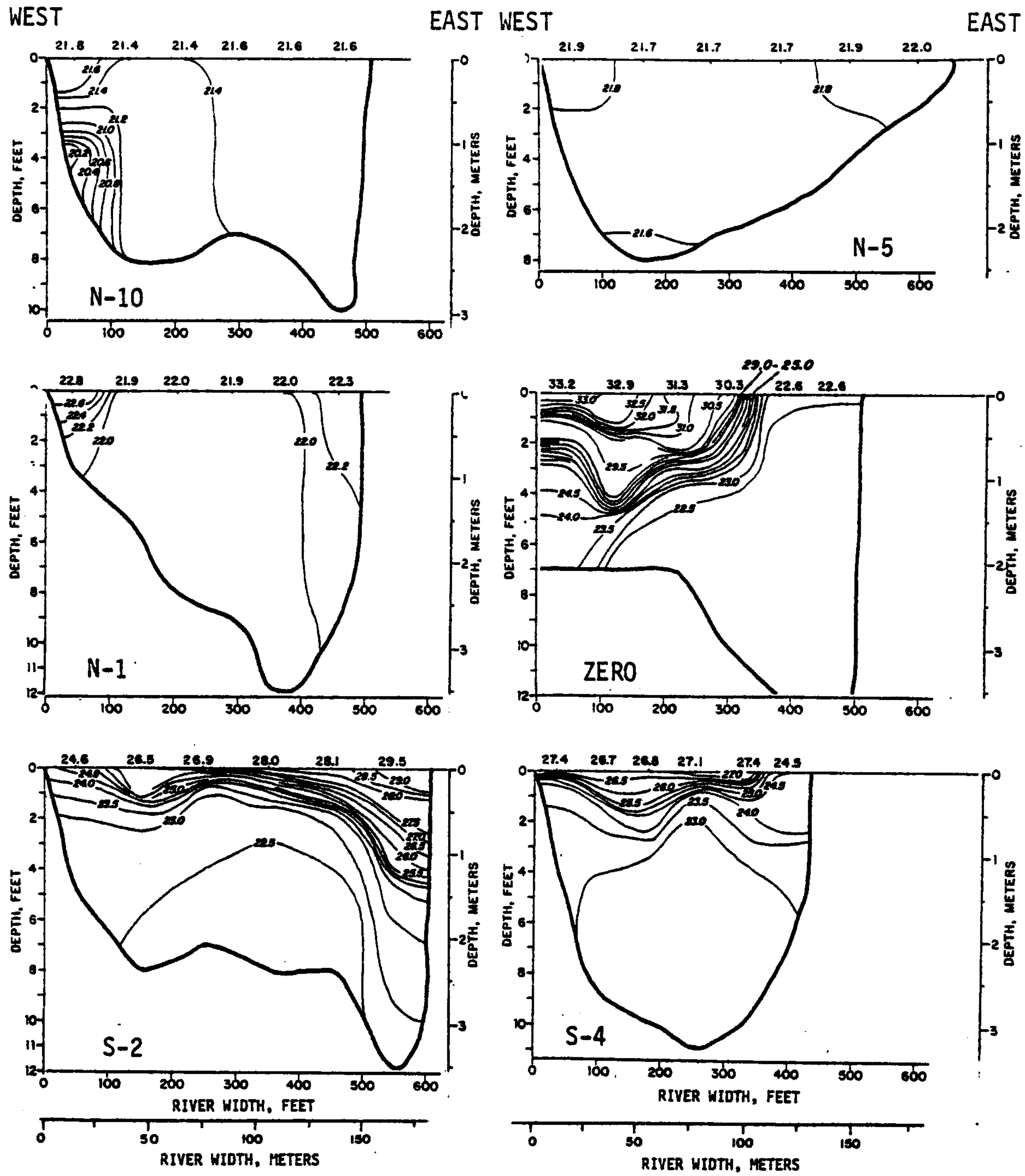
PHYSICAL, CHEMICAL AND BIOLOGICAL DATA DESCRIBING HOOKSETT POND



Appendix I, Figure 1. Merrimack River longitudinal profile locating impoundments, cities and Merrimack Station. Merrimack River Anadromous Fisheries Investigation, 1978.

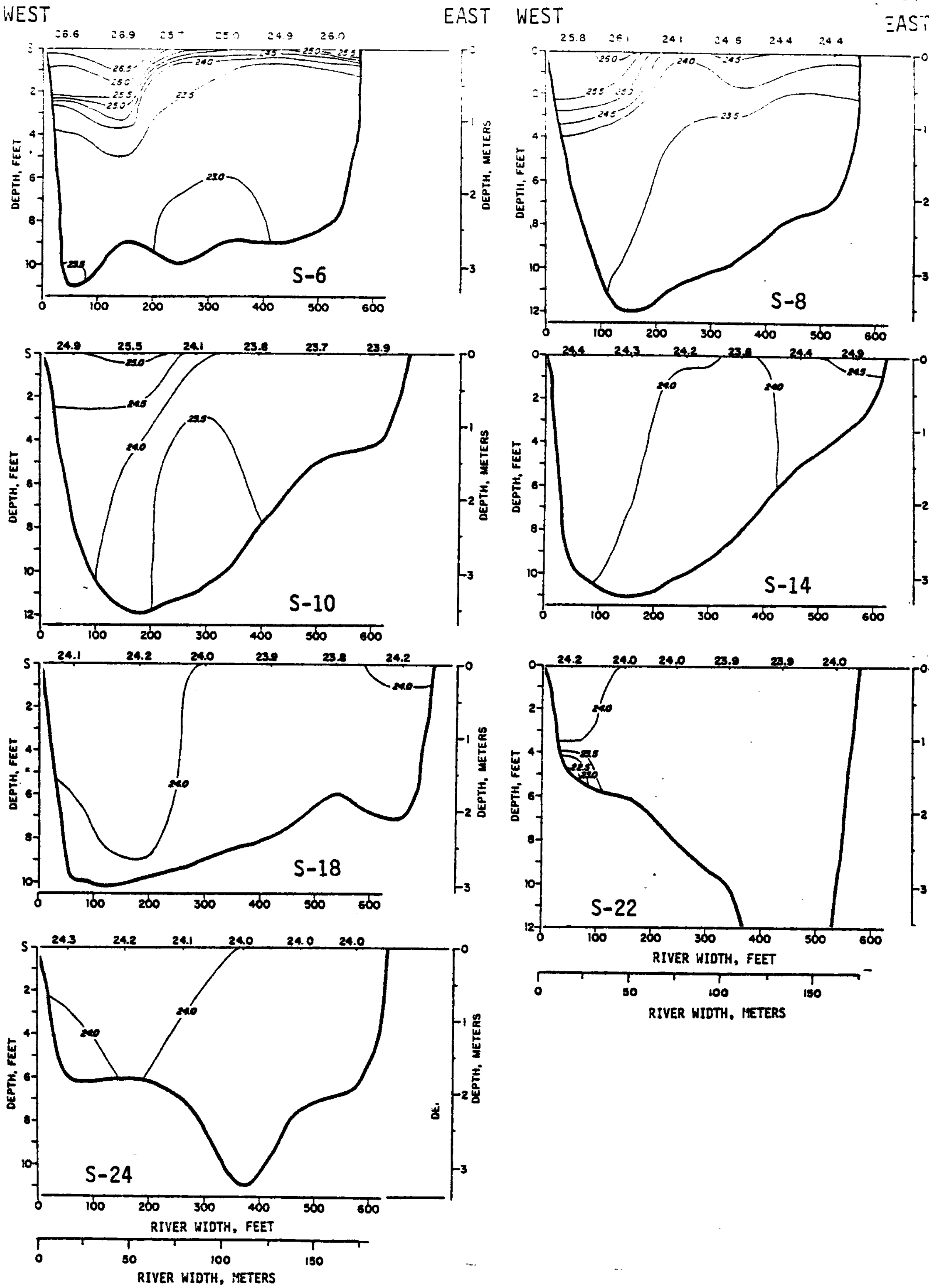


Appendix I, Figure 2. Range of daily Garvin's Falls discharge, 1969-1978. Merrimack River Anadromous Fisheries Investigation, 1978.



Appendix I, Figure 3. Temperature profiles (°C) of Hooksett Pond on May 31, 1978. Merrimack River Anadromous Fisheries Investigation, 1978.

Continued



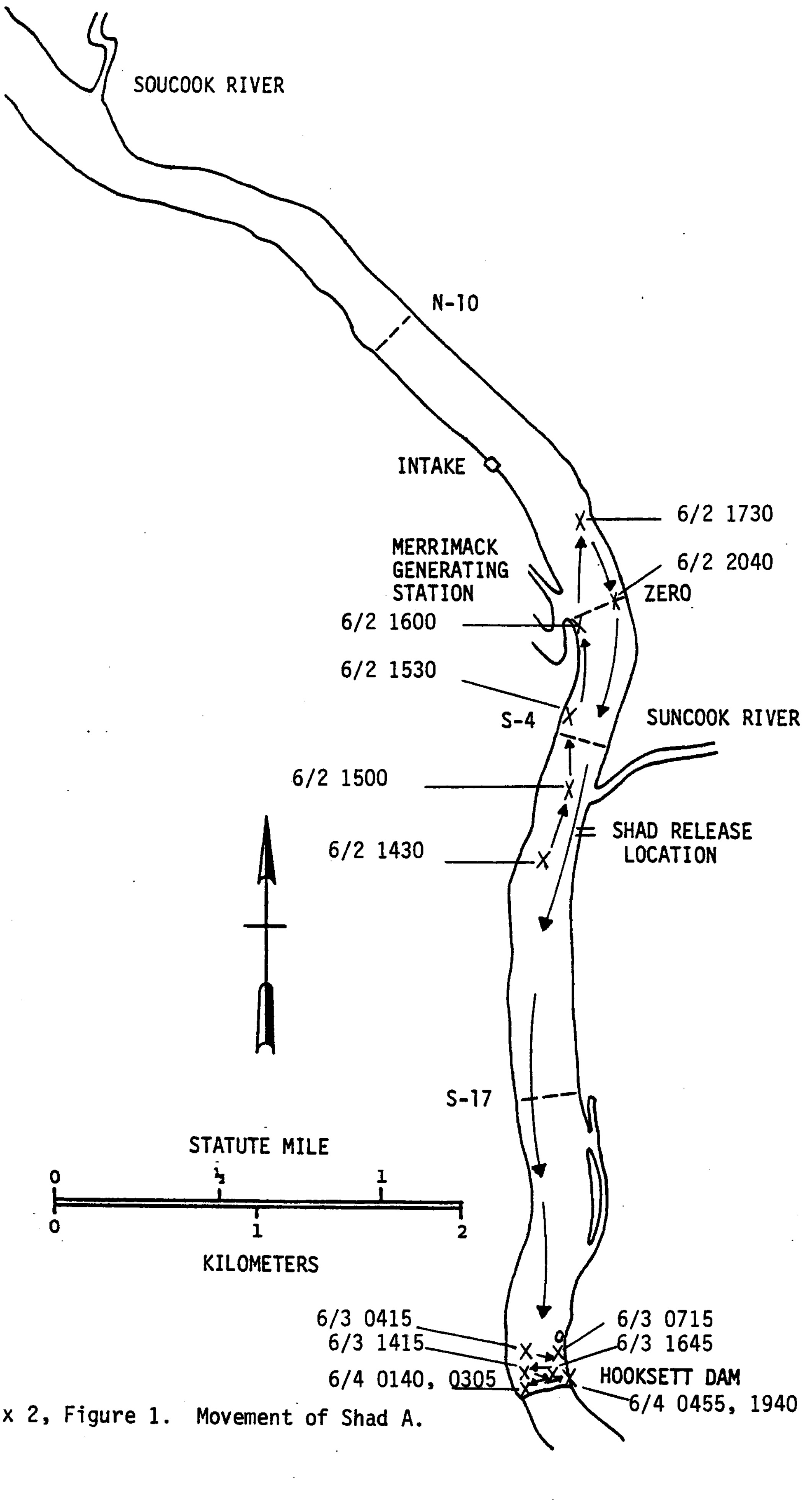
Appendix I, Figure 3. (Continued)

APPENDIX I, TABLE 1. RESIDENT AND MIGRATORY FINFISH OBSERVED IN HOOKSETT POND FROM 1967 THROUGH 1978. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.

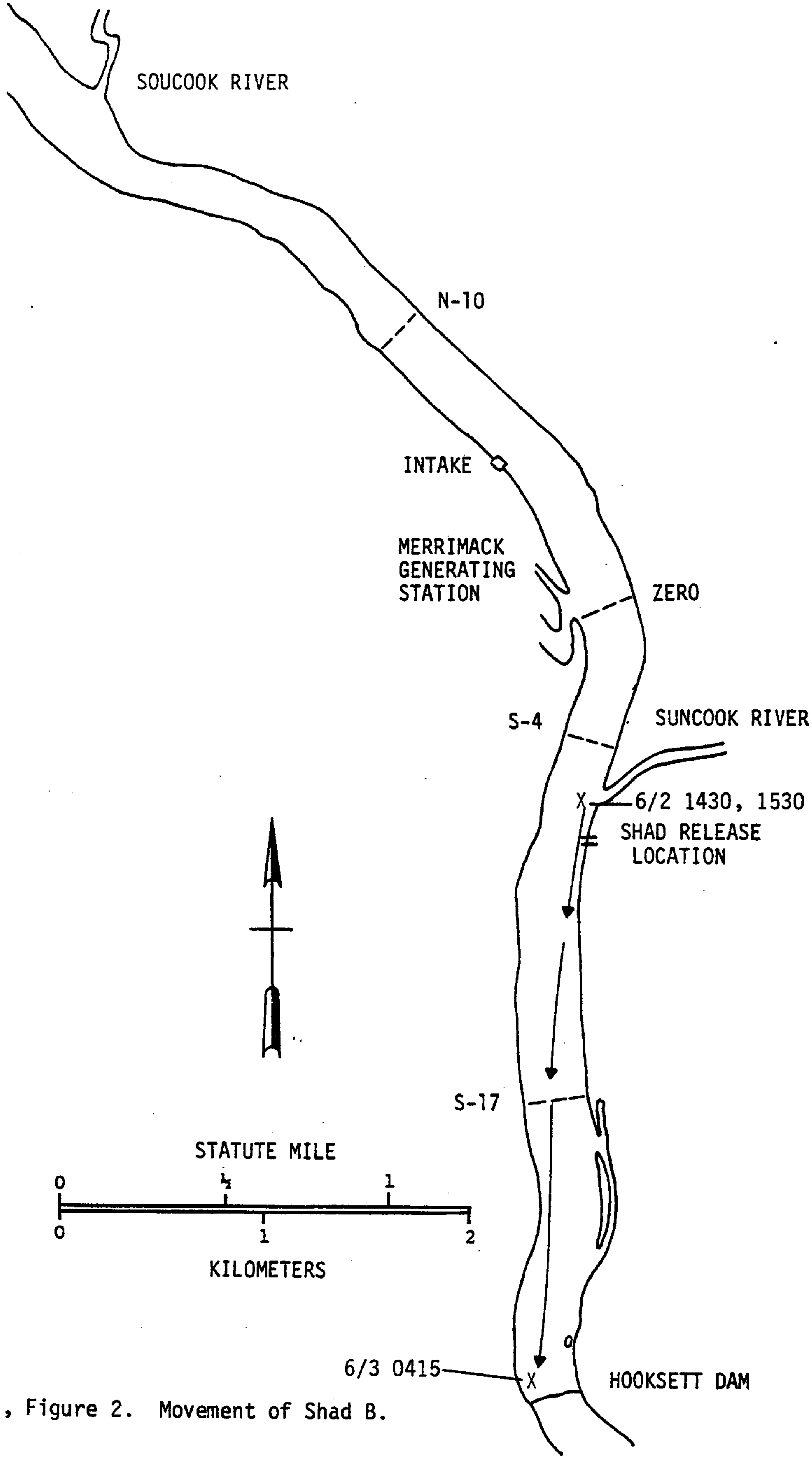
SCIENTIFIC NAME	COMMON NAME
Anguillidae	
Anguilla rostrata	American eel
Salmonidae	
Salmo gairdneri	Rainbow trout
Salmo salar	Atlantic salmon
Salmo trutta	Brown trout
Salvelinus fontinalis	Brook trout
Osmeridae	
Osmerus mordax	Rainbow smelt
Esocidae	
Esox niger	Chain pickerel
Cyprinidae	
Notemigonus crysoleucas	Golden shiner
Notropis cornutus	Common shiner
Notropis hudsonius	Spottail shiner
Notropis spp.	
Semotilus corporalis	Fallfish
Catostomidae	
Castostomus commersoni	White sucker
Ictaluridae	
Ictalurus natalis	Yellow bullhead
Ictalurus nebulosus	Brown bullhead
Noturus gyrinus	Tadpole madtom
Noturus insignis	Margined madtom
Percichthyidae	
Morone americana	White perch
Centrarchidae	
Lepomis auritus	Redbreast sunfish
Lepomis gibbosus	Pumpkinseed
Lepomis macrochirus	Bluegill
Micropterus dolomieui	Smallmouth bass
Micropterus salmoides	Largemouth bass
Percidae	
Etheostoma nigrum	Johnny darter
Perca flavescens	Yellow perch
Stizostedion vitreum	Walleye

APPENDIX II.

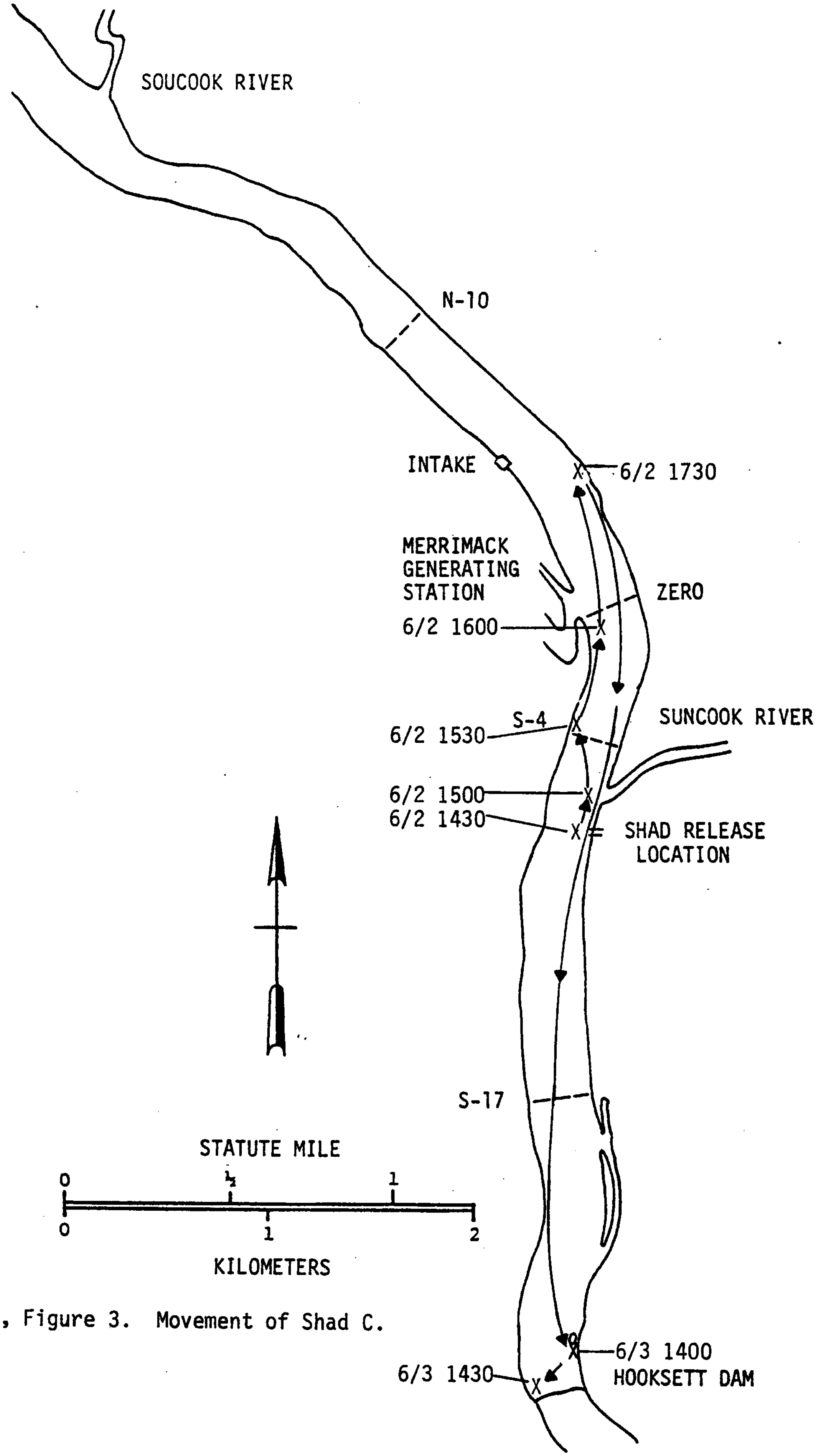
MOVEMENT OF RADIO-FREQUENCY TAGGED AMERICAN SHAD IN HOOKSETT POND, MERRIMACK RIVER, NH. JUNE 2 THROUGH 5, 1978. ARROWS INDICATE DIRECTION OF NET MOVEMENT BETWEEN SIGHTINGS, AND DO NOT IMPLY LINEAR MOVEMENT BETWEEN TWO LOCATIONS. RIVER WIDTH IS EXAGGERATED; OTHER DISTANCES ARE TO SCALE. DATE AND TIME OF EACH SIGHTING ARE INDICATED. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1978.



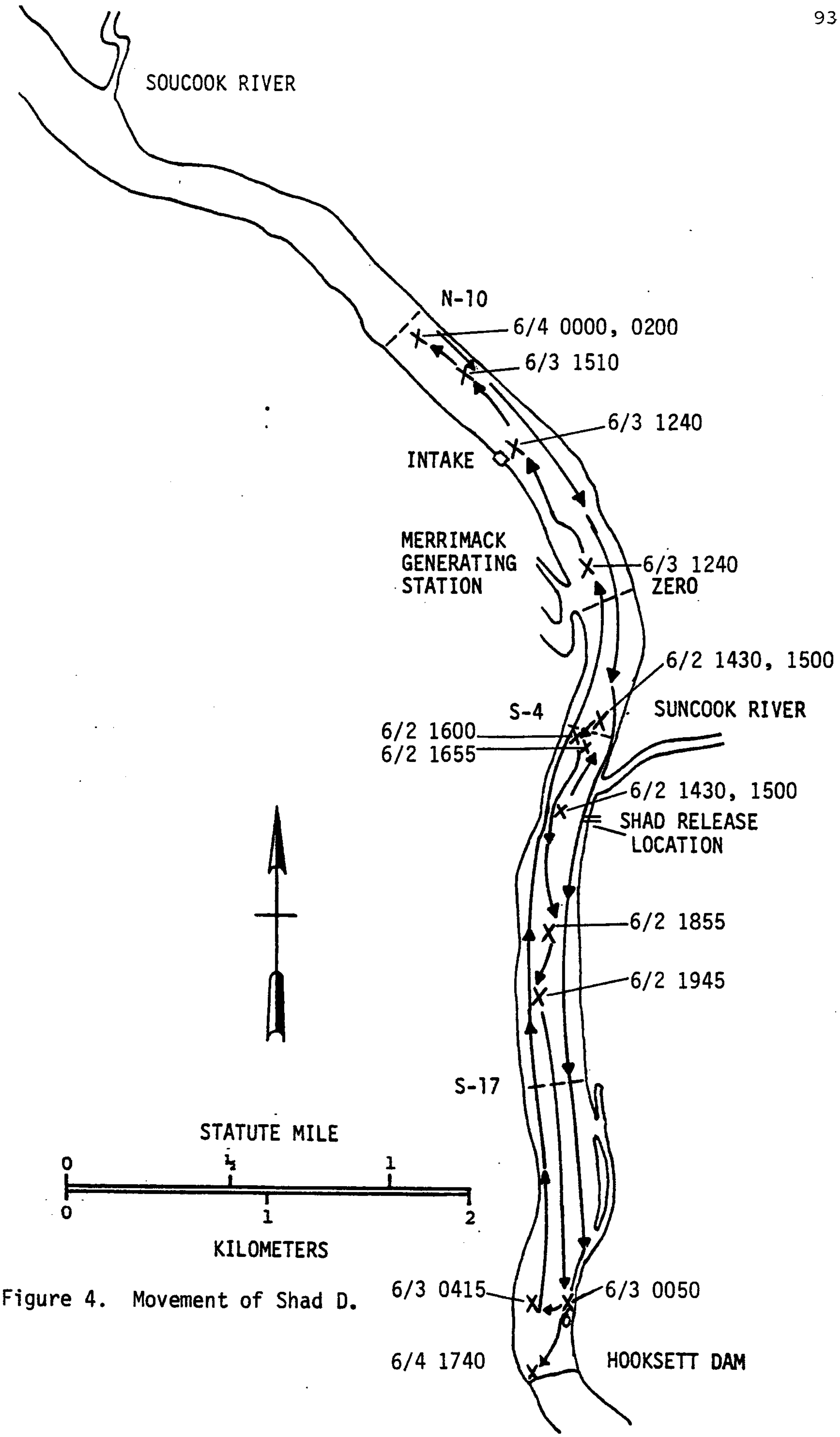
Appendix 2, Figure 1. Movement of Shad A.



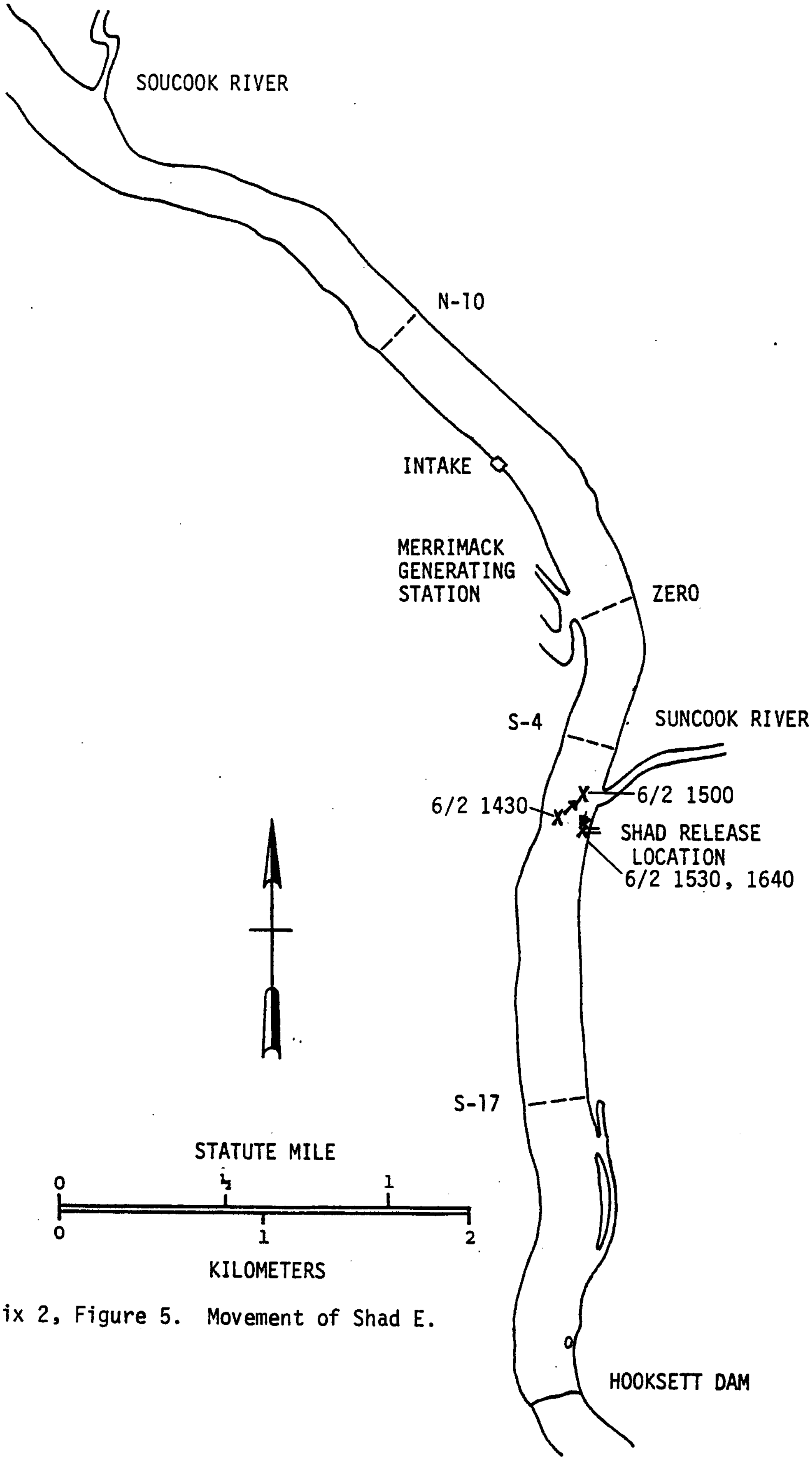
Appendix 2, Figure 2. Movement of Shad B.



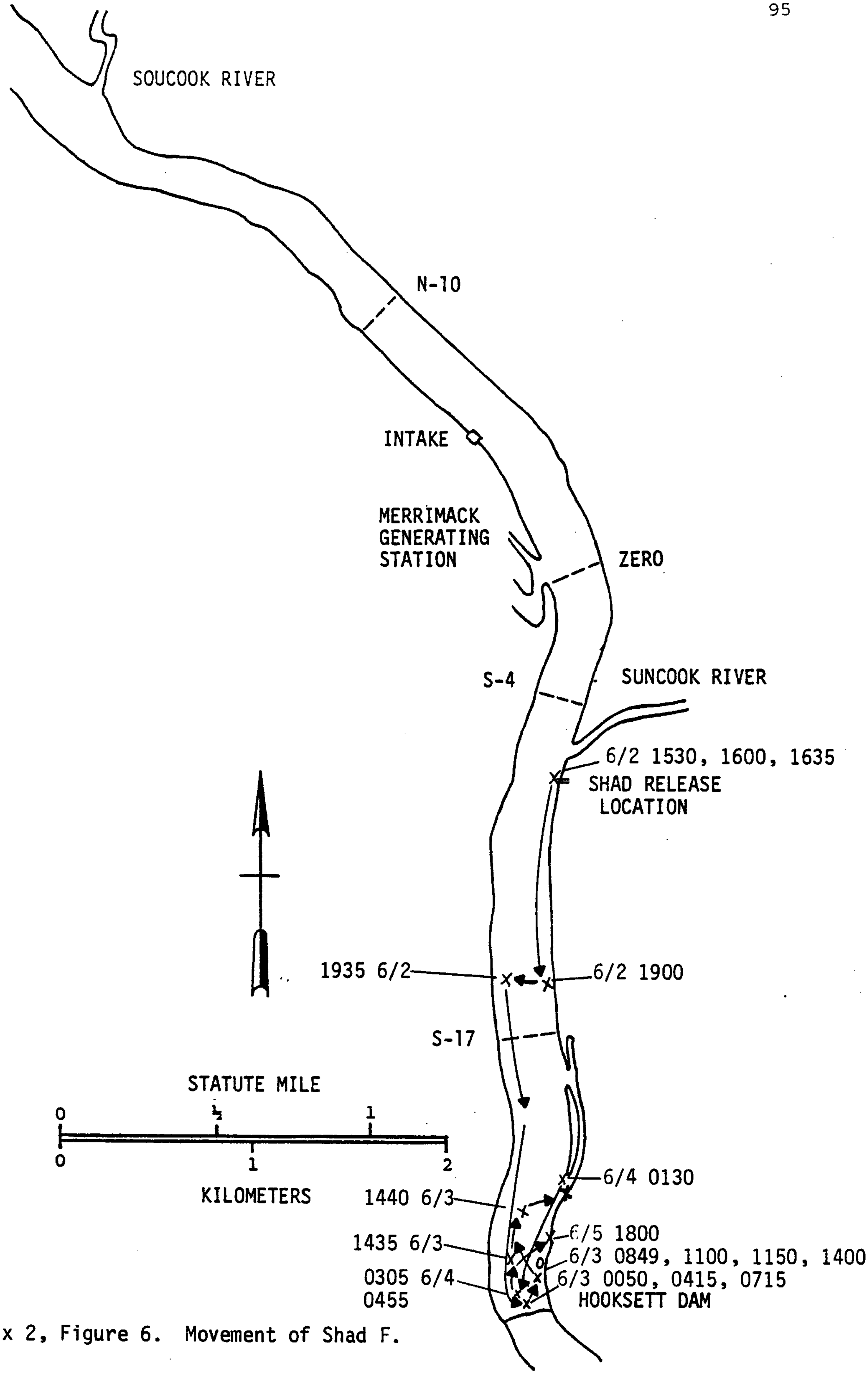
Appendix 2, Figure 3. Movement of Shad C.



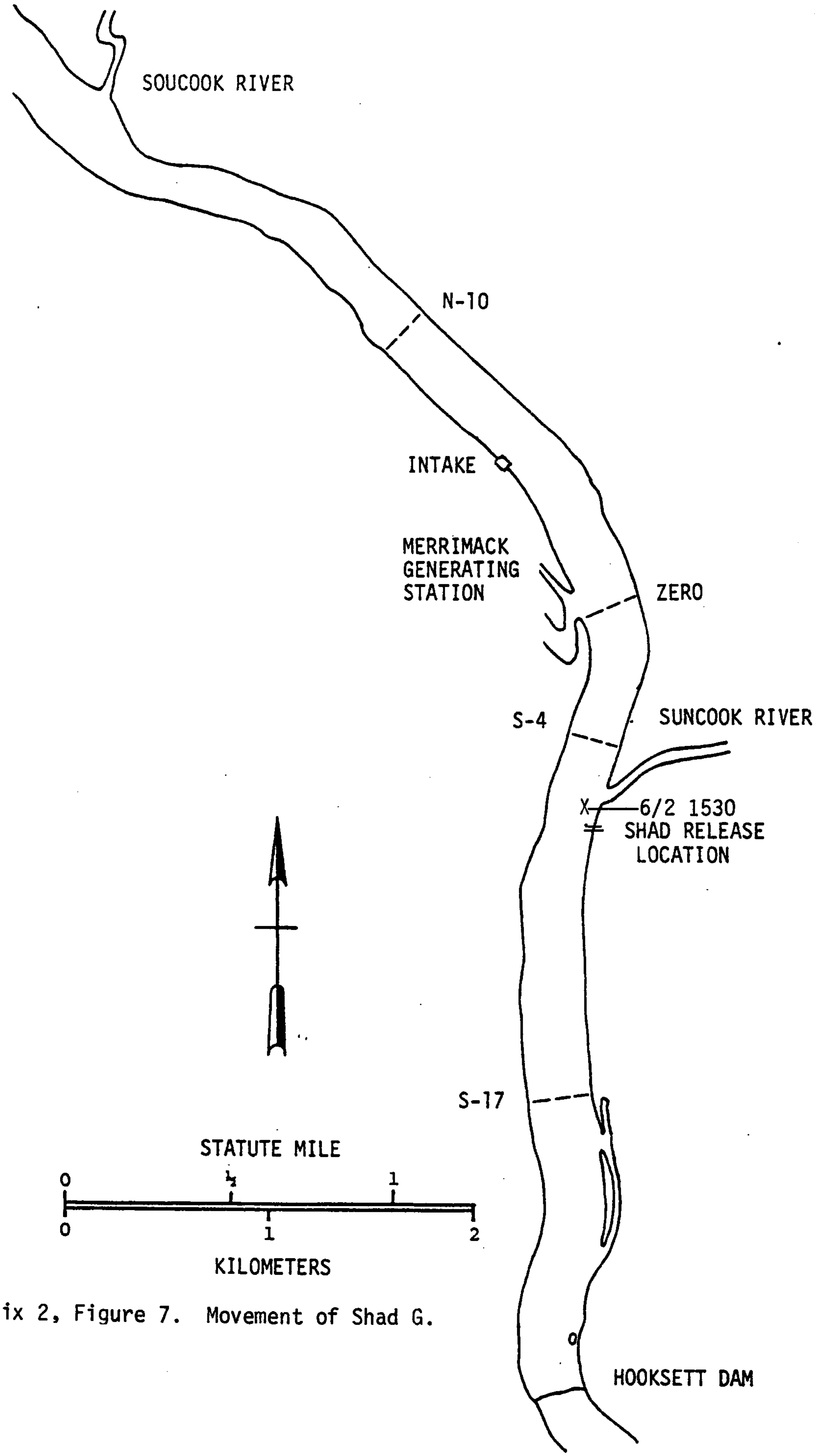
Appendix 2, Figure 4. Movement of Shad D.



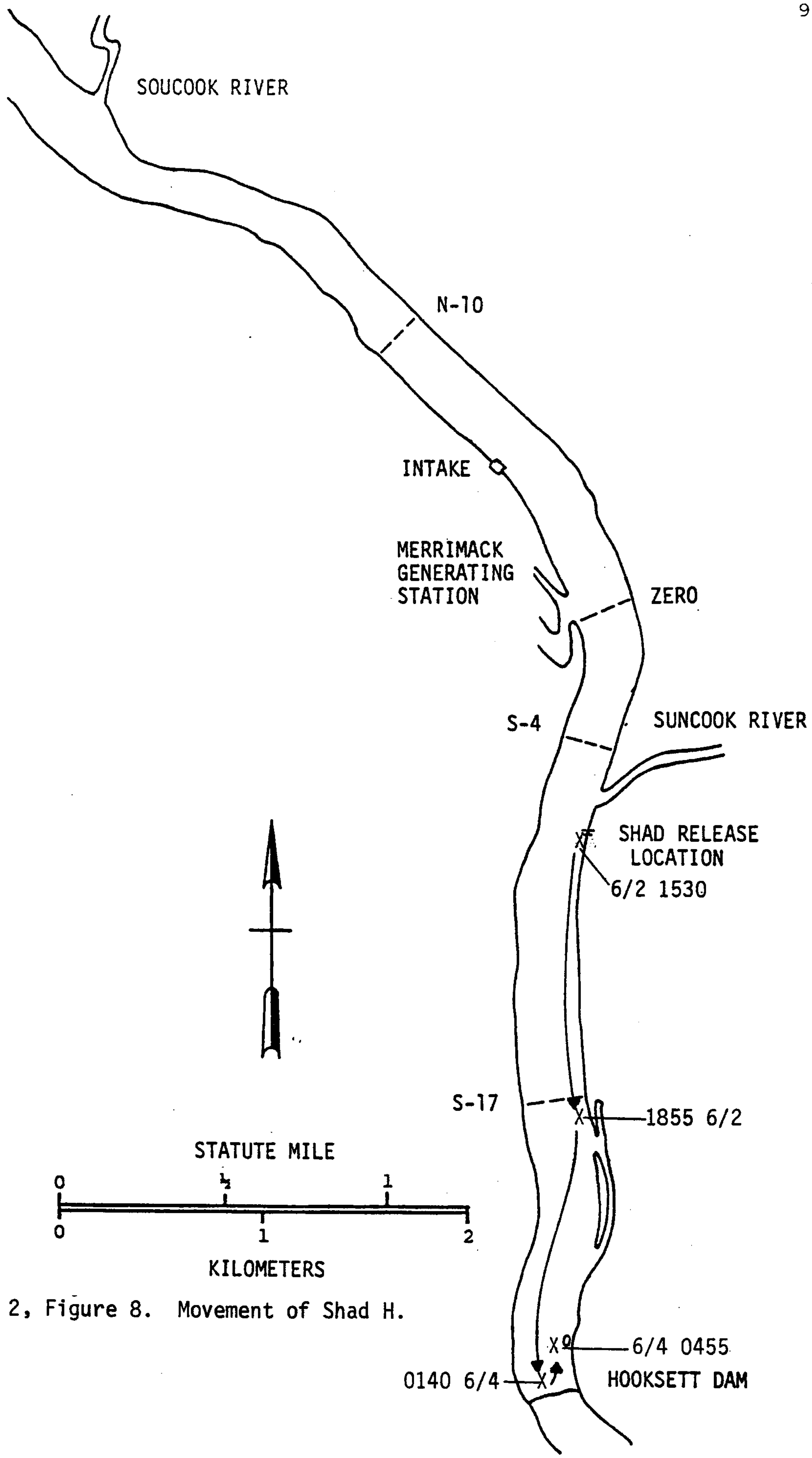
Appendix 2, Figure 5. Movement of Shad E.



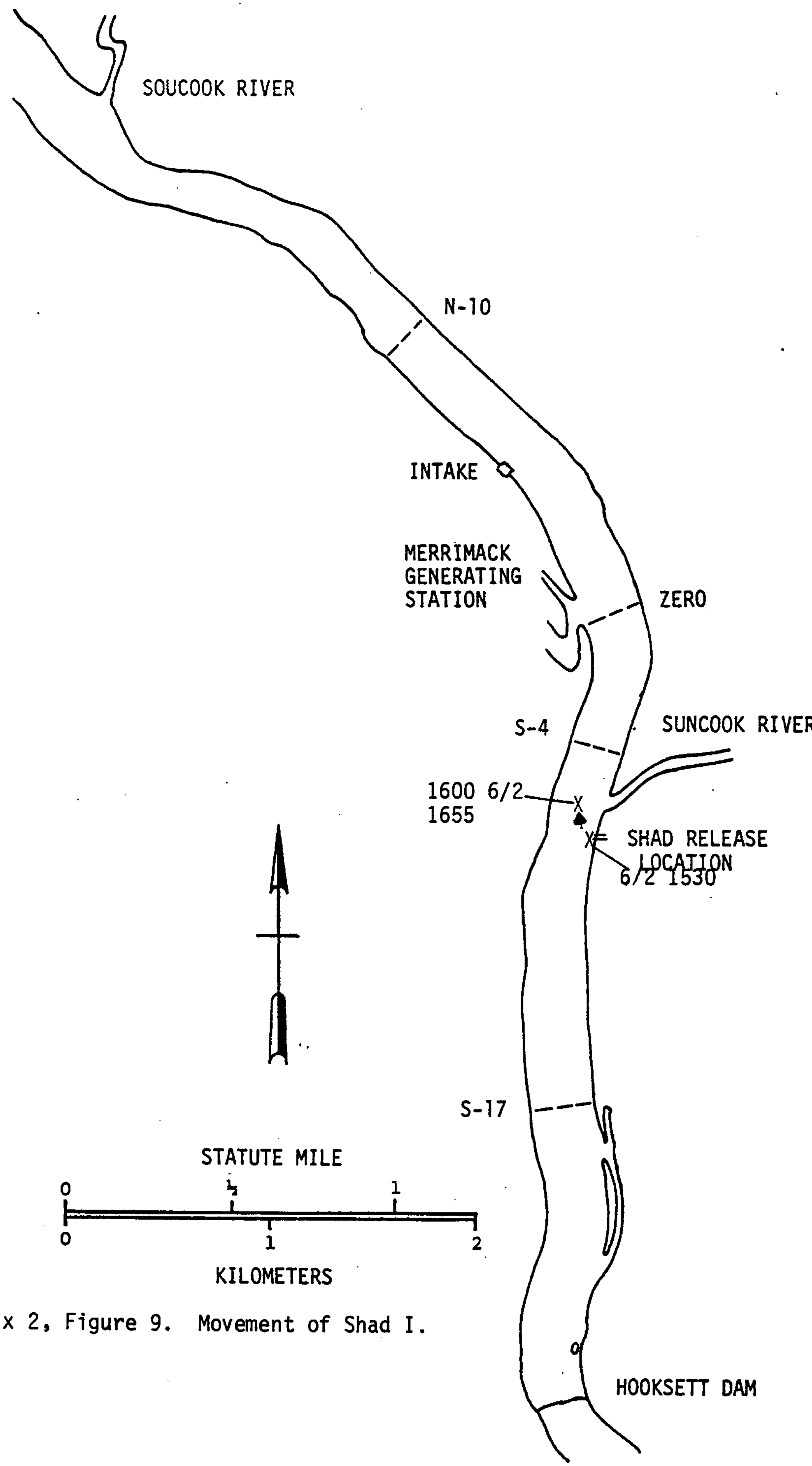
Appendix 2, Figure 6. Movement of Shad F.



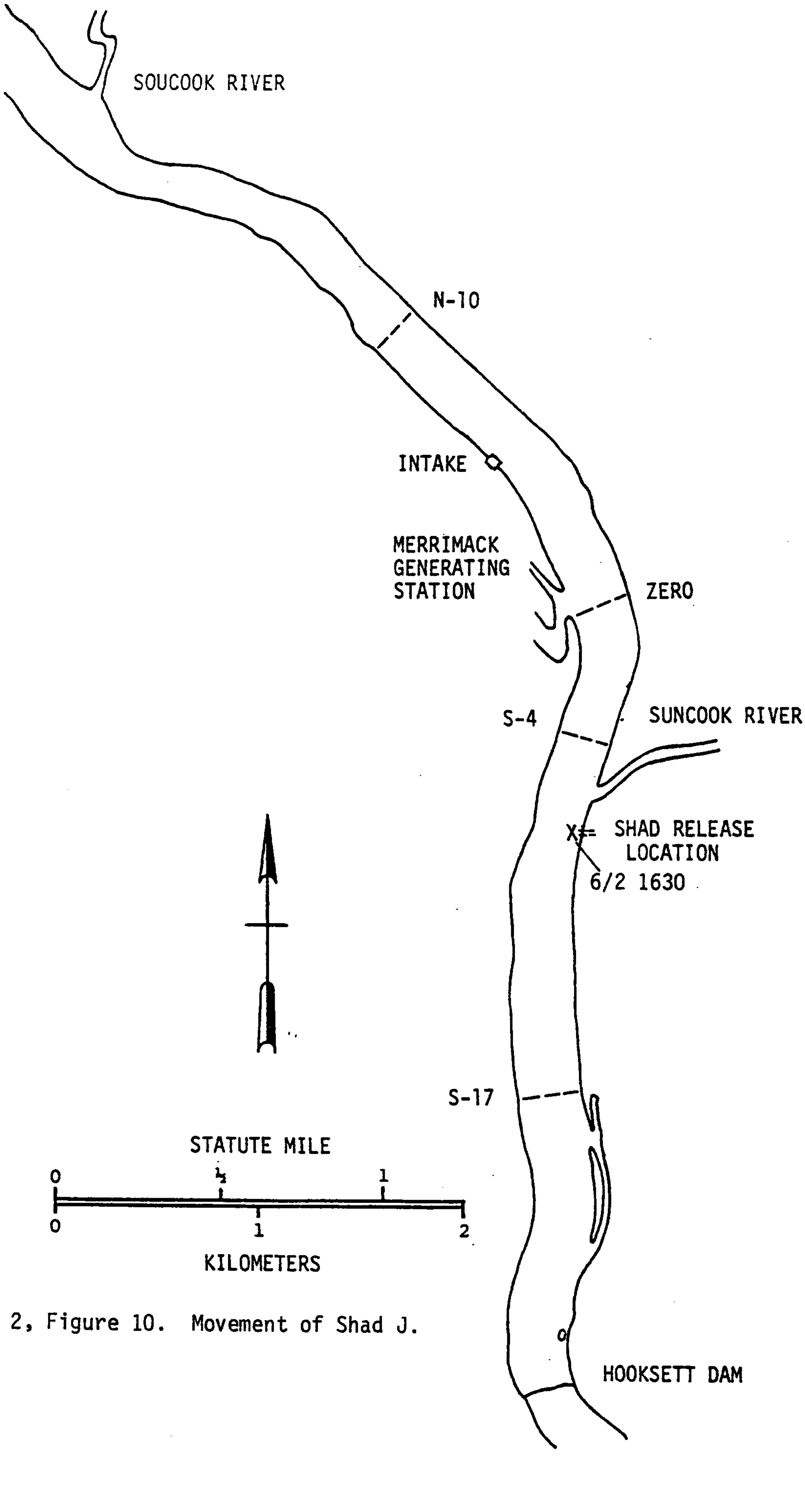
Appendix 2, Figure 7. Movement of Shad G.



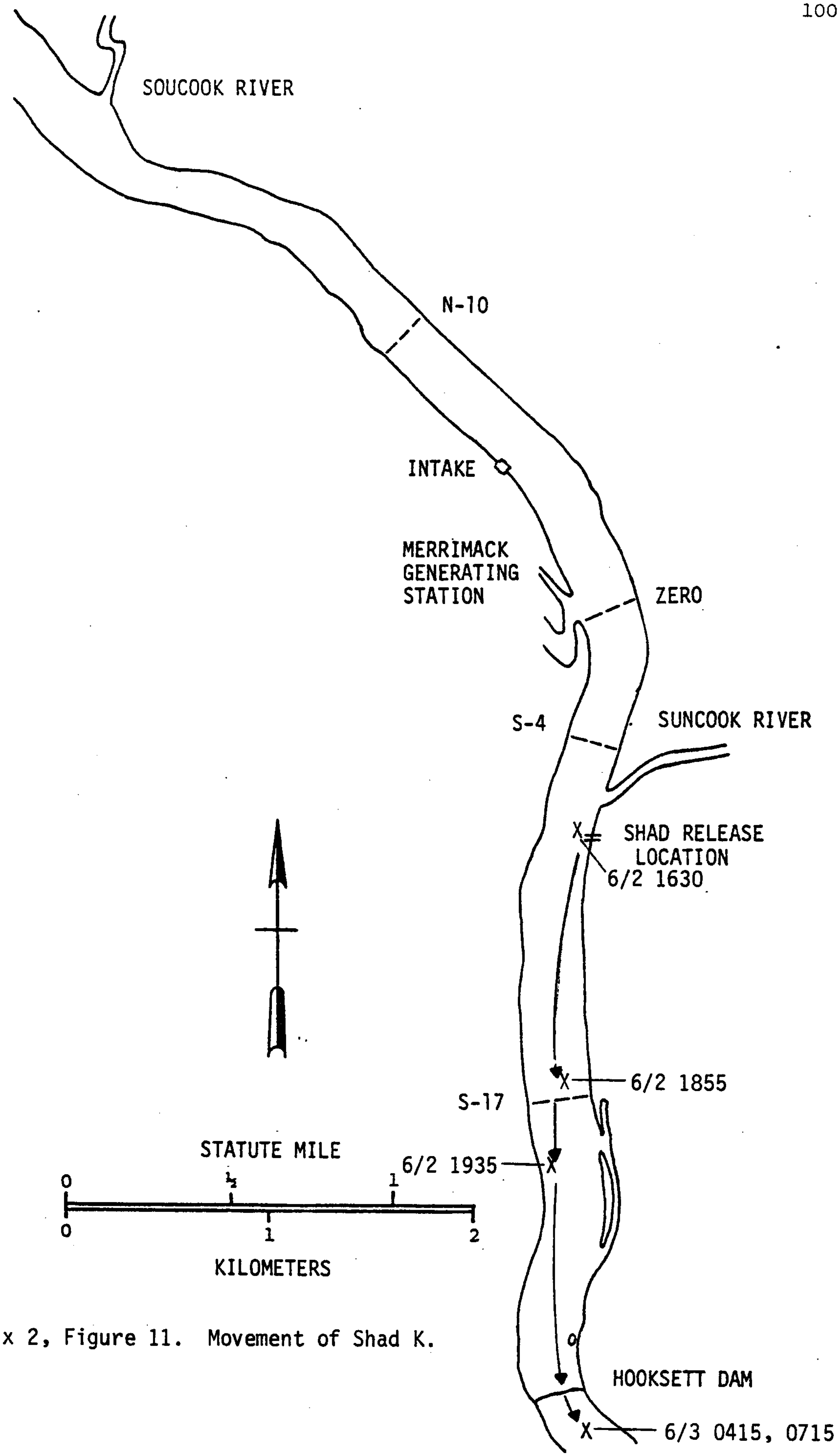
Appendix 2, Figure 8. Movement of Shad H.



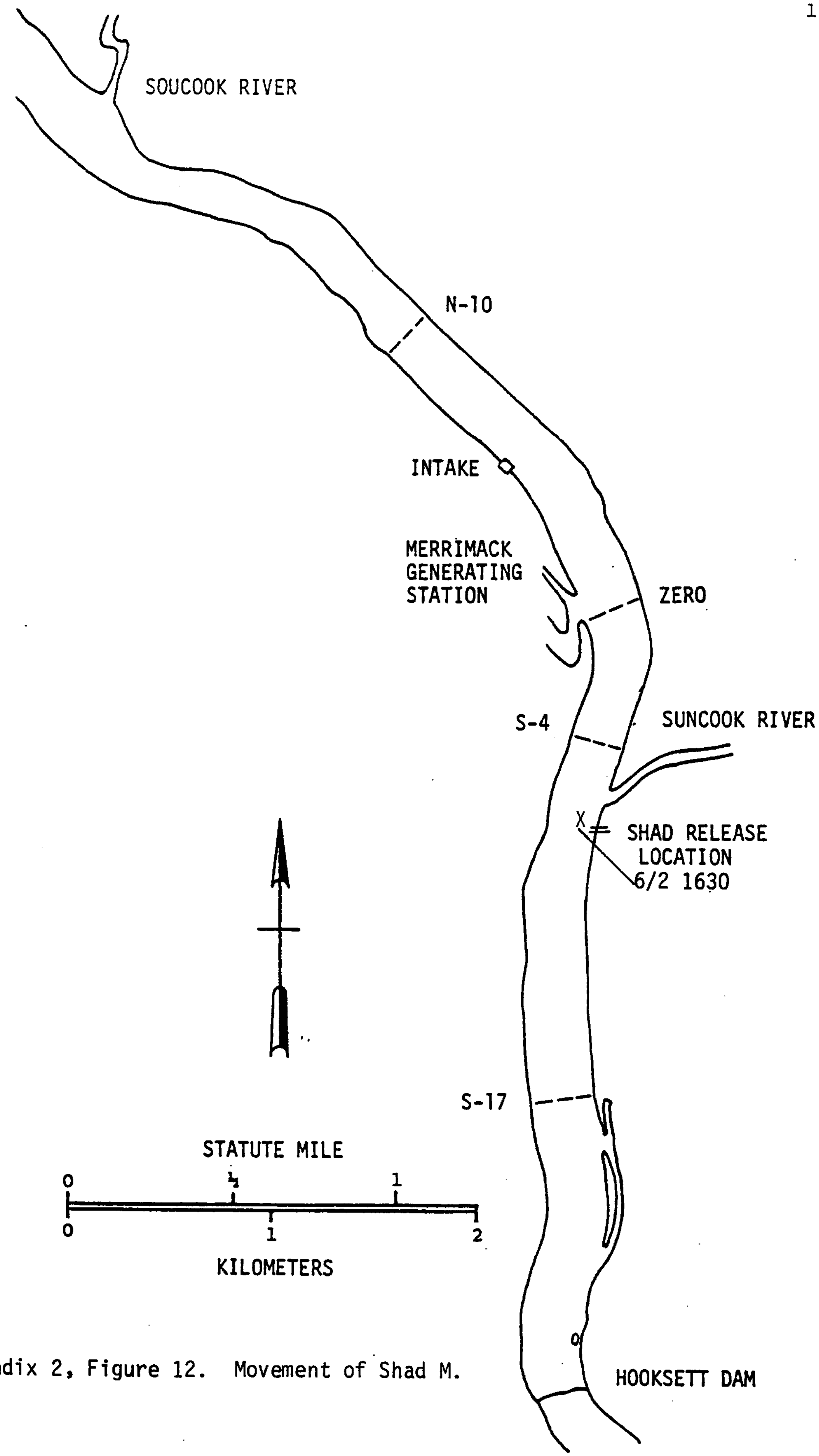
Appendix 2, Figure 9. Movement of Shad I.



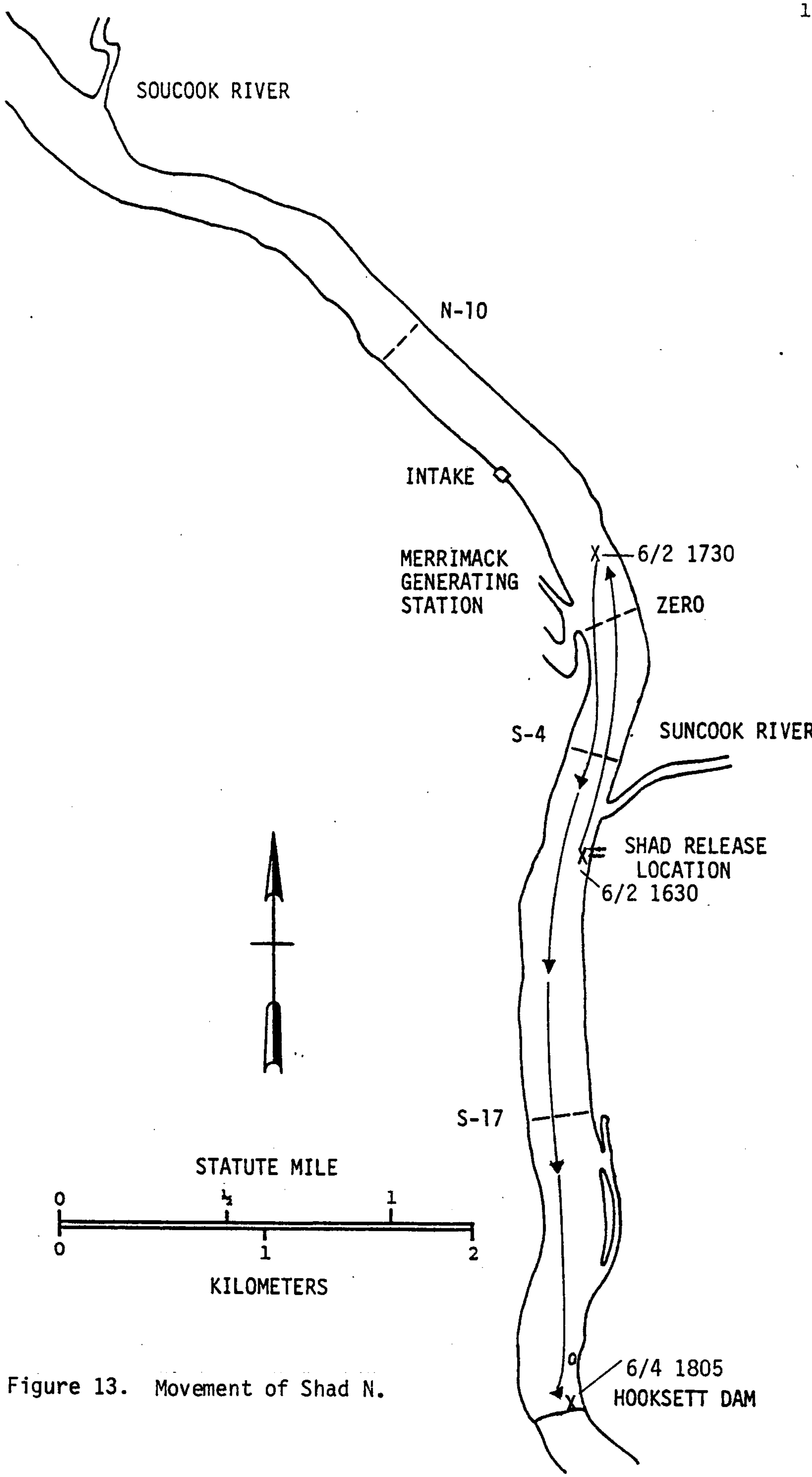
Appendix 2, Figure 10. Movement of Shad J.



Appendix 2, Figure 11. Movement of Shad K.



Appendix 2, Figure 12. Movement of Shad M.



Appendix 2, Figure 13. Movement of Shad N.