FINAL REPORT:

MERRIMACK RIVER
ANADROMOUS FISHERIES INVESTIGATIONS
1975-1976

Prepared for
PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE

By
NORMANDEAU ASSOCIATES, INC.
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Shad egg & larvae transport - larvae response to varying velocity & substrate medium sand to gravel - alternating so fish exposed to each type.

1975 -
Fall velocity - viable eggs - ~~average~~ average 1.25 cm/sec (t = 21.0°C)
Velocity varied little w/ age of egg & temp.

transport - plane grass - ~ 3cm/sec needed to initiate motion.
Sediment - 4-5cm/sec needed for motion @ 10cm/sec "hops" began and further velocity ↑ resulted in transport of both bed load & suspended load

optimum sheltering were realized when bed features were 10-100 times the diameter of shad eggs.

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I. INTRODUCTION

A. BACKGROUND

The Merrimack River has 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. The shad program began in 1969 with the release of fertilized eggs from the Connecticut River in the Massachusetts portion of the Merrimack. Egg releases have continued on an annual basis; eggs were released in the Essex Pool, Lawrence, MA during 1975 and in Hooksett Pond during 1976.

Representatives of the agencies involved in the restoration program have expressed some concern over the possibility that the Public Service Company of New Hampshire's (PSCoNH) 470 MW Merrimack Generating Station, located on the Hooksett Pond reach of the Merrimack River in Bow, New Hampshire, may interfere with the successful reintroduction of salmon and shad to the river. Such effects as blockage of upstream and downstream migrations by the thermal discharge, entrapment of juveniles on the travelling screens, and the entrainment of eggs and larvae in the cooling waters and in the thermal plume have been cited. In the absence of specific knowledge concerning the effects of a powerplant on American shad and/or Atlantic salmon, the Public Service Company's NPDES Permit (Permit No. NH0001465) was modified in 1975 in such a way that cold-water stream standards (FWPCA, 1968), which the thermal component of the

plant's discharge may presently violate, would be enforced unless it could be shown within two years through specific research that less-stringent standards will adequately protect the fisheries. To meet this permit requirement, Normandeau Associates, Inc. (NAI) was employed by Public Service Company to design and initiate such studies as would be necessary. NAI then proceeded with biological and hydrographic investigations during the spring, summer, and fall of 1975 which were designed to assess more adequately the potential interaction between Merrimack Station and the anadromous fisheries restoration program. The results of the first year's studies were contained in a progress report submitted to Public Service Company in May 1976 along with recommendations for a continuation of some study aspects and initiation of new studies for 1976.

1. The Study Area

This section represents a brief narrative description of Hooksett Pond and Merrimack Station. More complete descriptive data are contained in Appendix A.

a. Hooksett Pond

1) Physical Description

Hooksett Pond is a 5.75 mi (9.2 km) long section of the Merrimack River, NH, bounded on the southern, downstream end by Hooksett Dam at river mile 81.05 and on the northern, upstream end by Garvins Falls Dam at river mile 86.8 (Figure 1, Appendix Figure A3). Both dams were originally low-head (15 and 33 ft, respectively), run-of-river type peaking hydropower units; neither has significant storage capacity. Garvins Falls is currently operated by PSCoNH for peaking power, and flow varies according to power demand with a minimum required discharge of ≈500 cfs. Hooksett Dam is maintained by PSCoNH to regulate

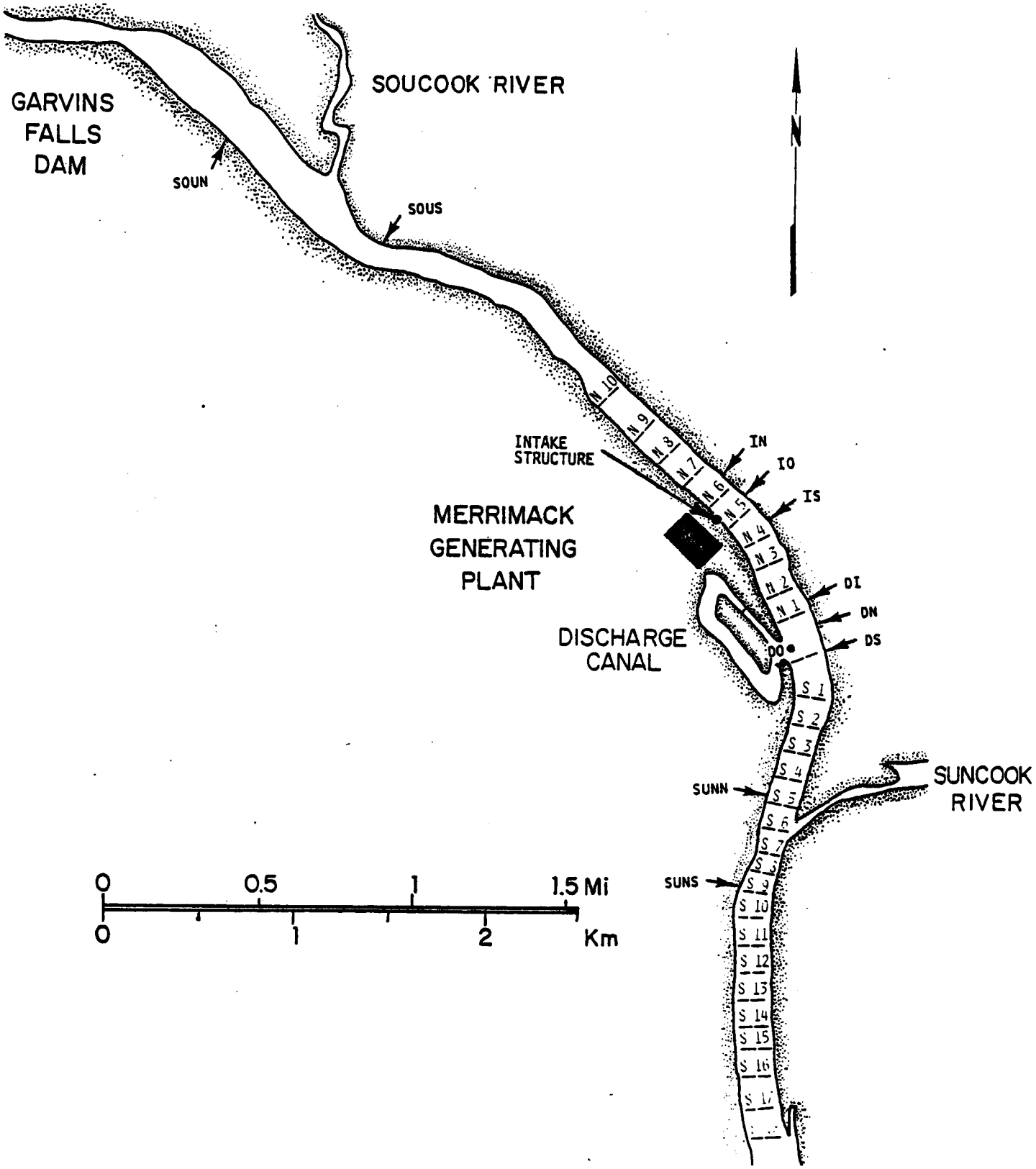

Figure 1. Hooksett Pond, NH. Arrows locate hydrographic transects. Numbered transects were used in biological studies. Merrimack River Anadromous Fisheries Investigations, 1976.

flow for Amoskeag Dam, located 7.9 mi (12.6 km) downstream, and to maintain suitable head for the cooling system at Merrimack Station.

Physically, Hooksett Pond is fairly homogeneous. The reach from Garvins Falls downstream to the Soucook River (Figure 1) changes quickly from the rapidly-flowing tailrance and spillway area to a broad, shallow reach typified by a sand bottom and the presence of several extensive shoals and sandbars. A short distance below the Soucook River confluence the river enters slight left, then right turns and becomes somewhat constricted. Current in this reach is stronger and, as a result, the substrate grades from sand to cobble. Eddies are present on the insides of these two turns, with the west (downstream-most) of these being the strongest. From this turn, just upstream of Station N-10 (Figure 1), the river is fairly uniform downstream to the Merrimack Station discharge. Substrate is nearly all sand, and few macrophytes are present except for an area between N-8 and N-9. In this region, several macrophyte beds are noticeable late in the growing season.

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

2) Water Temperature and Discharge

Garvins Falls discharge varies from a low of about 500 cfs to a maximum of over 30,000 cfs during an annual cycle (see Appendix A, Figure A2). Annual maxima usually occur during April and early May due to snowmelt, and minima occur from late July through September. During late May and June, when shad passage and, possibly, spawning in Hooksett

Pond would most likely occur, flow is usually between 1500 and 8000 cfs with a minimum of approximately 1000 and occasional spates of over 10,000 cfs (Figure A2).

Ambient Hooksett Pond temperatures during May and June typically average about 55 and 67°F, respectively and range anywhere from 42 to 78°F (Figure 2). These temperatures are roughly comparable to those of the Connecticut River.

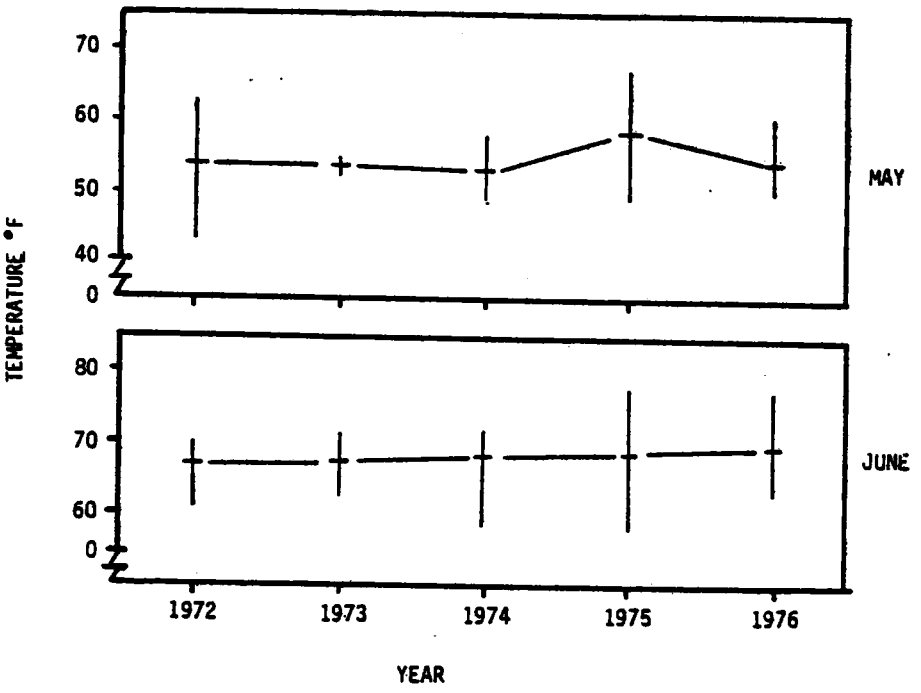

Figure 2. May and June Hooksett Pond surface ambient temperatures (mean and range) 1972-1976 based on field data taken in conjunction with monitoring study activities. Merrimack River Anadromous Fisheries Investigations, 1976.

3) Other Parameters

NAI monitoring studies (NAI, 1969; 1971-74; 75a; 76) have shown Hooksett Pond water quality during May and June to be quite high. Dissolved oxygen levels are generally at or near 100% saturation and there are usually no serious point pollution problems. Several low-volume sewage discharges enter Hooksett Pond and there have been several small-scale point source problems, such as a minor oil spill emanating from Suncook Village, in recent years.

4) Indigenous Biota

Hooksett Pond supports a diverse, productive aquatic community as revealed by NAI monitoring studies. Most notable is the indigenous warm-water fish community supporting high quality sport fishery, especially for smallmouth bass (*Micropterus dolomieui*). Additional warmwater game species include largemouth bass (*M. salmoides*), pickerel (*Esox niger*), yellow perch (*Perca flavescens*), pumpkinseed and redbreast sunfishes (*Lepomis gibbosus* and *L. auritus*), and white perch (*Morone americana*). A complete list of indigenous and introduced fish species is contained in Appendix A (Table A1).

b. Merrimack Station and Its Thermal Discharge

Merrimack Station is a coal-fired steam-electric powerplant producing a total of 470 MW. It is situated at river mile 84, approximately midway between the Hooksett and Garvin's Falls Dams (Appendix Figure A3). Two units of 120 and 350 MW require 444 cfs (total) of river water for once-through condenser cooling with a designed total temperature increase (Δt) of 20°F (11.1°C). Cooling water is drawn through two intake structures located on the river's west bank at Station N-4 (Figure 1); each is equipped with a 3/8 inch mesh travelling

screen. Water velocities in the Unit I and II intake structures average 1.5 ft sec^{-1} (45.7 cm sec^{1}), respectively.

After passing through the plant, cooling water is circulated through a 3900 ft long discharge canal equipped with 54 banks of 4 (216 total) power spray cooling modules (psm). At the canal's river re-entry point (Station Zero; Figure 1), discharge temperature is a maximum of about 18-20°F warmer than ambient.

Upon entering the Merrimack River, the powerplant thermal plume assumes the form of a warmwater surface lens. 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. It 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 (Figure 1). From there southward to Hooksett Dam mixing occurs progressively such that waters exiting the pond at Hooksett are fully mixed and a maximum of about 3°F warmer than the upstream ambient. A description of the thermal discharge under typical spawning season conditions is depicted in Appendix A (Figure A1).

2. Hooksett Pond as American Shad Habitat

Hooksett Pond may represent satisfactory habitat for all aspects of the American shad's freshwater life history. A substrate study (Normandeau, 1969) indicated that most of the Hooksett Pond bottom is of "medium" coarseness (fine sand to pebbles). A few cobble substrate areas are also present. Since shad prefer spawning over alluvial depositions (gravel substrates) bathed by running water (Walburg and Nichols, 1967), many places in Hooksett Pond represent suitable spawning areas, especially upstream of Merrimack Station. *In situ* studies by Wightman (1971) have demonstrated the hatching ability of shad eggs in the Franklin Falls Section of the Merrimack. Similar experiments conducted in Hooksett Pond a year earlier failed to yield any juveniles.

Nevertheless, the upper reaches of Hooksett Pond are probably suitable for spawning and egg development.

B. AMERICAN SHAD AND POWER PLANTS: LITERATURE REVIEW

American shad eggs are semi-buoyant and non-adhesive; they either remain suspended in the water column or sink to the bottom, depending on water velocity and turbulence. Although the larvae are difficult to capture by normal plankton sampling techniques, they are considered to be somewhat planktonic. Both of these life history phases, then, are potentially entrainable. At Merrimack Station they may be entrained either directly in the cooling water or by momentum entrainment in the thermal discharge plume. Either form of entrainment may represent a potentially lethal condition depending on hydraulic and mechanical stresses and the time-temperature histories encountered.

After transformation from larvae to juveniles, young shad become surface-oriented in their feeding behavior, consuming mostly insects (Massman, 1963). At this time they may be exposed to thermal stresses imposed by Merrimack Station's surface-oriented warmwater discharge. Adult shad may also be exposed to the discharge although they do not generally feed while in fresh water.

Literature assessing the potential harmful interaction of an electric generating station is more complete for some American shad life history phases than for others. Entrainment has been studied intensively at the Connecticut Yankee Atmoic Powerplant on the Connecticut River, CT. investigations there have been summarized by Marcy (1976). Marcy (1976) found that although river herrings (*Alosa* spp.) together made up 97% of the entrained eggs and larvae, American shad eggs and larvae represented less than 1% of the total. American shad ranked ninth in overall ichthyoplankton abundance in the part of the river adjacent to the plant, and both eggs and larvae were present in plankton tows taken at a station located directly upstream of the intake

(Marcy, 1976, Table 69), yet few were entrained. Similarly, studies funded by the Central Hudson Gas and Electric Company on ichthyoplankton and entrainment in the Hudson River near Poughkeepsie, NY demonstrated the presence and entrainment of many *Alosa* spp. larvae but relatively few American shad eggs and larvae (QLM, 1974).

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

The effects of heat shock have been studied in a different manner for other clupeid fishes. Hoss *et al.* (1971), for example, found that the critical temperature for larval menhaden (*Brevoortia tyrannus*), alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*)

survival was between 28 and 30°C (83-86°F). Similarly, Marcy (1971; 1973) found temperatures of 28-30°C to be lethal to most larval fishes entrained in the cooling water of a nuclear power plant.

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

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

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

The impingement of juvenile shad on intake travelling screens has recently been studies. On the Hudson River, QLM (1974) found that American shad represented far less than 1% of the over 100,000 specimens collected from the intake screens at Central Hudson's Danskammer Point Station. Similarly, the U.S. Fish and Wildlife Service conducted an intensive impingement survey at over 150 Delaware River intakes and found that shad made up less than 1% of the more than 160,000 specimens examined (Loftan, 1976). On the Connecticut River, Connecticut Yankee impinges about 200 juveniles annually out of a total of some 125,000-150,000 fish (Merriam and Thorpe, 1976) with the total varying directly with shad abundance in a given year. During 1976, for example, impingement at Connecticut Yankee totalled about 1800 juvenile shad at the rate of ≈ 200 per day during the peak autumn downstream migration (Graves, 1976). This was believed caused by the much greater than usual abundance of juvenile shad throughout the Connecticut River system during 1976 (W. Renfro, NEUSCo, pers. comm).

C. GENERAL APPROACH TO MERRIMACK RIVER INVESTIGATIONS

NAI has adopted a two-phase general approach to the study of Merrimack Station's effects on American shad: First, the likely interaction of each life history phase with the powerplant will be estimated using best available techniques. Then, when anadromous fishes are actually restored to Hooksett Pond, potential negative aspects associated with each phase will be monitored. Investigations conducted during 1975-1976 were primarily designed to estimate pump and momentum entrainment of eggs and larvae. Specifically, 1975 studies (a) assessed the transport characteristics of viable and artificial shad eggs; (b) identified the source of Merrimack Stations' cooling water using preliminary hydrographic field surveys; and (c) determine the thermal tolerance of shad eggs and larvae under field and laboratory conditions. During 1976 the hydrographic studies were completed with the inclusion of a hydrographic simulation, the laboratory and field bioassays were expanded and repeated, and the egg transport studies were replaced by

similar investigations to assess some aspects of larval behavior and determine their relative susceptibility to entrainment. Planned studies involving juveniles, which included determining their ability to negotiate the Merrimack Station discharge during autumn downstream migration and potential impingement on the intake travelling screens, failed when no juveniles could be captured.

II. STUDIES COMPLETED DURING 1975-76

A. HYDROGRAPHIC INVESTIGATIONS

1. Field Studies

a. Methods of Study

1) Establishment and Marking of Transects and Stations

For the purposes of the hydrographic study, transect lines were selected both upstream and downstream of the mouths of the major Hooksett Pond tributaries (Soucook and Suncook Rivers) and in the vicinities of the intake structure and discharge canal (Figure 1). Once the general positions of transects lines were established, they were located precisely using a transit, and stakes were driven into the river bank on both sides of the river for permanent reference. Stations along the transect lines were located using a marked line, and anchored markers were placed at the selected locations.

2) Field Procedures

a) Current Profiles

Vertical current profiles were obtained at each station indicated in Figure 1. Measurements were made from aboard an 18 ft workboat anchored alongside the marker at each station. Current velocity was obtained at 1 ft depth intervals using a Bendix Q-15 ducted current meter. Current speed and direction were recorded on an NAI Model 1001 current meter recorder.

b) Current Meter Moorings

Additional current information was obtained using two moored current meters, one at mid-river abreast of the intake structure and the other at mid-river abreast of the discharge canal. The mooring system employed is shown in Appendix Figure B-1. The current meters used were as follows:

1. Intake site: Bendix Q-15R
2. Discharge site: Bendix Q-16

The current meters were hard-wired to shore where speed and direction were recorded on either an NAI Model 1001 recorder or a Bendix 270 recorder.

c) Temperature

Vertical temperature profiles were obtained at the same time and in the same locations as the vertical current profiles. A YSI thermistor probe was attached to the current meter so that temperatures were obtained at all the same depths as currents. The thermistor probes were connected to an NAI Model 1001-T-2 dual channel temperature recorder.

d) Turbulence

Longitudinal and vertical components of turbulence were monitored by means of a fixed mooring equipped with a Marsh-McBirney Model 711 electromagnetic current meter. This type of current sensor can monitor both longitudinal and vertical current components at once when properly positioned. The mooring was established at mid-river along Transect IN (Figure 1), and was left in position for two days to obtain sufficient data to adequately characterize river turbulence. A continuous record of the two current components was made using a Gould-Brush two-channel strip chart recorder.

b. Results

1) Current Speed

Anchor station current surveys were conducted on the days listed in Appendix A, Table B1. Also noted in that table are the daily average discharge, the average discharge between 0600 and 1800 hours, and Merrimack Station output. Characteristic current speeds throughout the range of discharge levels investigated are indicated in Table 1, which shows average surface and bottom currents along each transect for selected dates. Figures 3 through 12 are cross sectional diagrams depicting current speed isopleths at certain transects on the dates included in Appendix Table B1 (for transect locations see Figure 1). Detailed current profiles from all stations on all dates are presented in Appendix B (Figure B1). Data obtained from the current meter moorings are also presented in Appendix B (Figure B2).

2) Temperature

Several of the transects were essentially isothermal on each of the survey dates. Others were isothermal on some dates, but stratified on others. Table 2a lists the isothermal transects and their cross sectional temperatures on each date of the study. Table 2b indicates temperature of transects that were isothermal occasionally, while Figures 13 through 19 illustrate cross sectional temperature distributions for transects that were not isothermal. Ambient temperature for any date is defined as the mean cross sectional temperature at Transect IN. Powerplant operating data for the days of the survey are shown in Appendix Table B1.

TABLE 1. AVERAGE SPEEDS IN KNOTS AT SURFACE AND BOTTOM ALONG ALL TRANSECTS FOR SELECTED DATES (1 kn = 51.44 cm/sec). MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DATE TRANSECT	SURFACE AVERAGE	BOTTOM AVERAGE	SURFACE AVERAGE	BOTTOM AVERAGE	SURFACE AVERAGE	BOTTOM AVERAGE
SOU-N	0.24	0.27	0.87	0.78	0.98	0.83
SOU-S	0.54	0.38	1.62	0.91	---	---
I-N	0.21	0.17	0.85	0.67	0.98	0.75
I-0	0.17	0.15	0.91	0.81	---	---
I-S	0.14	0.12	0.87	0.71	0.97	0.71
D-I	0.16	0.13	0.93	0.69	1.05	0.8
D-N	0.10	0.13	0.93	0.66	1.05	0.75
D-0	0.19	0.04	0.22	0.46	0.07	0.4
D-S	0.15	0.15	0.83	0.71	1.09	0.8
SUN-N	0.33	0	0.88	0.66	1.10	0.62
SUN-S	0.35	0	0.84	0.62	1.02	0.73

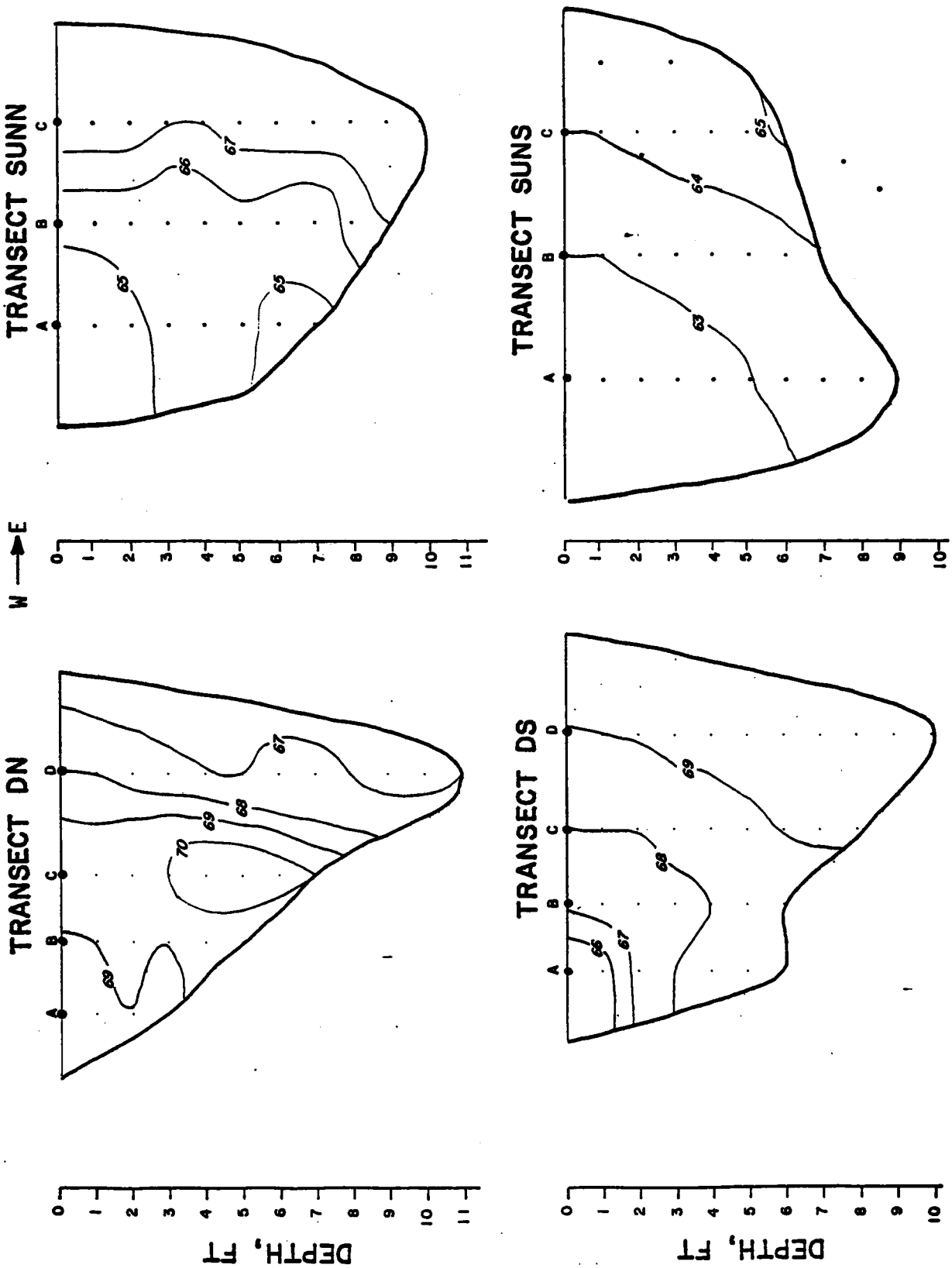

Figure 3. Cross sectional temperature profiles at transects DN, SUNN, DS, and SUNS, August 8, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

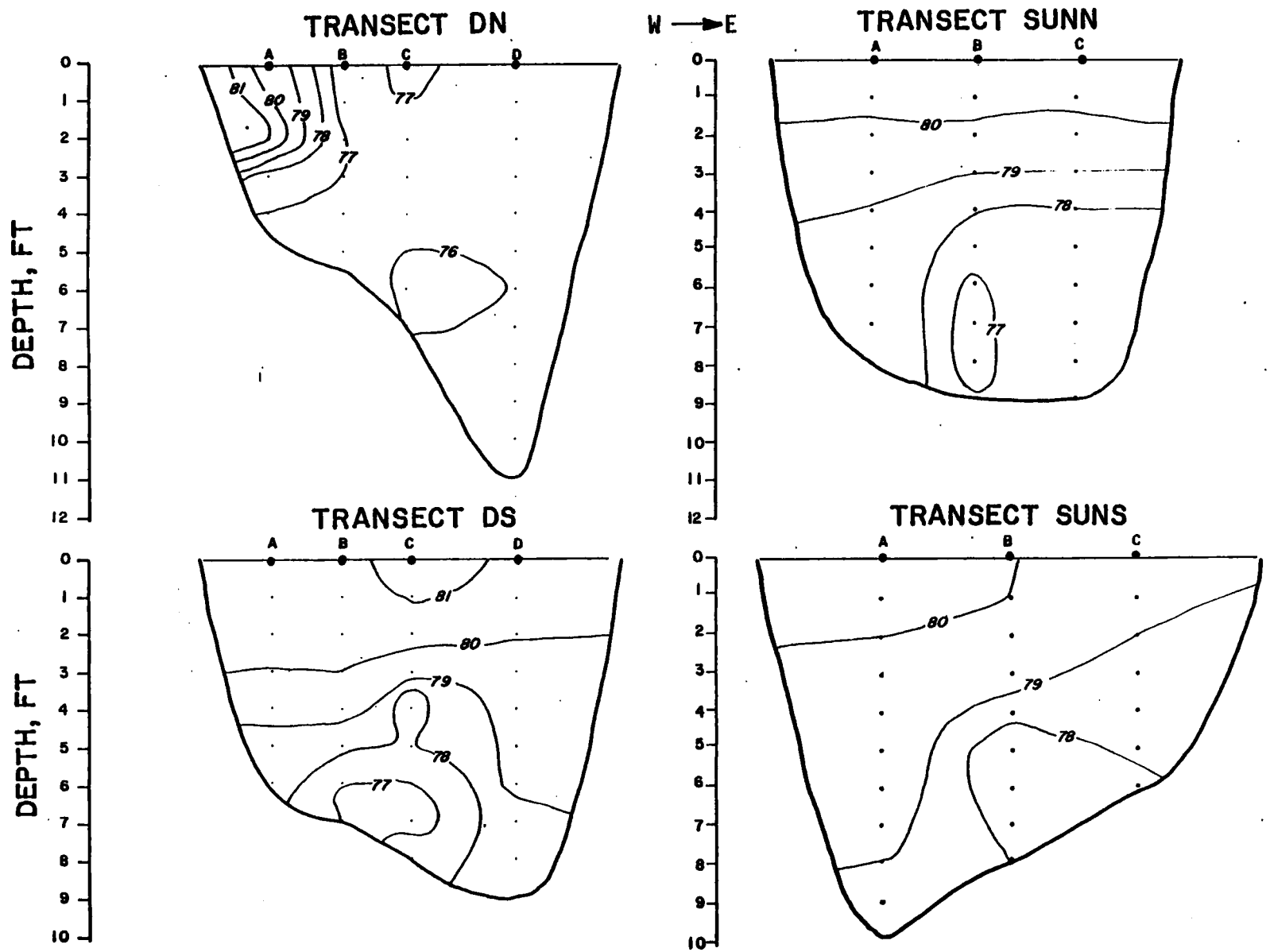

Figure 4. Cross sectional temperature profiles at transects DN, SUNN, DS, and SUNS, August 14, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

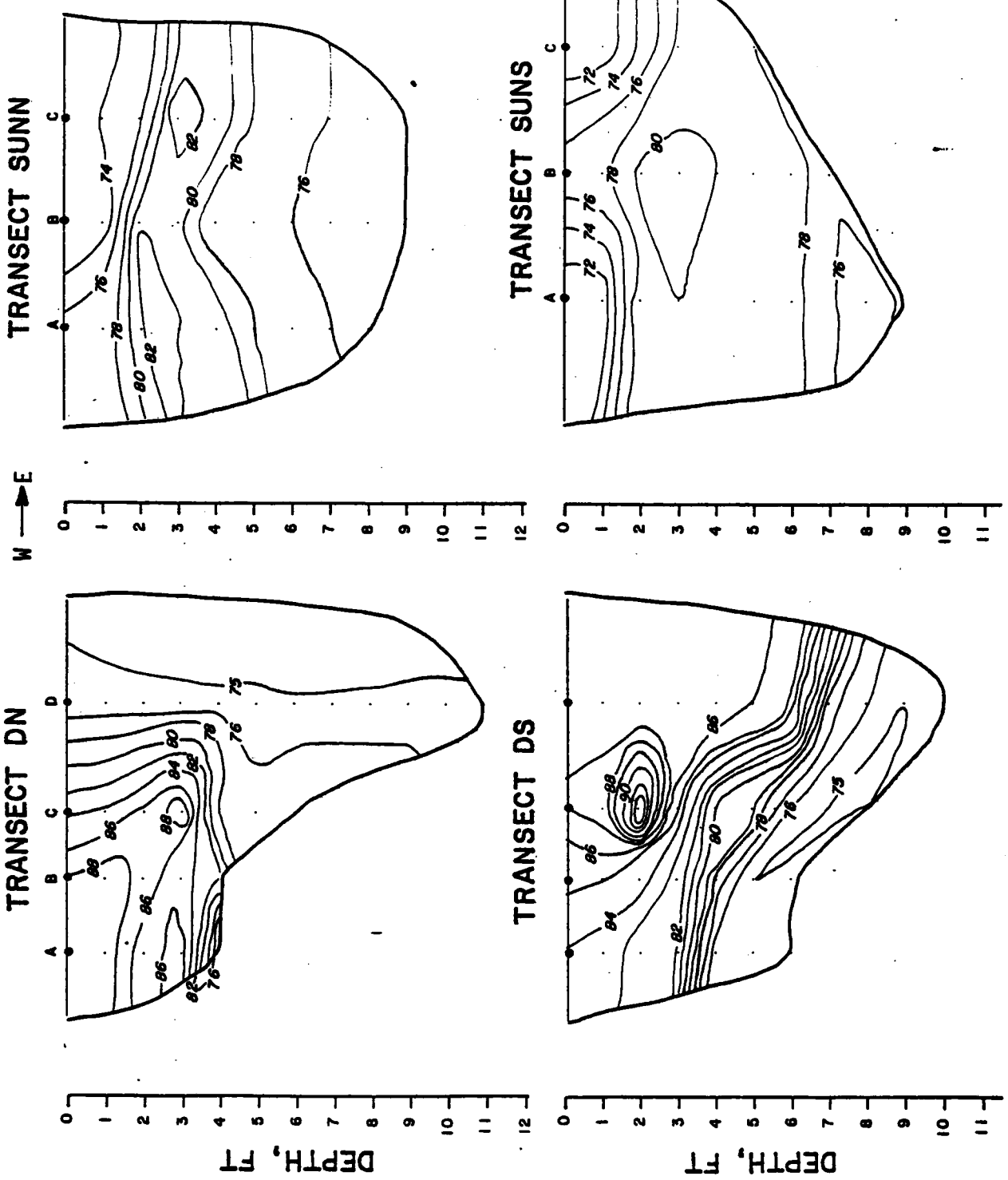

Figure 5. Cross sectional temperature profiles at transects DN, SUNN, DS, and SUNS, August 15, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

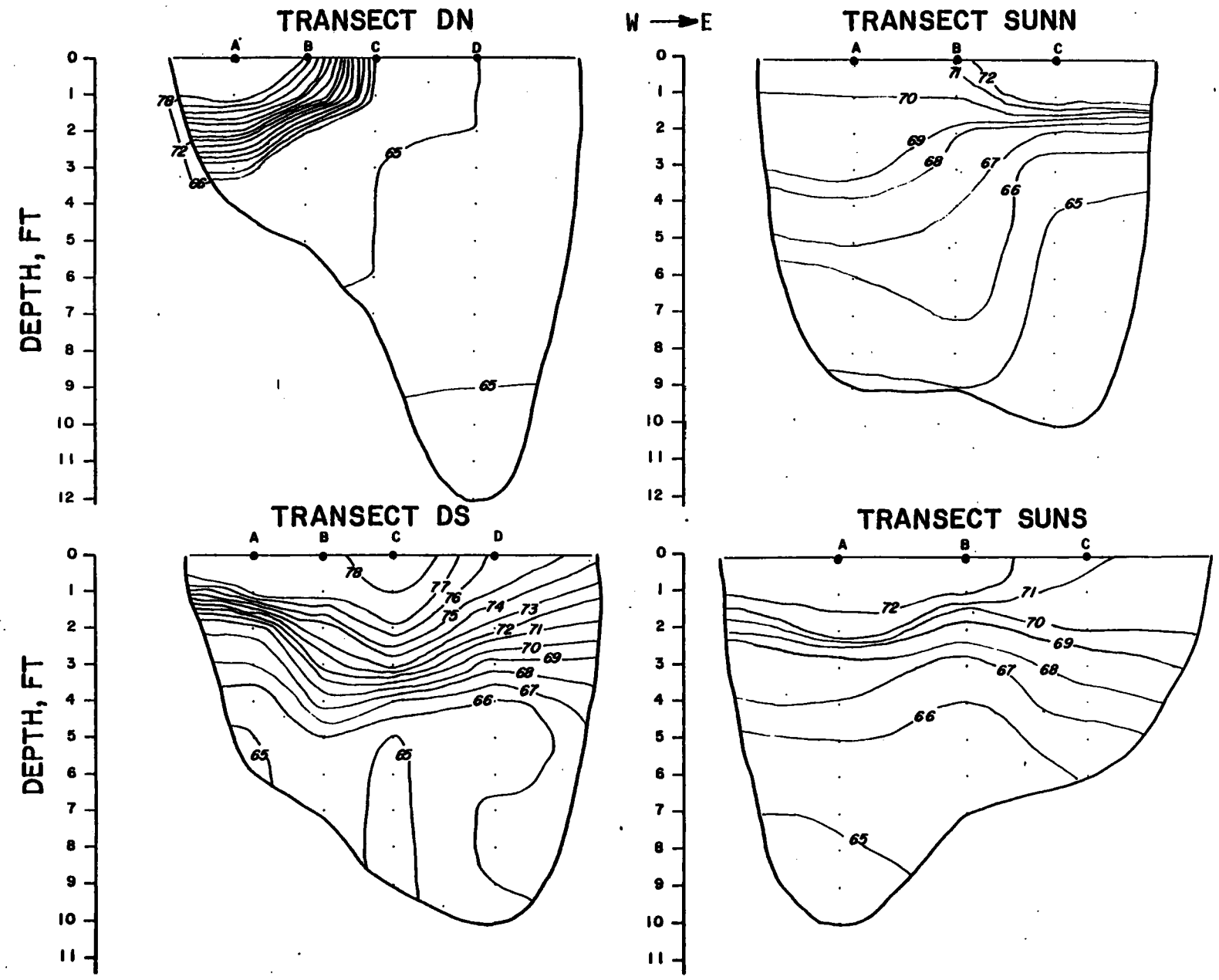

Figure 6. Cross sectional temperature profiles at transects DN, SUNN, DS, and SUNS, September 4, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

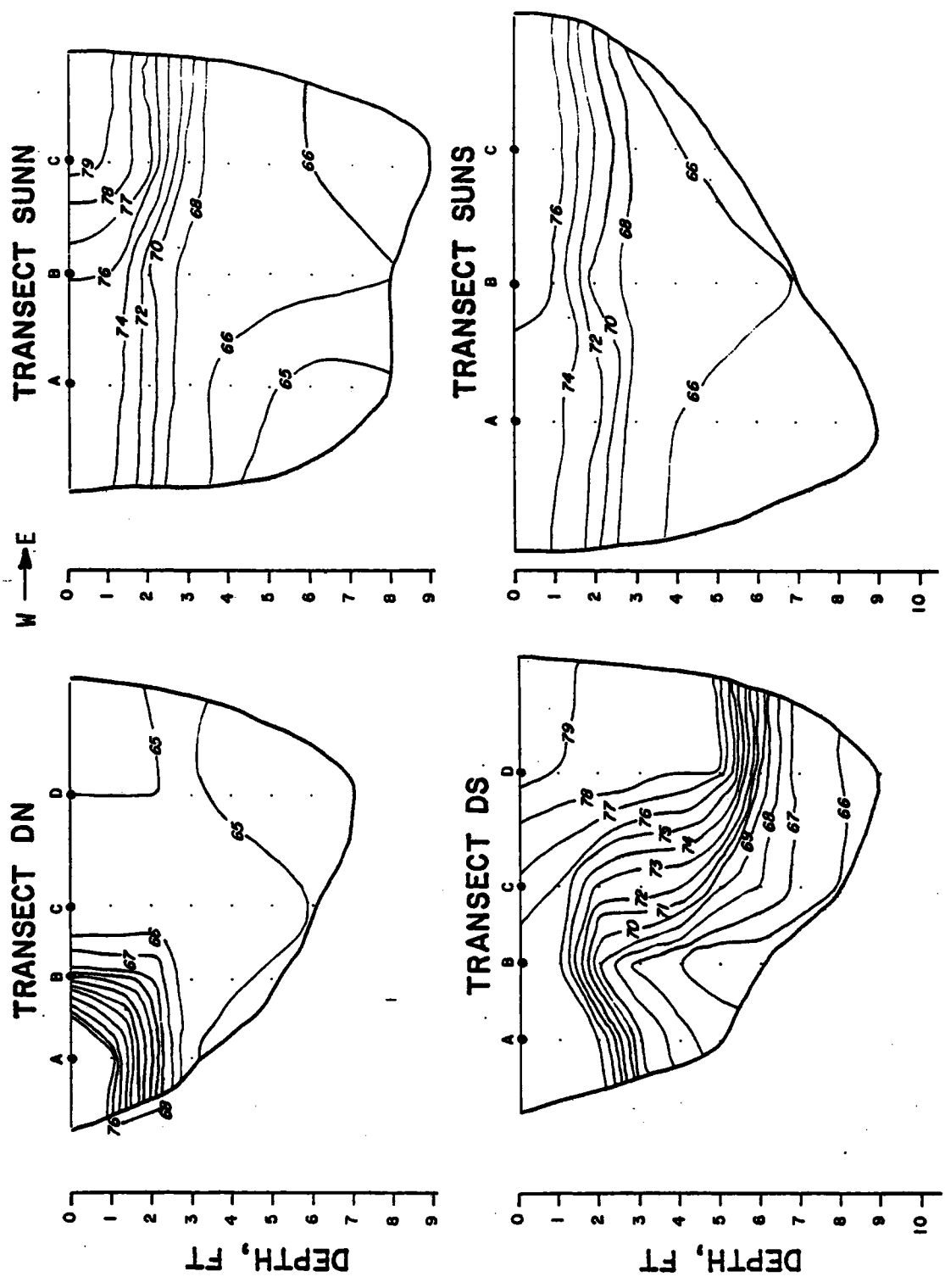

Figure 7. Cross sectional temperature profiles at transects DN, SUNN, DS, and SUNS, September 5, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

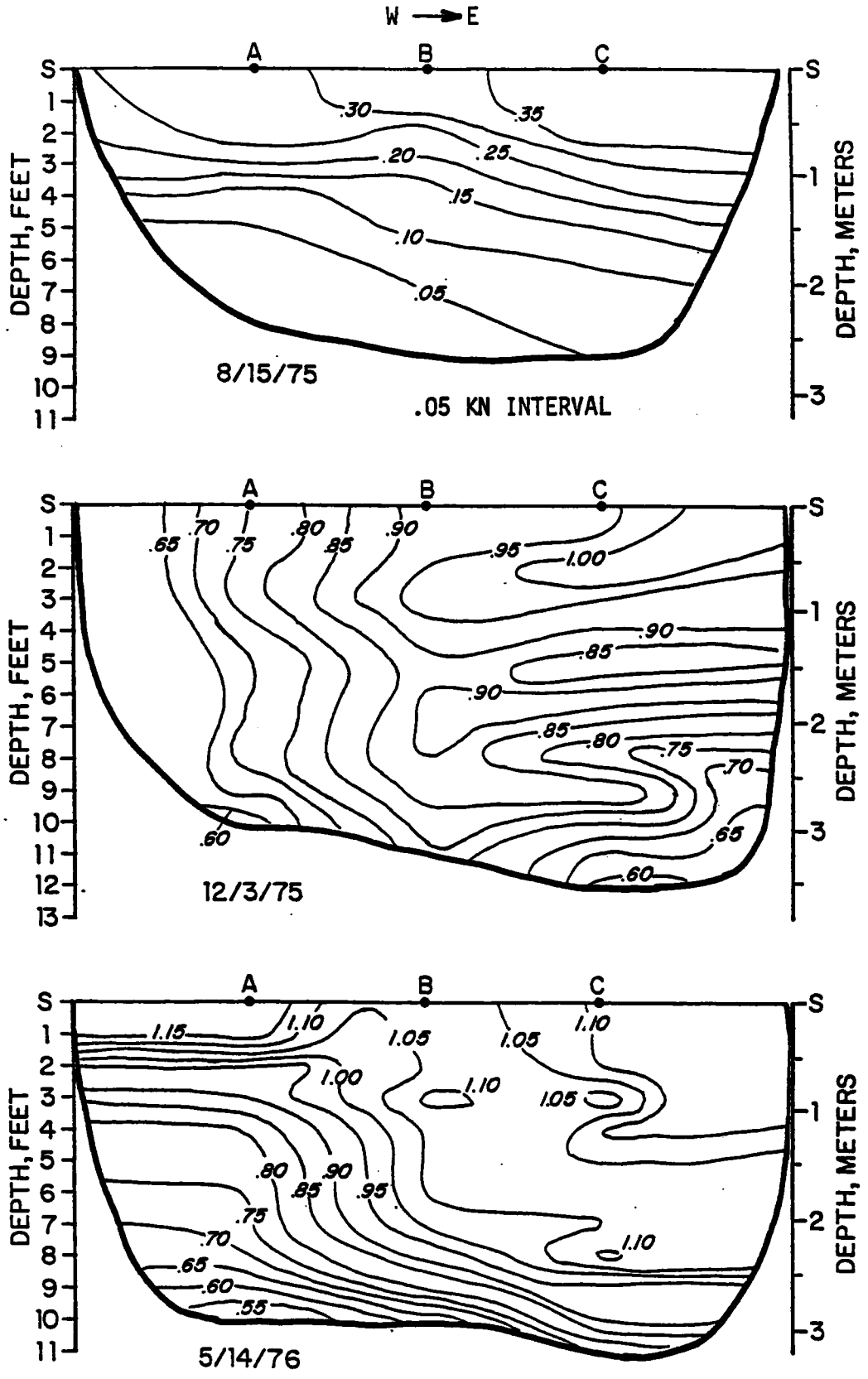

Figure 8. Cross sectional current (knots) diagrams at Transect SUNN on three representative dates. Merrimack River Fisheries Investigations, 1976.

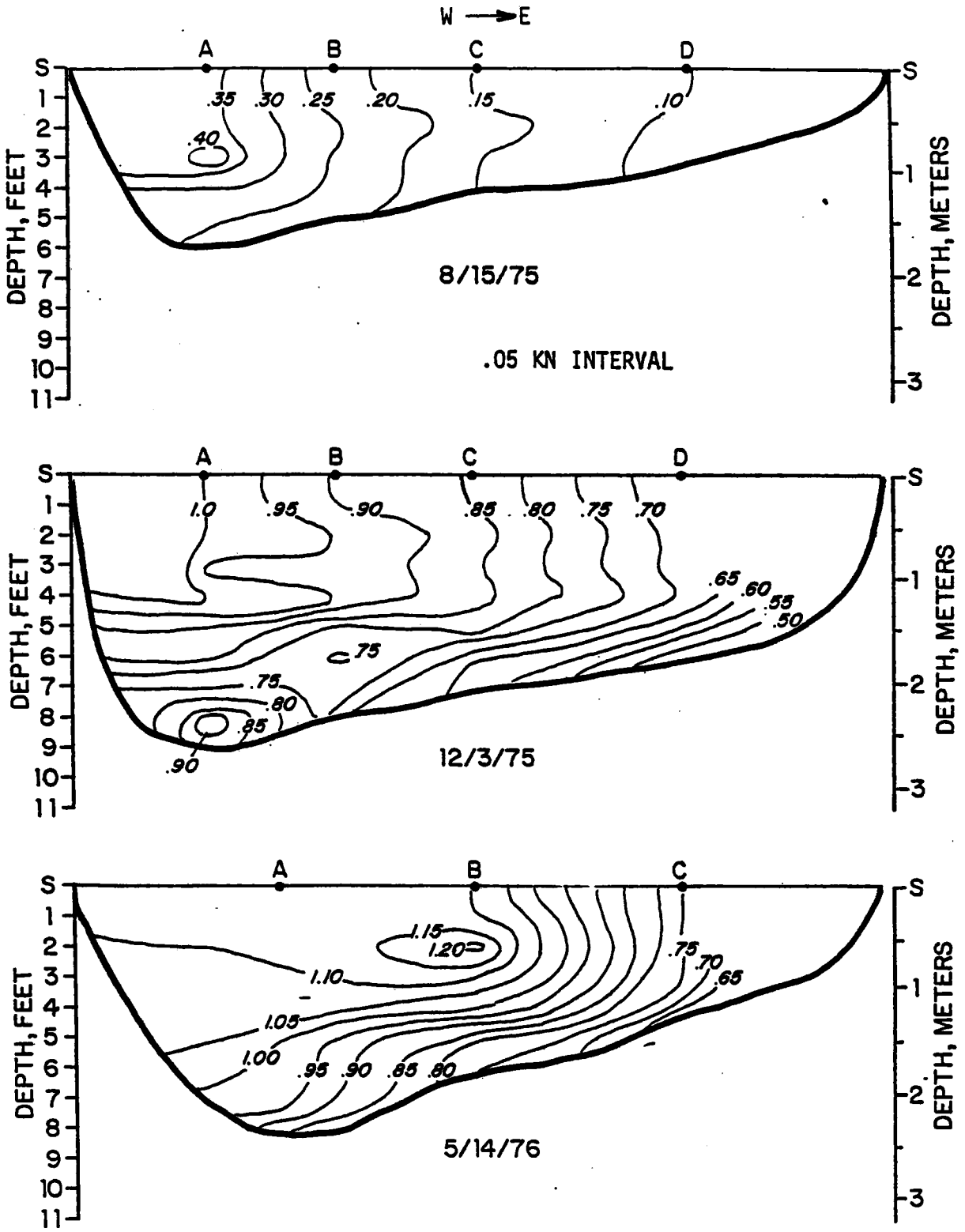

Figure 9. Cross sectional current (knots) diagrams at Transect IN on three representative dates. Merrimack River Fisheries Investigations, 1976.

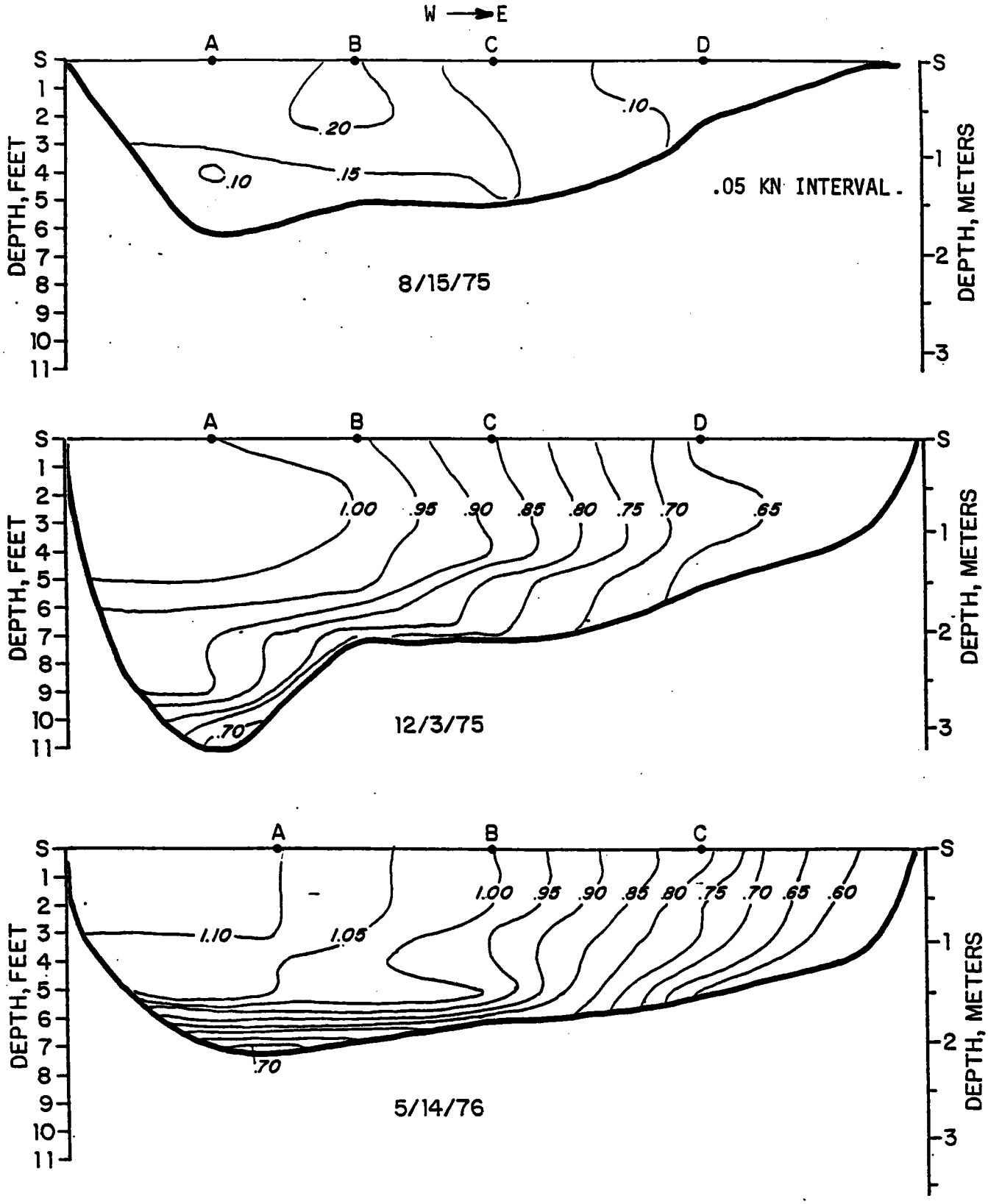

Figure 10. Cross sectional current (knots) diagrams at Transect IS on three representative dates. Merrimack River Fisheries Investigations, 1976.

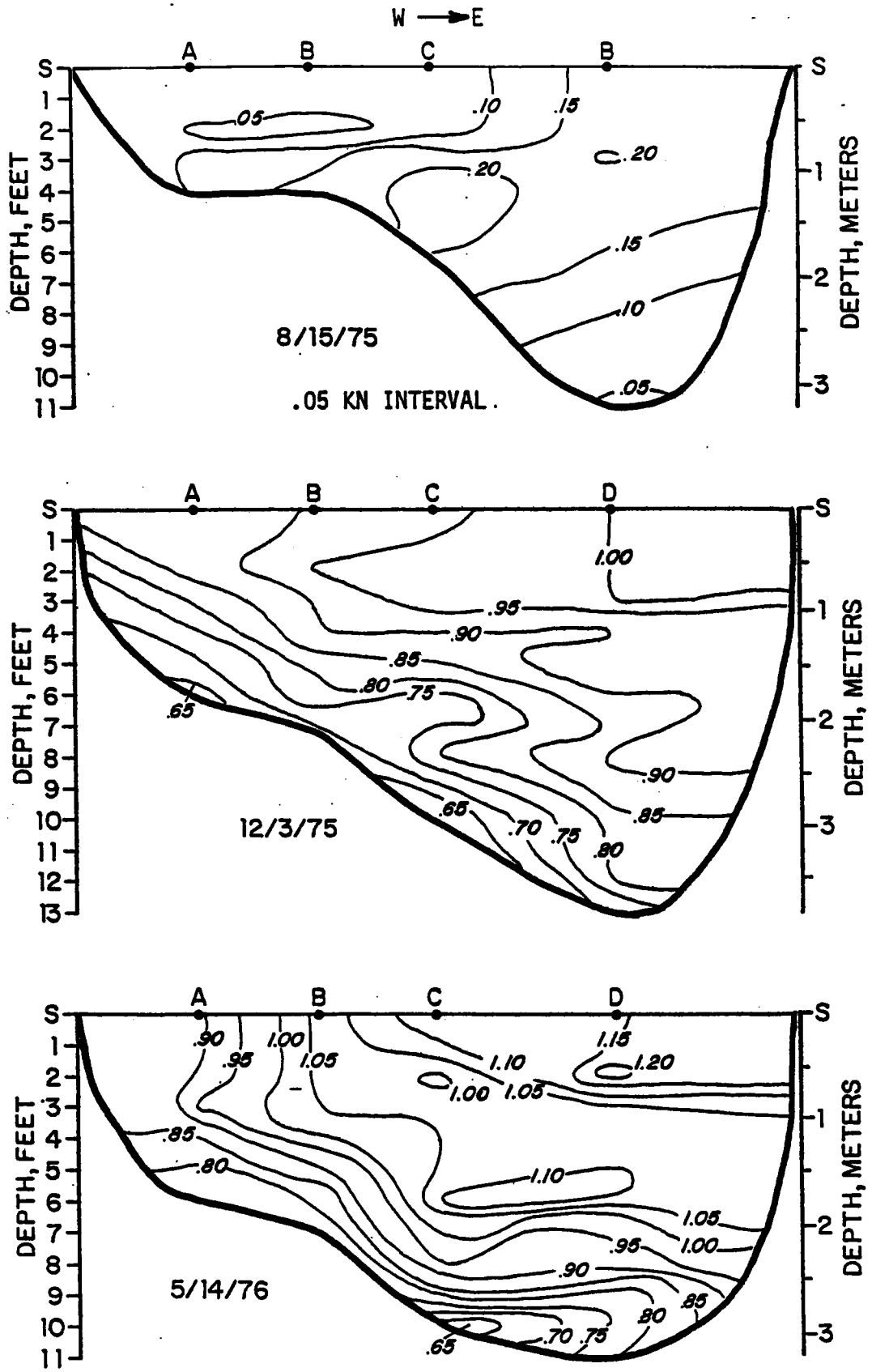

Figure 11. Cross sectional current (knots) diagrams at Transect DN on three representative dates. Merrimack River Fisheries Investigations, 1976.

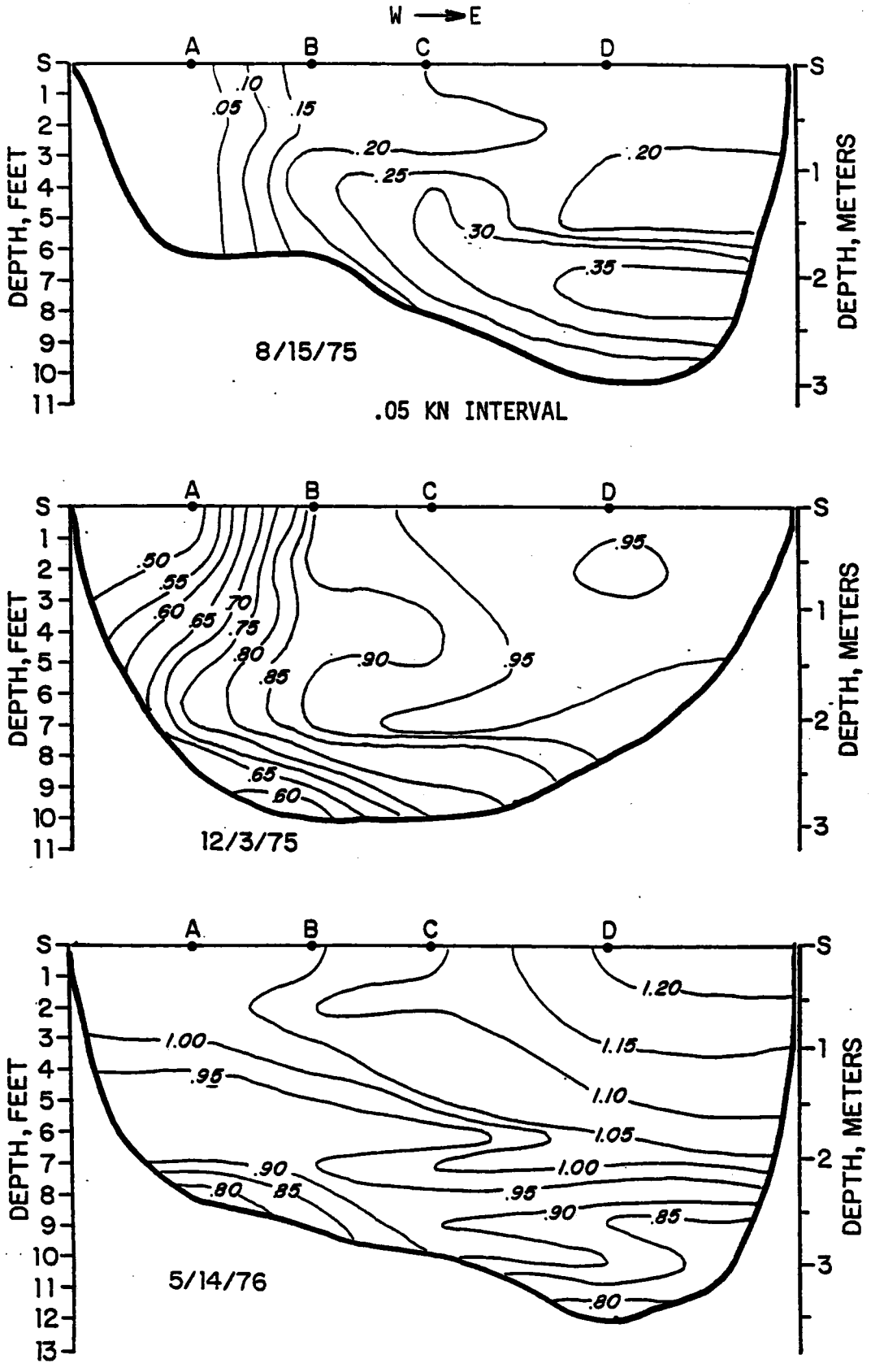

Figure 12. Cross sectional current (knots) diagrams at Transect DS on three representative dates. Merrimack River Fisheries Investigations, 1976.

TABLE 2a. CROSS SECTIONAL TEMPERATURES (°F) OF TRANSECTS WHICH WERE ISOTHERMAL THROUGHOUT THE STUDY. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

TRANSECT/ DATE	SOUN	SOUS	IN	IO	IS	DI
8-08-75	72.5	72	72	2	2	1
8-14-75	75.5	75.5	76	76	76	75
8-15-75	75	74.5	74.5	75	75	75
9-04-75	64	64	64	64	64.5	64.5
9-05-75	64.5	64.5	65	65	64.5	65
10-02-75	58	58.5	58.5	58.5	58.5	58.5
10-03-75	56	56	56.5	56.5	57	56.5
10-24-75	50	[1]	50	50	50.5	50.5
10-30-75	50	50	50	50	50	50
11-07-75	43	43	43	43.5	43.5	44
11-20-75	42	42	42	42.5	43	43
12-03-75	38	38	38	38	38	38

[1] no data
[2] slightly stratified near west bank

TABLE 2b. CROSS SECTIONAL TEMPERATURES (°F) OF TRANSECTS WHICH WERE ISOTHERMAL ON SOME BUT NOT ALL SURVEY DATES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

TRANSECT/ DATE	DN	DS	SUNN	SUNS
10-02-75	38.5	1	1	59.5
10-05-75	57.5	57	57	57
10-24-75	50.5	1	1	51.5
10-30-75	50	50	50	50
11-07-75	44.5	1	1	1
11-20-75	43	1	1	1
12-03-75	38	1	1	1

[1] stratified

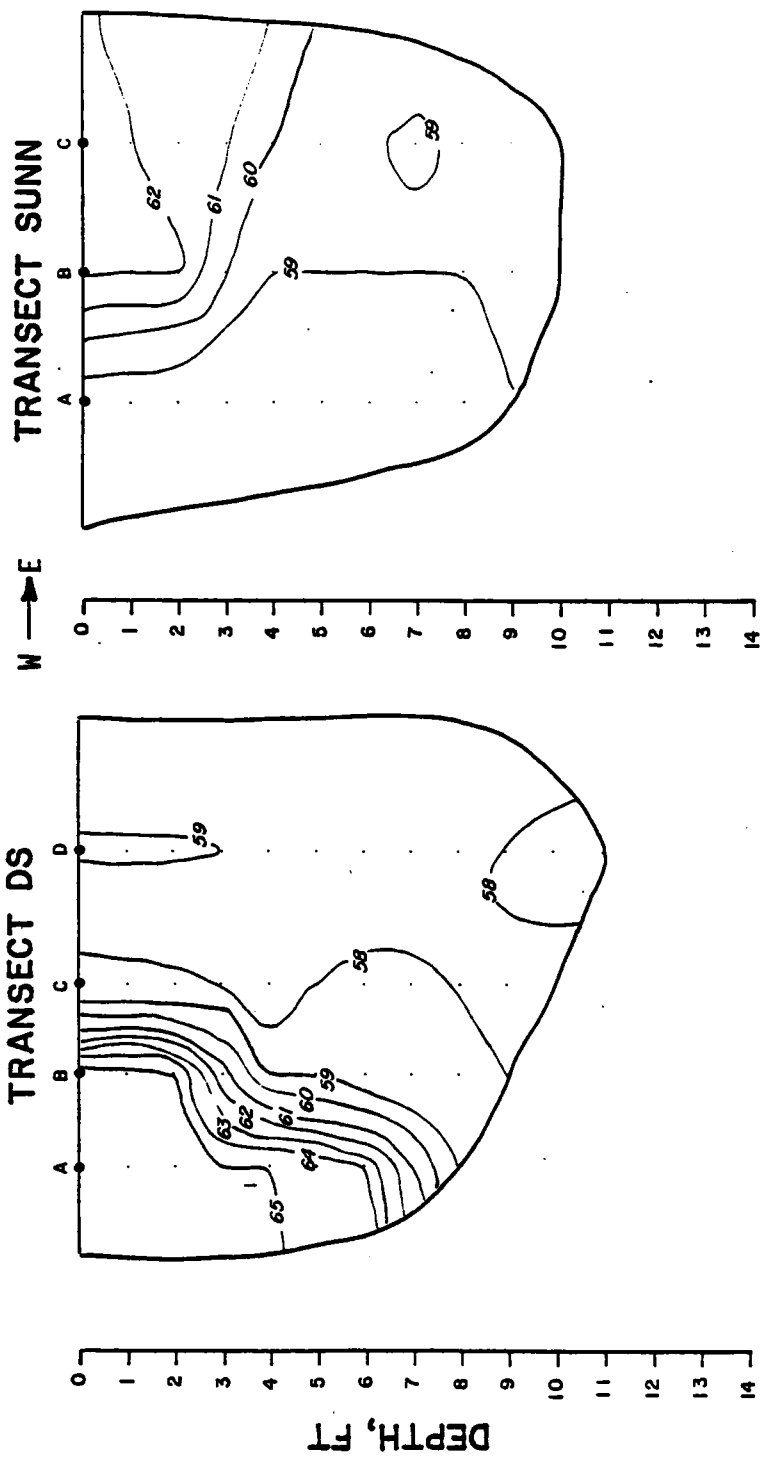

Figure 13. Cross-sectional temperature profiles at transects DS and SUNN, October 2, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

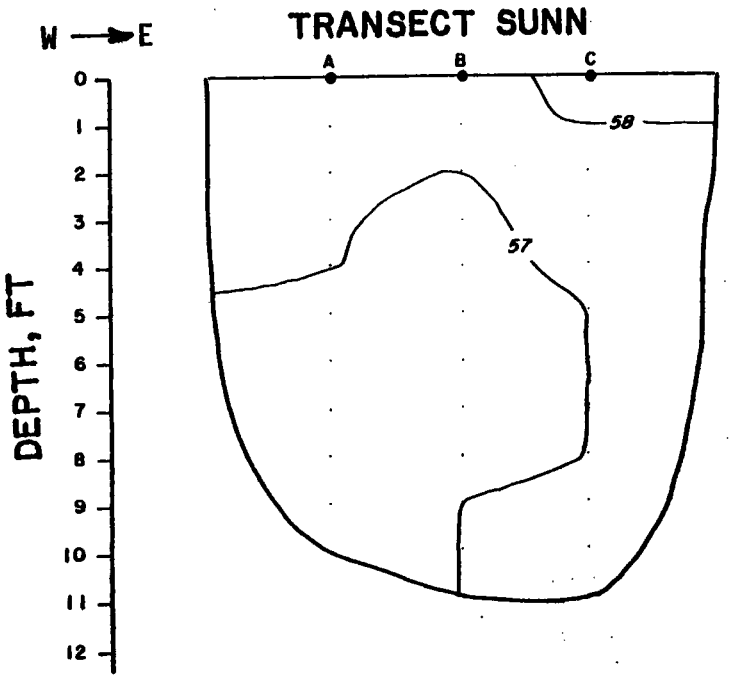

Figure 14. Cross sectional temperature profile at transect SUNN, October 3, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

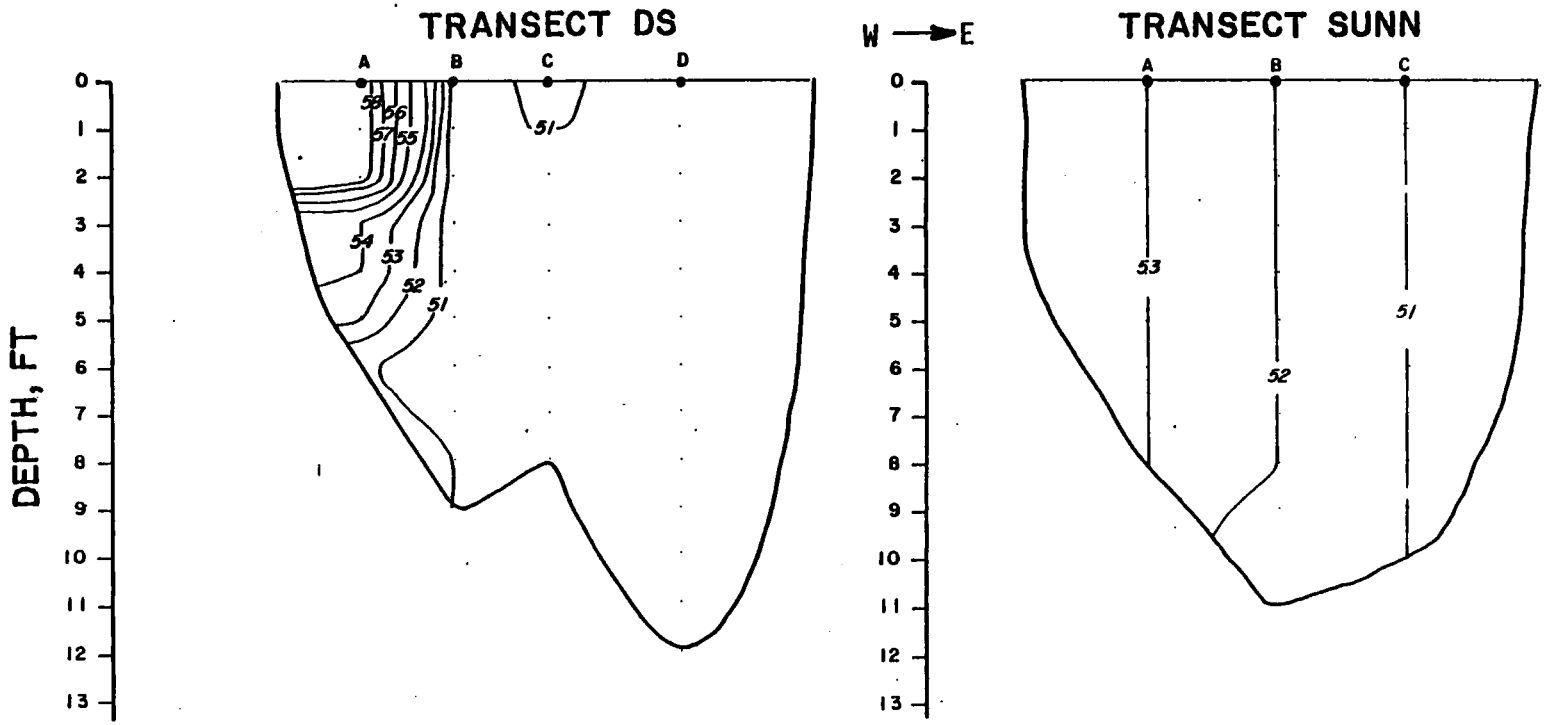

Figure 15. Cross sectional temperature profiles at transects DS and SUNN, October 24, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

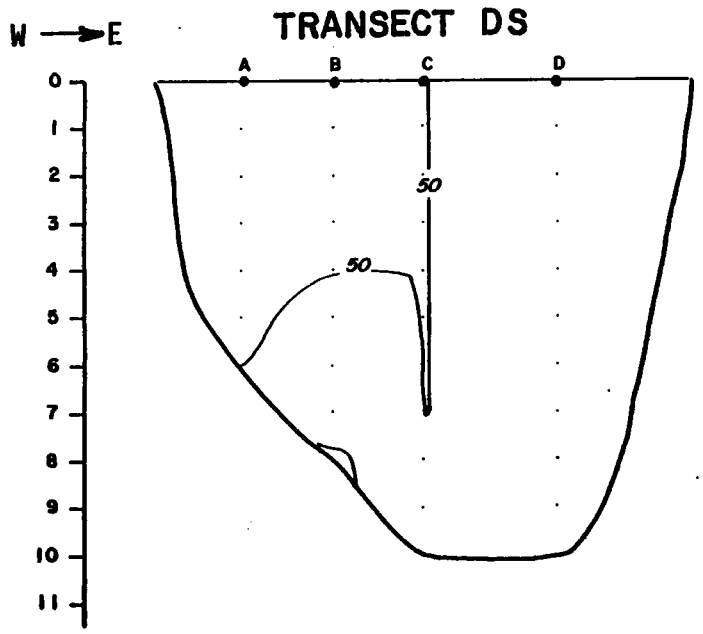

Figure 16. Cross sectional temperature profile at transect DS, October 30, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

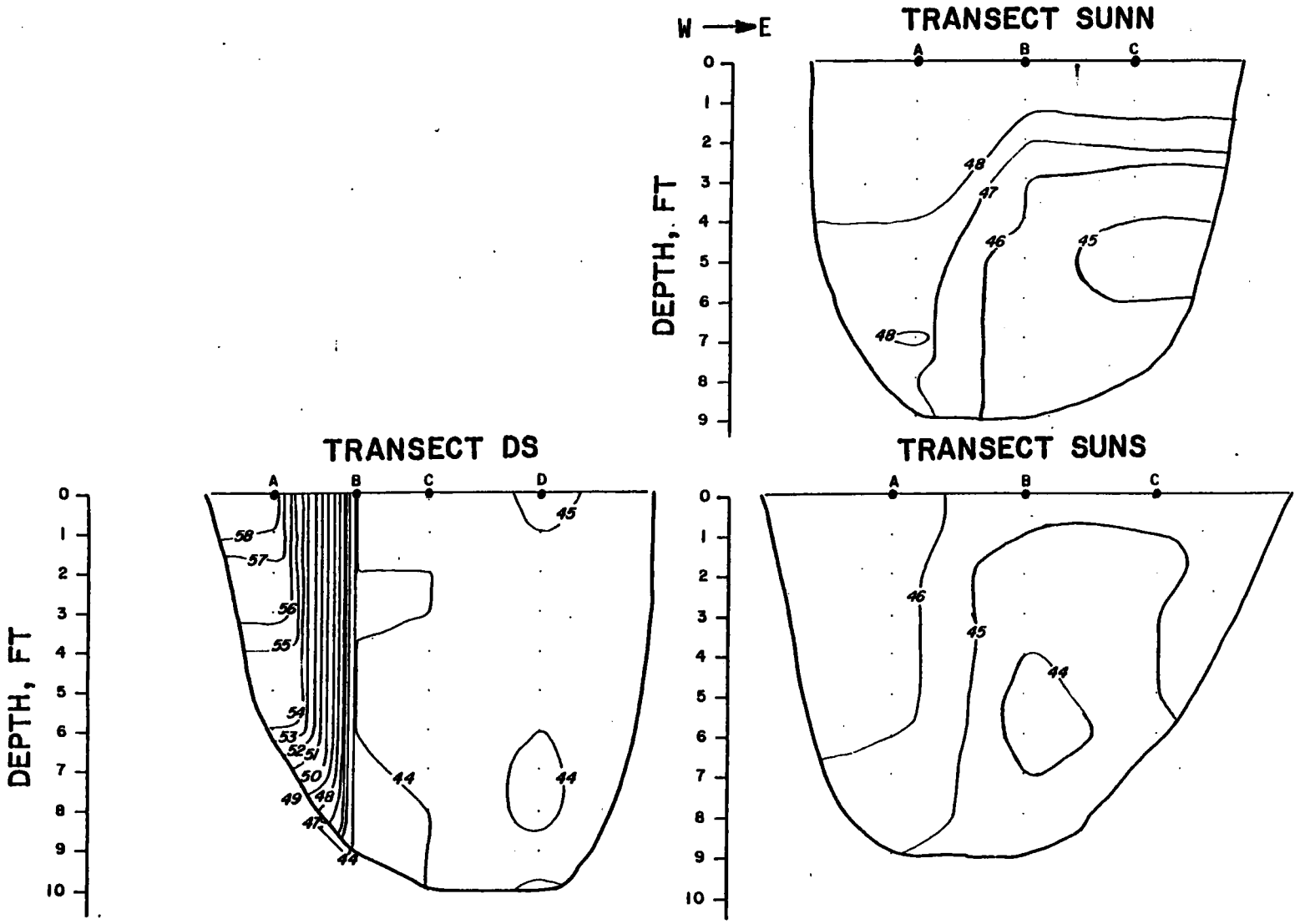

Figure 17. Cross sectional temperature profiles at transects SUNN, DS, and SUNS November 7, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

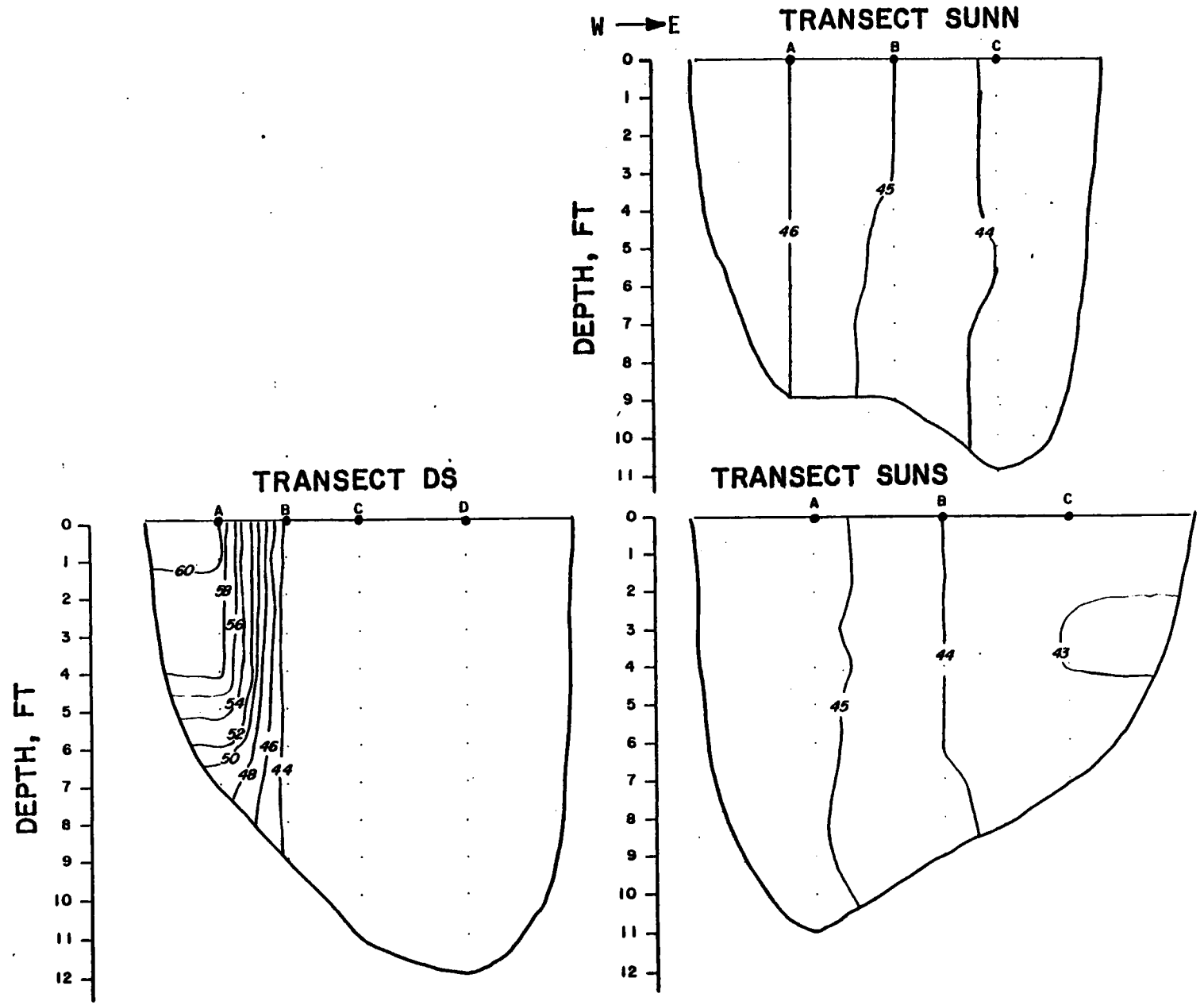

Figure 18. Cross sectional temperature profiles at transects SUNN, DS, and SUNS November 20, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

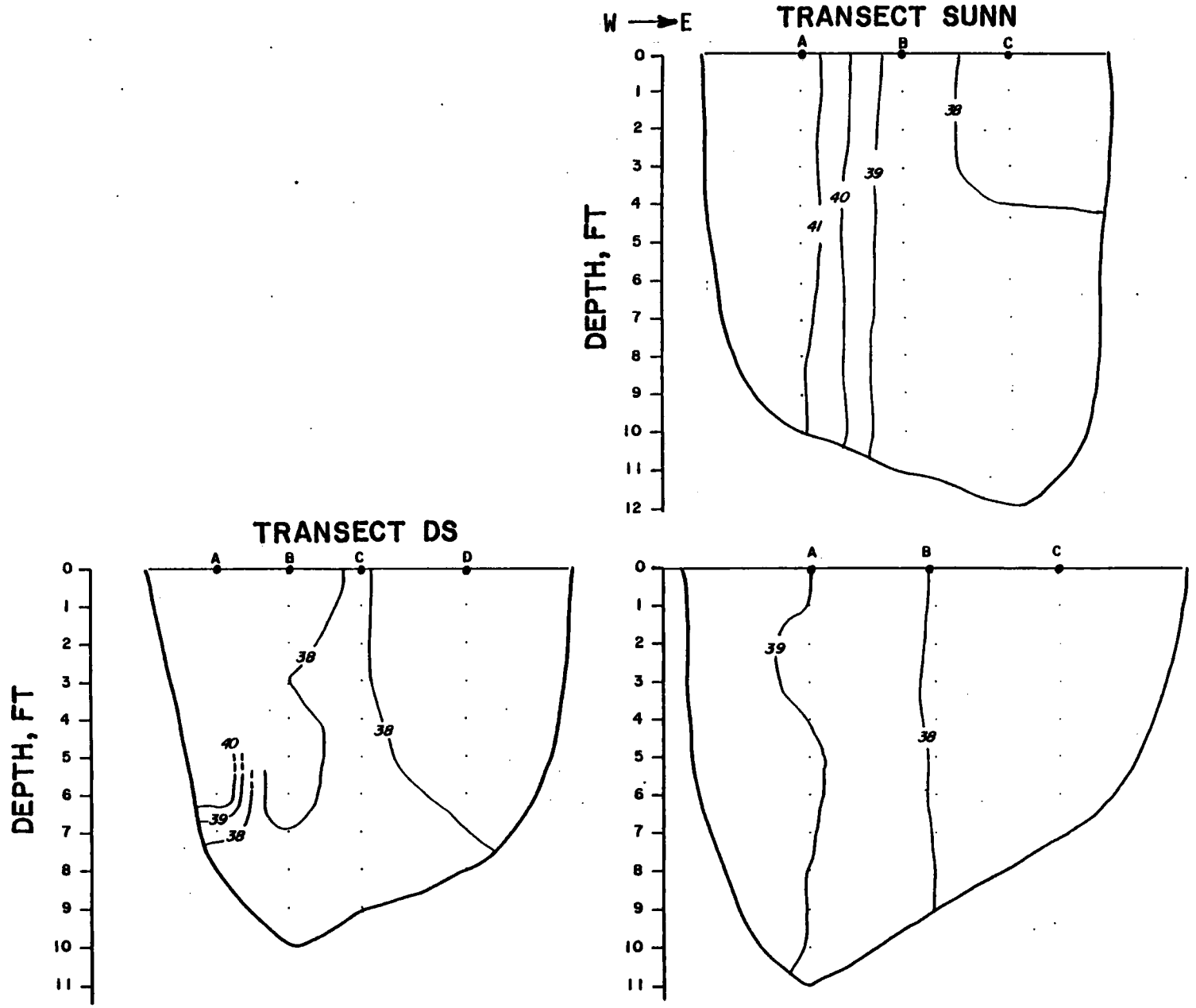

Figure 19. Cross sectional temperature profiles at transects SUNN, DS, and SUNS SUNS, December 3, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

3) Turbulence

Electromagnetic current meter observations taken over a 24-hr period on July 2 and 3, 1975 indicated that typical variation in the velocity field's longitudinal and vertical components averaged ±20% of the mean velocity (Figure 20). Discharge during this period ranged from ≈1000 to 1500 cfs (Appendix A, Figure A2).

c. Discussion

1) Current

Current data have been obtained over a fairly wide range of river discharge levels; the data have been used in the calibration of the Hooksett Pond hydrodynamic model.

The extent to which current speeds varied with river discharge is indicated in Table 1. Of the three dates represented therein, the lowest discharge was on August 15, 1975, the highest was on May 14, 1976 and the midrange of the three was on December 3, 1975. In general, both surface and bottom average currents increased with increasing discharge, however two anomalous results can be seen: at Transects IS and SUNN the bottom currents on December 3 were equal to or greater than what they were on May 14. During low discharge the current was generally less than 0.3 kn*. At moderate discharge the surface current ranged between 0.8 kn and 0.9 kn (except at Transect SOUS and Station DO) and the bottom ranged primarily between 0.6 kn and 0.8 kn. For high discharge the surface current was generally a little more than 1 kn, and the bottom current was between 0.6 kn and 0.8 kn.

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*1 kn = 1.14 mph = 1.67 ft/sec = 51.44 cm/sec

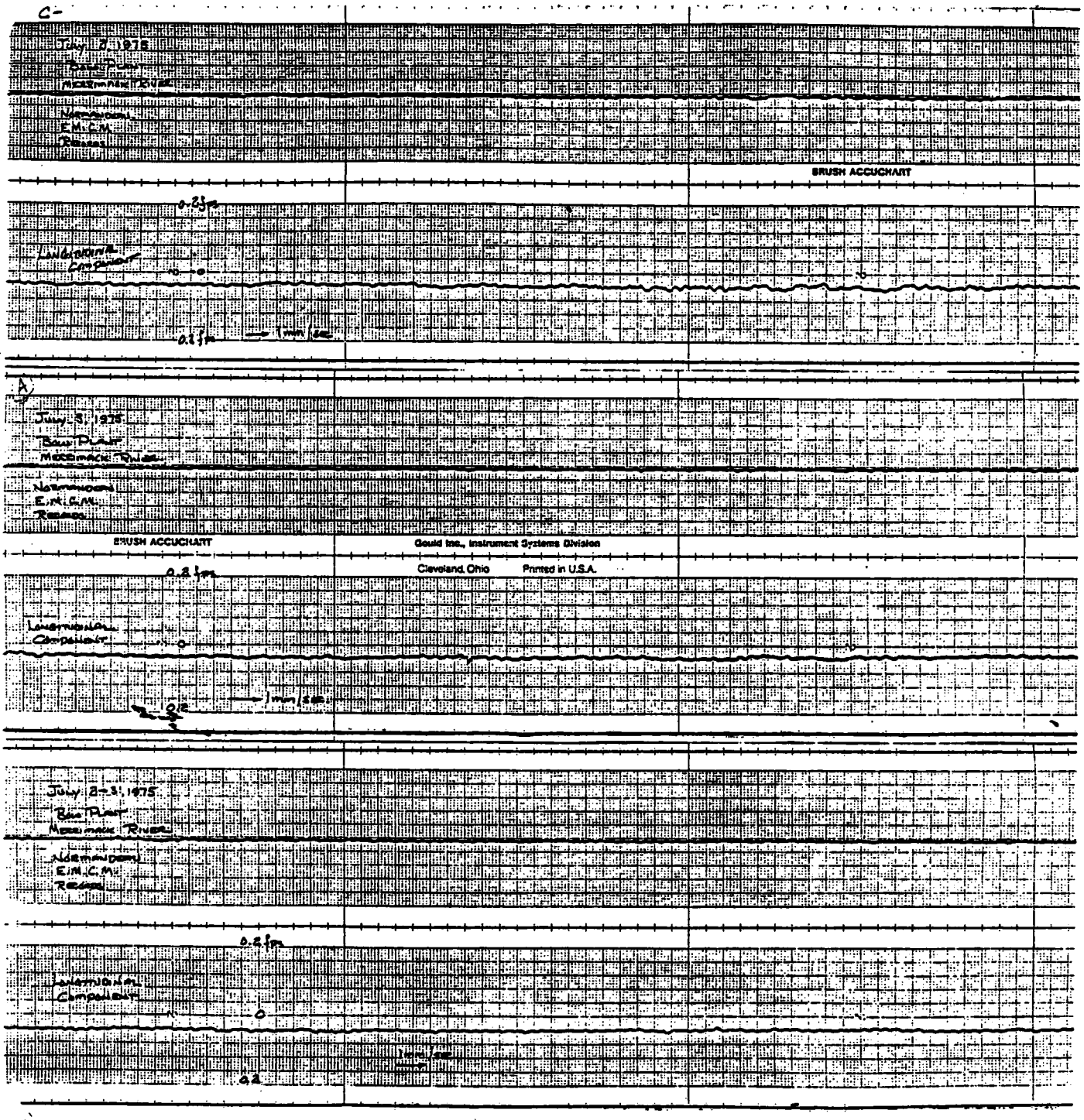


Figure 20. Longitudinal and vertical current component tapes from electromagnetic current meter moored at Transect N-0. Tape speed = 1 mm/sec. Vertical scale = 0.4 ft/sec. Merrimack River Anadromous Fisheries Investigations, 1976.

An apparent anomaly is also indicated at Station DO. This is unimportant, however, since DO is located right at the mouth of the discharge canal where motion is extremely complex. The flow from the discharge canal is directed essentially upstream with respect to the river channel so it opposes the river flow. This creates a turbulent situation in which currents at DO behave randomly.

Figures 3 through 7 reveal certain characteristics of the cross sectional flow patterns at each transect that remain essentially unchanged throughout the range of discharges investigated. The selected transects depict flow conditions immediately upstream and downstream of the discharge (Figures 5 and 6) and far downstream of the discharge (Figure 7). Parts a, b and c in each figure correspond respectively to August 15, 1975, December 3, 1975 and May 14, 1976.

Near the intake the river is much deeper on the west side (the intake side) than on the east side. Because of this the current near the western shore is always greater than the current near the eastern shore, as each section of Figures 3 and 4 indicates. Additionally, the qualitative nature of the flow in the vicinity of the intake did not vary as a function of discharge. At Transects IN and IS (Figure 3) the basic pattern of the isopleths was the same for each date.

In the vicinity of the discharge the river is considerably deeper on the east side. In addition there is a bend in the river, and the east bank is the outside bank (Figure 1). Both of these conditions influenced the flow such that the current was stronger toward the eastern shore, as illustrated in Figures 5 and 6, which show the cross sectional current patterns at Transects DN and DS, respectively. At these two transects the isopleth patterns do not demonstrate the consistency that marked Transects IN and IS. While Figures 5b and 5c are basically similar they both differ substantially from Figure 5a. The contours near the west bank in Figure 5b have similar slopes and magnitudes to the contours near the west bank in Figure 5c. In addition the vertical and horizontal speed gradients indicated by the two illustra-

tions are about the same. In Figure 5a the contours near the west bank do not resemble those in Figures 5b and 5c in terms of slope and vertical speed gradient. The features common to Figures 6a and 6b are the nearly vertical contours near the west bank (implying a strong local horizontal speed gradient), the gently sloping contours close to the bottom near the east bank, and the large area of essentially constant speed near the surface on the east side. In Figure 6c the contours near the west bank are primarily horizontal indicating a pronounced vertical speed gradient. There is also a sizable vertical speed gradient near the west bank.

The dissimilarities discussed above were most likely the result of turbulence associated with water issuing from the discharge canal; the dissimilarities were confined mainly to the west side of the river near the discharge canal (Figures 5-6).

At Transect SUNN the river is only slightly deeper on the east side than on the west side, but the current was generally stronger on the east side (Figure 7). This difference probably resulted from the river bend's effects on the current patterns. When river discharge was fairly low (Figure 7a) the speed increased slightly from west to east. When discharge was moderate (Figure 7b) the west to east increase was much more pronounced. This sizable west to east increase was confined to depths below three feet when the flow was fairly high (Figure 7c); above three feet there was little change from west to east.

2) Temperature

For any given day the stretch of river from Transect SOUN downstream to the powerplant discharge canal was very nearly isothermal. For example on August 15, 1975, the transects in that stretch display average temperatures which differ from one another by no more than 0.5F (Table 2a). On December 3 the average temperature of those transects were all the same -- 38F. The greatest variation among these transects

was seen on August 14 when the average temperature differed by 1.5F between transects SOUS and DI. Occasionally some or all of the transects downstream of the discharge were essentially isothermal, notably on October 3 and October 30 (Table 2b). On October 3, neither power plant unit was operating; on October 30 Unit 2 was not operating and Unit 1 was out of operation until 1400 EST. Appendix Table B2 lists plant output data for the dates on which hydrographic surveys were conducted.

Downstream of the discharge canal the heated effluent created a stratified situation, which varied from day to day in intensity and extent. For instance, all downstream transects (i.e. downstream of the discharge canal) as well as Transect DN were affected on August 15, 1975 (Figure 10), but on October 2, 1975 the only affected transects were DS and SUNN, (Figure 13). There were two reasons for this: on the later date, the river flow was much higher and, since the flow from the discharge canal was the same as before, there was greater dilution effect. On October 2 Unit 1 was not operating, whereas on August 15 both units were operating the entire day. Additional cross-sectional temperature profiles and plant operating data are contained in Appendix B (Figure B3, Table B2).

2. Numerical Simulation

a. Methods of Study

1) Model Description

A mathematical model of river flow was implemented to complement data gathered on site. The model selected was an adaptation of a two-dimensional hydrodynamic model developed for coastal circulation analysis (Connor and Wang, 1973; Celikkol and Reichard, 1976). It solves vertically-averaged conservation of mass and momentum equations for two horizontal velocity components and water level.

This model was chosen for its numerical solution scheme, the finite element method. The method is quite flexible in that it uses a grid of triangles, variable in both shape and size, to represent the model area and handles boundary conditions directly, eliminating the boundary condition problems encountered in other modelling schemes.

In principle, the finite element method approximates the solution of boundary value problems using functions composed of piece-wise continuous polynomials. It is based on discretization of the continuum (water body) into an equivalent system of finite elements. The values of the parameters at any point within the element are assumed a function of the values at the nodes, which are specific points on the element boundaries, common to adjacent elements. The nodes represent the corners of the triangles mentioned previously. The equations are transformed for application to the element using the previously assumed function. Treatment of the entire continuum is accomplished through summation of the contributions of each element. Because the solution is piece-wise continuous, only one parameter (in this case usually Garvin's Falls discharge) must be specified at the boundary.

The finite element grid requires individual placement of the nodes and elements. The following general guidelines were followed in selecting the grid:

(a) An element could not have more than two of its nodes on a land boundary;

(b) Element angles were less than or equal to ninety degrees;

(c) The area of adjacent elements varied less than twenty percent.

The grid selected is represented graphically as Appendix Figure C-1. After the grid was selected, the nodes and elements were numbered and coded for the model. Boundary conditions were then set up for both land

and water boundaries. Land boundary nodes were identified and normal angles specified for each, forcing the flow to be tangential to these land boundaries. The water boundary nodes were identified and either water level or flow rate, or both, specified. Specification of flow rate appeared to be the best way of handling the water boundary condition for this study. The last step in setting up the grid was selection of the river bottom elevation (with respect to a reference level) for each node. Recording fathometer traces from Hooksett Pond were used in this step.

Additional descriptive material pertaining to the numerical simulation, including equations and programs, are contained in Appendix C.

2) Preliminary Model

During 1975 a small (twenty element) model of a sloped rectangular channel, open at both ends, was developed and run. This model was used as an aid in the final model selection process and to provide an experimental basis for evaluation of bottom friction and eddy viscosity coefficients.

b. Results and Discussion

1) Model Results

Merrimack River flow patterns in the vicinity of Merrimack Station were modeled as potential flow. Potential flow is based on the following assumptions:

(a) flow is 2-dimensional (vertically constant)

(b) driving forces are in equilibrium at time of simulation (steady-state flow)

(c) flow is inviscid (water has insignificant viscosity).

The flow is represented by either the potential function or the stream function. The stream function ψ is defined as follows:

$$\psi = \psi (x,y)$$

$$u = \frac{-\partial\psi}{\partial y}$$

$$v = \frac{\partial\psi}{\partial x}$$

where x and y are cartesian coordinates and u and v are velocity components in the x and y directions respectively. The curves represented by ψ = constant are called streamlines. Streamlines are significant in that they are always parallel to the current velocity; therefore, water does not cross a streamline. The stream function for a sink or intake in a uniform flow field is:

$$\psi = U_y - m \tan^{-1} \left(\frac{y}{x}\right) \quad \text{(Milne-Thompson, 1950)}$$

where U is the velocity of the uniform flow field an infinite distance from the intake, and m is the strength of the intake. This can be transformed into an intake on the wall of a rectangular channel of constant depth and width W using the method of images:

$$\psi = U_y - m \tan^{-1} \left(\frac{y}{x}\right) - m \sum_{n=1}^{\infty} \left[\tan^{-1} \left(\frac{y+2nW}{x}\right) + \tan^{-1} \left(\frac{y-2nW}{x}\right)\right]$$

(Milne-Thompson, 1950)

This is the equation for the stream function in a rectangular channel of width W and constant depth.

The stream function was used to define seven equally incremented streamlines in the channel for ten flow rates between 1000 and 10,000 cfs and an intake of 444 cfs. The results of these simulations are depicted in Figure 21. The first and the last streamline define the sides of the channel. For the 1000 and 2000 cfs cases, streamlines disappear, indicating that all of the water contained by these streamlines flows into the intake. The decreasing effect of the intake on flow patterns as flow rate increases is clearly illustrated by the model results (Figure 21).

The hydrodynamic model was used in steady-state mode to predict current speed at each field station for flow rates of 1000 through 10,000 cfs in 1000 cfs increments. The vertically averaged speeds predicted by the model are presented graphically in Appendix Figure C1. Vertical averages of the field data are presented on the same plots for purposes of comparison.

In general, the model results compare favorably with the field data. There are sizable discrepancies in places, however, some of which are the result of inaccuracies in the flow rate measurement (errors may be as large as 1000 cfs due to time-varying discharge at Garvin's Falls) and others resulting from model assumptions. Some of these include: (a) the bathymetry of the model is only approximate, which leads to some errors in places where the flow is highly dependent on geometry; (b) the numerical structure tends to damp out cross channel velocity differences, resulting in some distortion where high cross-channel gradients are present. This effect is particularly noticeable for the SOUS transect (Appendix Figure B-4). And (c) the absence of high flow rate data for some of the transects detracts slightly from the accuracy of some model predictions; however, there is sufficient data at other stations to ensure reasonable results.

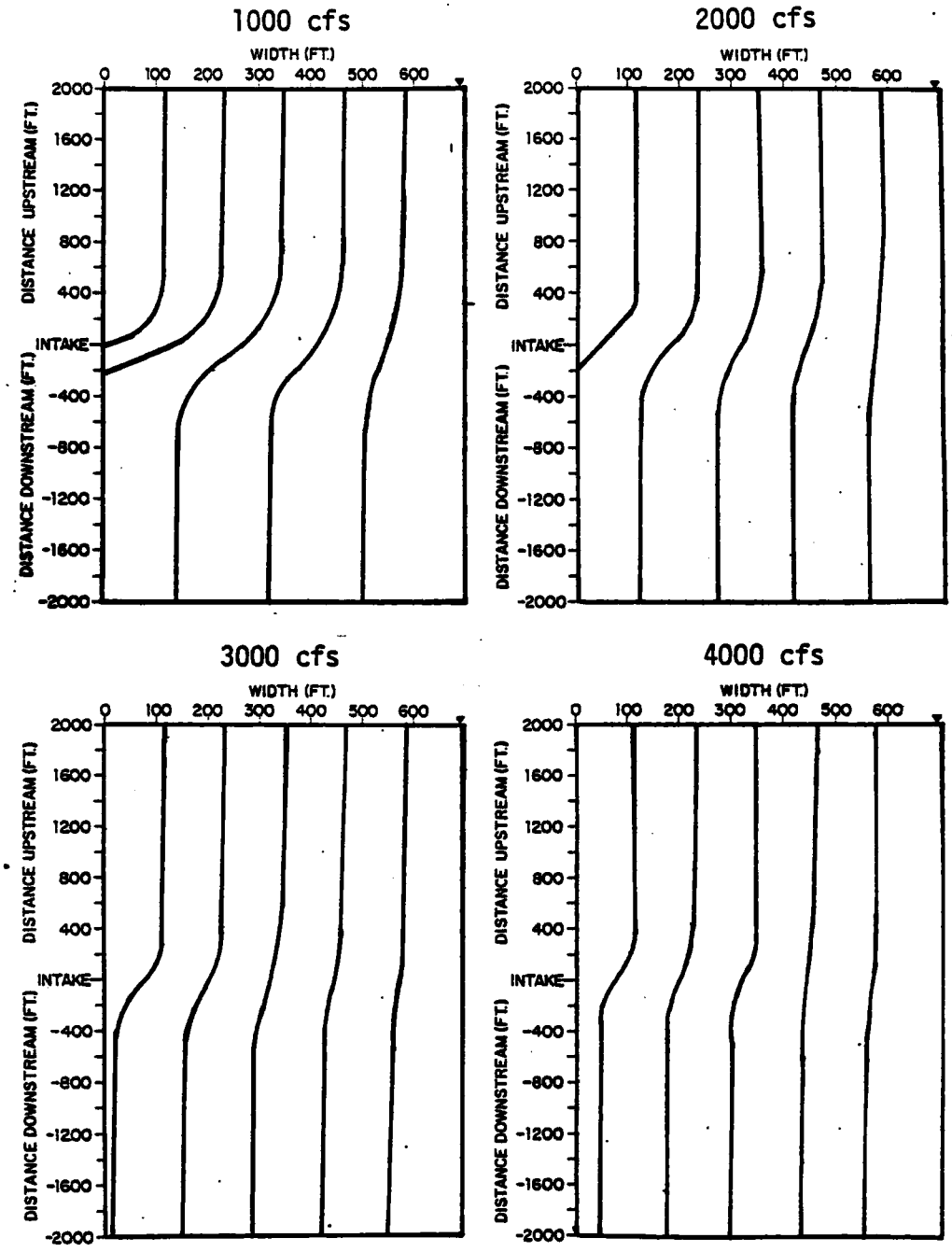


Figure 21. Predicted streamlines in the vicinity of Merrimack Station at 10 levels of Garvin's Falls discharge. Merrimack River Anadromous Fisheries Investigations, 1976.

Continued

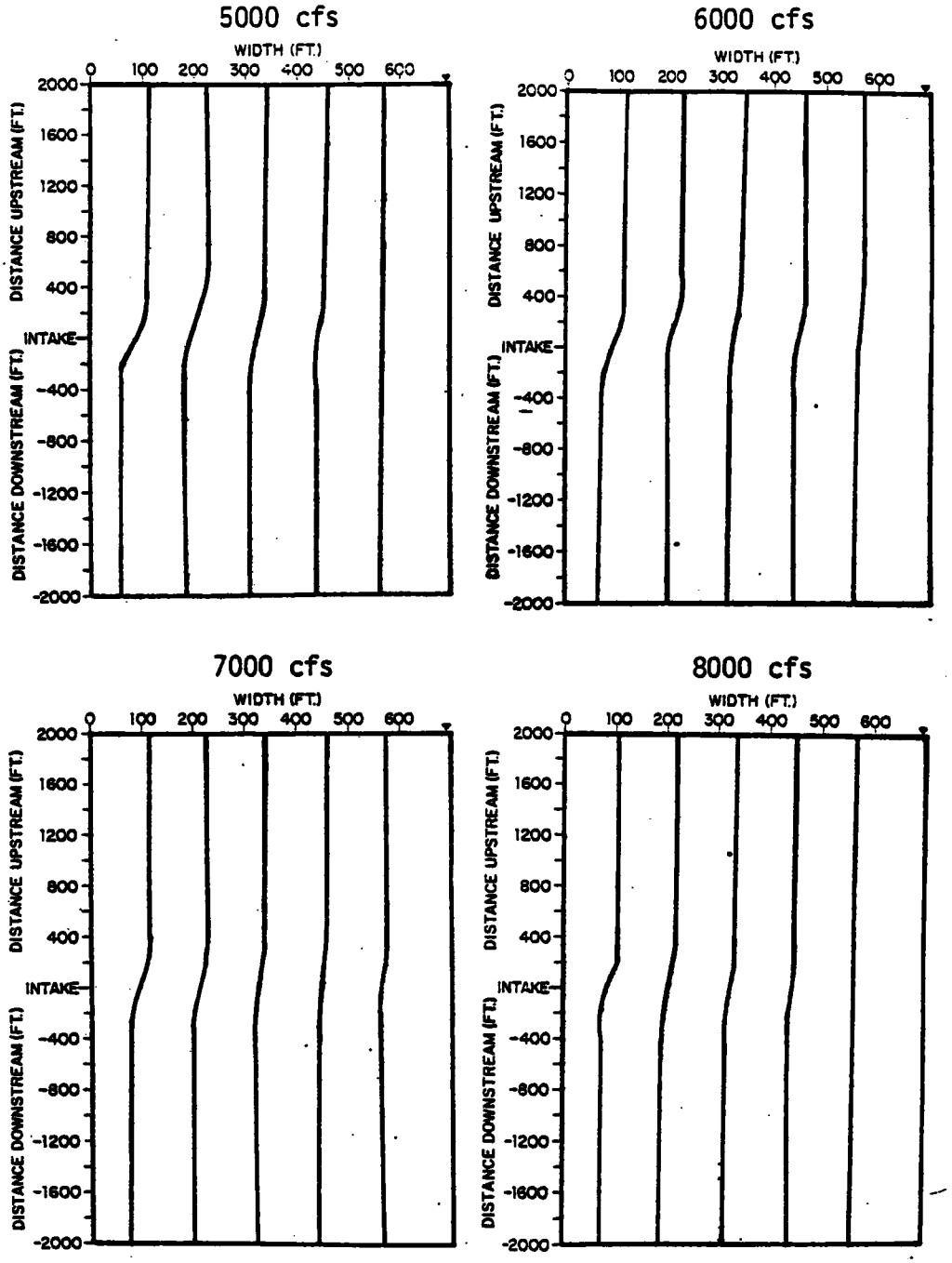


Figure 21. (Continued)

Continued

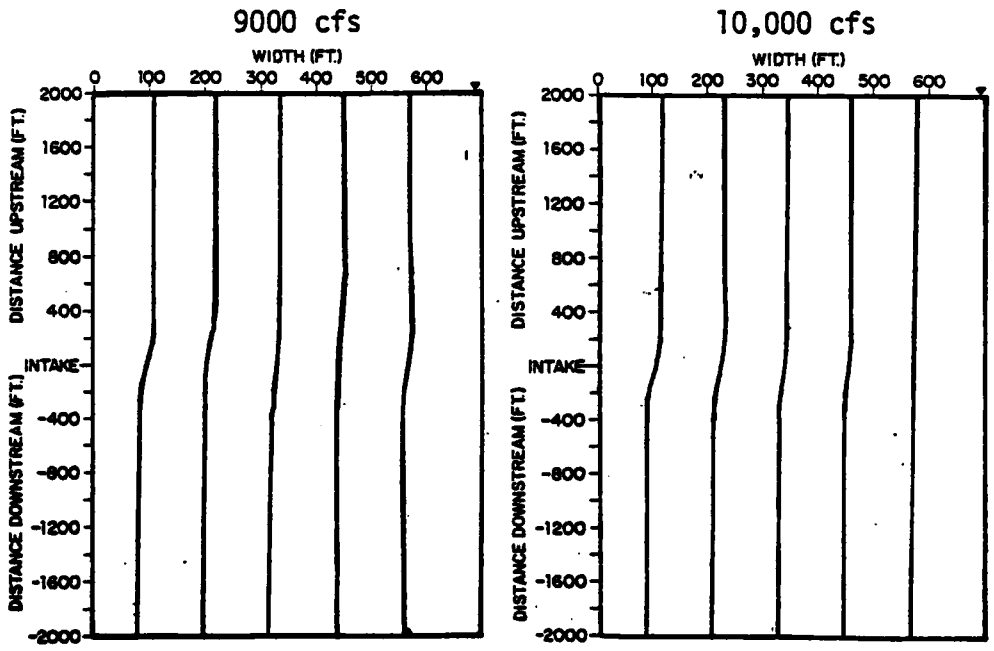


Figure 21. (Continued)

The general trend of both the field data and model predictions is a rapid velocity increase with increased flow rate below 4000 cfs, and a relatively small increase in velocity with flow at rates above 5000 cfs. This results from the interaction of two basic phenomena: bottom friction, the resisting force; and river slope, the driving force. At the lower flow rates, river level is lower, and bottom friction is the limiting factor. At higher flow rates, river level rises and the limiting factor becomes river slope. This is illustrated conceptually in Figure 22. A typical vertical velocity profile is assumed and presented for three flow conditions. For low flow conditions (a) and accompanying low water levels, the entire water column is in the friction layer. At flow rates about 4500 cfs (b) the friction layer is fully developed, and transition occurs. High flow rate (c) velocities are limited by the river slope, with the average velocity assymptotically approaching V_o, the maximum velocity. In general, flow rates over 5000 cfs produce depth increases without corresponding velocity increases.

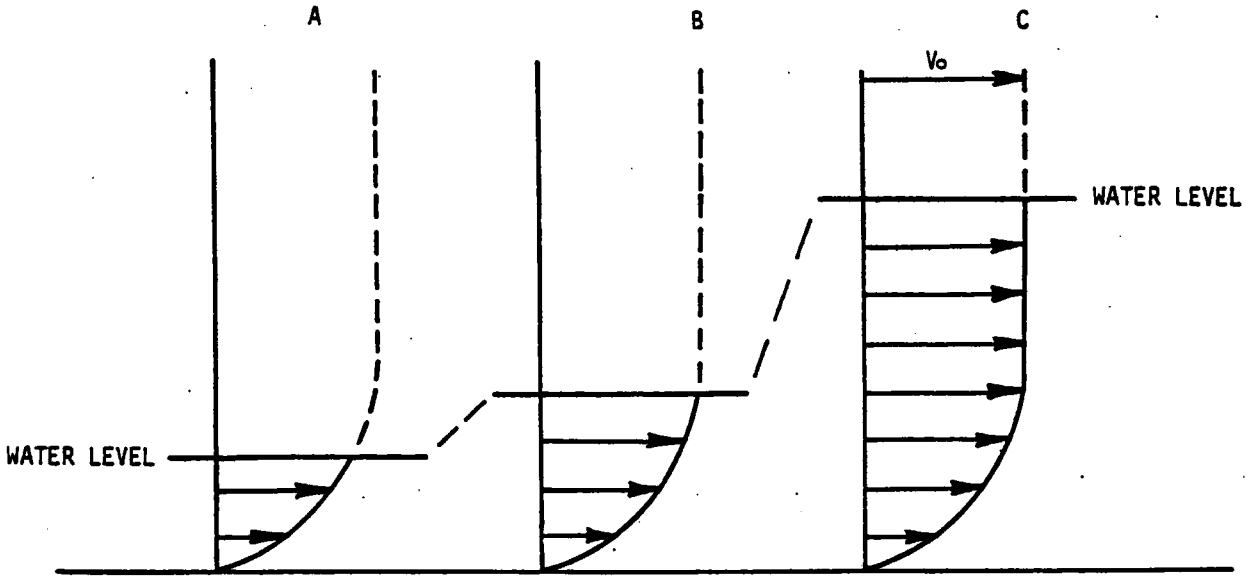


Figure 22. Conceptual model of velocity profile at three water levels. Merrimack River Anadromous Fisheries Investigations, 1976.

2) Velocity-Depth Computations

Generally, current speed is distributed inversely with the logarithm of depth such that greatest velocities occur near the surface and lowest near the bottom (Hynes, 1969). Using this generality and the mean velocity obtained from model predictions and field data, it is possible to compute the depth in the water column at which any velocity occurs at any node. This analysis is necessary to predict the likelihood of egg entrainment under various flow conditions. The computations involved in this procedure and their results are described in the following paragraphs.

The traditional form of the logarithmic profile is:

$$u(z) = A \ln(z) + C \qquad (1)$$

where z is distance from the bottom and A and C are parameters evaluated in a later step. It is not possible to apply a no-slip boundary condition [u(o) = 0] to this form as $\ln(0) = -\infty$. However, the form can be modified to accept the no-slip condition while maintaining the general concept of the logarithmic profile by defining a new form of the logarithmic profile such that:

$$u(z) = A \ln(z + B) + C \qquad (2)$$

where B has units of length and is generally quite small. Applying the no-slip condition,

$$u(o) = A \ln(B) + C = 0$$

or

$$C = -A \ln(B) \qquad (3)$$

Substituting this result into definition (2) yields

$$u(z) = A\,[\ln(z + B) - \ln(B)]$$

which simplifies to:

$$u(z) = A \ln\left(\frac{z+B}{B}\right) \qquad (4)$$

The parameters A and B can be evaluated for a specific profile if the velocity is known at two depths. It is also possible to evaluate one of the constants based on the vertical average velocity:

$$u_{av} = A \int_0^H \ln\left(\frac{z + B}{B}\right) dz$$

$$A = \frac{u_{av}}{\left[\left(1 + \frac{B}{H}\right) \ln\left(\frac{H + B}{B}\right) - 1\right]} \qquad (5)$$

where u_{av} is the vertical average velocity and H is the water depth. Analysis of Merrimack River data indicates that the parameter B is a function of flow rate (Figure 23). Thus only the parameter A must be obtained, which can be calculated using equation (5) and the vertical average current predicted by the hydrodynamic model. Comparisons of logarithmic profiles calculated using this method and field data profiles are presented in Figure 24. In general, the fit is quite good.

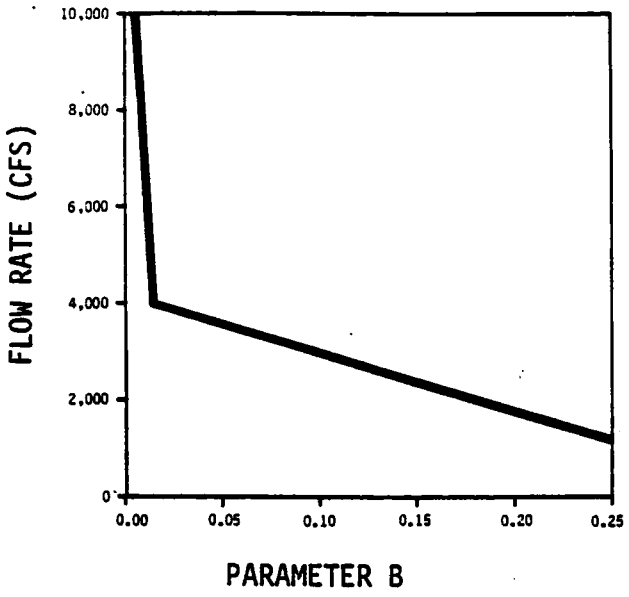


Figure 23. Parameter "B" vs. flow. Merrimack River Anadromous Fisheries Investigations, 1976.

The logarithmic profile is next used to calculate the height above the bottom at which critical velocities occur. Rearranging equation (4):

$$z = B[e^{u/a} - 1] \qquad (6)$$

Using this formula, the distances have been calculated for velocities of 5, 10 and 20 cm/sec at each data transect upstream of the intake for flow rates of 1000, 2500, 4000 and 8000 cfs. Two stations are presented for each transect (Table 3). The two values represent the minimum and maximum depths computed for each transect. As Table 3 illustrates, the velocities 5, 10 and 20 cm/sec occur proportionally closer to the substrate as flow increases at all stations, but the actual velocity under given depth and flow conditions varies from station to station. And, at some stations, these velocities do not occur under low-flow conditions.

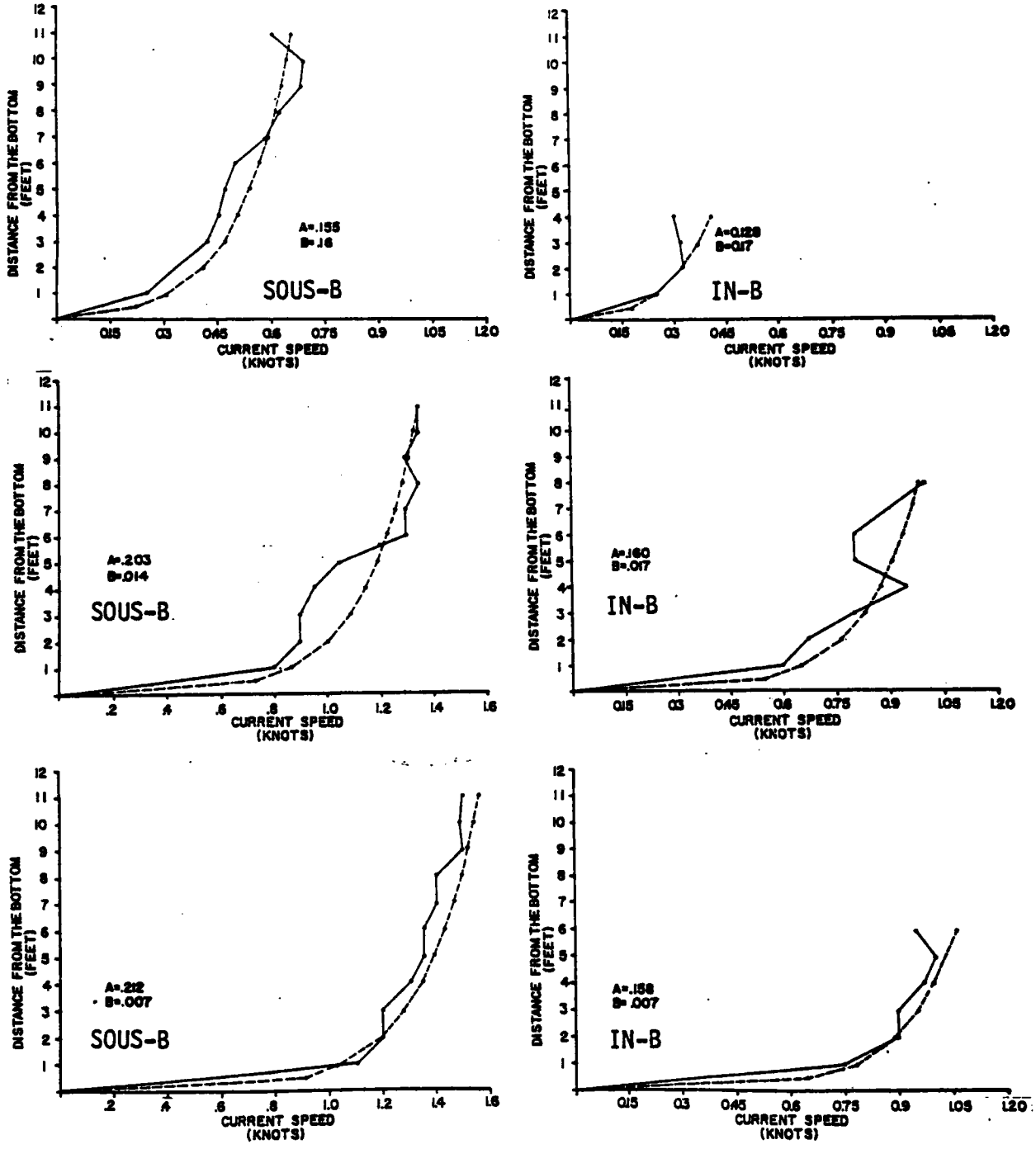


Figure 24. Calculated log profiles vs. actual current at six Hooksett Pond locations. Merrimack River Anadromous Fisheries Investigations, 1976.

TABLE 3. VELOCITY-DEPTH COMPUTATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

STATION	FLOW (CFS)	DEPTH (FT)	AVERAGE VELOCITY (KNOTS)	PARAMETERS		DISTANCE FROM BOTTOM AT WHICH VELOCITY OCCURS FT VELOCITY		
				B (FEET)	A (KNOTS)	5 CM/SEC	10 CM/SEC	20 CM/SEC
SOUN-B	1000	2	0.15	0.21	0.094	0.38	1.44	---
	2500	3	0.47	0.11	0.191	0.073	0.194	0.729
	4000	4	0.73	0.016	0.161	0.013	0.037	0.162
	8000	5	0.92	0.008	0.169	0.006	0.017	0.071
SOUN-A	1000	6	0.17	0.21	0.068	0.664	3.43	---
	2500	7	0.50	0.11	0.155	0.096	0.275	1.23
	4000	8	0.75	0.016	0.143	0.016	0.039	0.176
	8000	9	0.94	0.008	0.156	0.007	0.020	0.088
SOUS-A	1000	9	0.42	0.21	0.146	0.198	0.583	2.78
	2500	10	0.92	0.11	0.258	0.050	0.123	0.385
	4000	10	1.36	0.016	0.250	0.008	0.019	0.060
	8000	10	1.62	0.008	0.264	0.004	0.009	0.027
SOUS-B	1000	10	0.24	0.21	0.081	0.486	2.09	---
	2500	11	0.69	0.11	0.188	0.074	0.199	0.926
	4000	11	1.10	0.016	0.198	0.010	0.027	0.097
	8000	11	1.35	0.008	0.217	0.005	0.012	0.040
IN-B	1000	5	0.21	0.21	0.089	0.414	1.65	---
	2500	5	0.50	0.11	0.171	0.084	0.232	0.954
	4000	6	0.79	0.016	0.160	0.013	0.038	0.165
	8000	7	0.97	0.008	0.167	0.006	0.018	0.074
IN-D	1000	3	0.12	0.21	0.063	0.769	---	---
	2500	3	0.32	0.11	0.130	0.122	0.379	2.07
	4000	4	0.52	0.016	0.107	0.024	0.082	0.585
	8000	5	0.65	0.008	0.119	0.010	0.033	0.201
IO-B	1000	5	0.14	0.21	0.060	0.848	---	---
	2500	6	0.44	0.11	0.142	0.108	0.321	1.58
	4000	7	0.75	0.016	0.123	0.019	0.061	0.359
	8000	8	0.90	0.008	0.152	0.007	0.021	0.095
IO-D	1000	3	0.08	0.21	0.042	1.90	---	---
	2500	3	0.34	0.11	0.138	0.112	0.339	1.72
	4000	4	0.59	0.016	0.130	0.018	0.055	0.300
	8000	5	0.77	0.008	0.141	0.008	0.024	0.117

* Blank indicates velocity not attained anywhere in profile

C. BIOLOGICAL INVESTIGATIONS

Biological investigations conducted during 1975 and 1976 were primarily directed toward two goals: (1) to identify the effects of temperature on the survival of shad eggs and larvae through the use of field and laboratory bioassays; and (2) to document and quantify the behavior of the semi-buoyant shad eggs and the newly hatched larvae under controlled laboratory conditions so that estimates of transport characteristics relative to potential entrainment and thermal shock effects at Merrimack Station could be made.

1. Shad Egg and Larvae Transport and Fall Velocity Studies

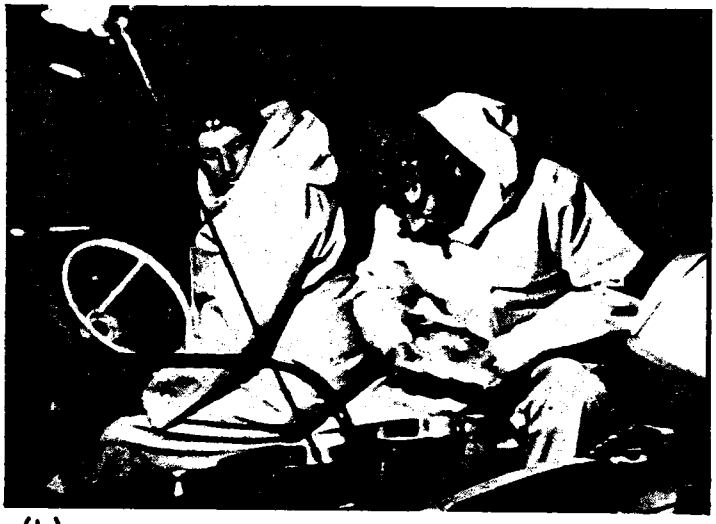
An encapsulation of these studies' results are contained in this section. More detailed data are contained in Appendix D.

a. Methods of Study

1) 1975

Fertilized shad eggs for use in the transport and fall velocity studies were obtained when needed from the Connecticut River, Holyoke, MA. The general procedure, some aspects of which are depicted in Plate 1, was as follows: 100 ft by 8 ft deep floating gill nets composed of 5 inch stretch-mesh monofilament nylon were drift-fished from about 2000 to 2300 hrs. The net was tended constantly, with ripe males and females being ferried to a central location for stripping. Eggs were stripped into stainless steel bowls and fertilized without the addition of water. After the eggs and milt of several males and females had been mixed the fertilized eggs were water-hardened by successive washings with river water (Leach, 1925). After water hardening, approximately 8-16,000 fertilized eggs were measured out volumetrically assuming 875 eggs/liquid ounce (Leach, 1925) and placed in plastic bags

(a)



(b)

(c)

(d)

Plate 1. Some aspects of shad egg procurement, Connecticut River, Holyoke, Massachusetts: (a) removing adult shad from gill net; (b) stripping eggs and milt for fertilization; (c) washing fertilized eggs with river water to water-harden; (d) bagging eggs for shipment. Merrimack River Anadromous Fisheries Investigations, 1976.

containing river water at the rate of approximately 4000 per bag. Oxygen was added to the bags before sealing. The bags were then placed into a portable cooler containing ambient river water for the approximately 2 hr trip to the University of Connecticut Marine Sciences Institute in Groton. Here, the eggs were maintained at ambient temperature in an aerated, thermostatically controlled bath containing dechlorinated tap water. In this bath, the first group of eggs was kept in a floating wooden box with a 571μ nitex mesh bottom. Aerating stones under the box kept the eggs agitated. The second group was divided equally between 2 large bell jars equipped with aerating stones. Half the water in each was replaced daily. In the laboratory, studies of fall velocity and critical velocity of movement were undertaken using fertilized eggs at various developmental stages. Artificial eggs (Stira *et al.*, 1976) were also evaluated for possible future field use in the Merrimack River. Finally, preliminary observations on the behavior of the prolarvae immediately after hatching were made.

a) Fall Velocity

Fall velocities were measured by carefully placing individual fertilized eggs in 1000 ml graduated cylinders and allowing them to reach terminal velocity. The amount of time it took each egg to travel 10 cm was then measured with a stopwatch. The process was repeated several times using developing eggs of varying ages, artificial eggs, and eggs preserved in 5% formalin. Trials were run at 14 and 21°C, which represents the usual shad spawning temperature range (Walburg and Nichols, 1967). No less than 50 measurements were obtained during each set of observations.

b) Transport Characteristics

Critical transport velocities were determined for viable eggs in several stages of development and for artificial eggs using a four-

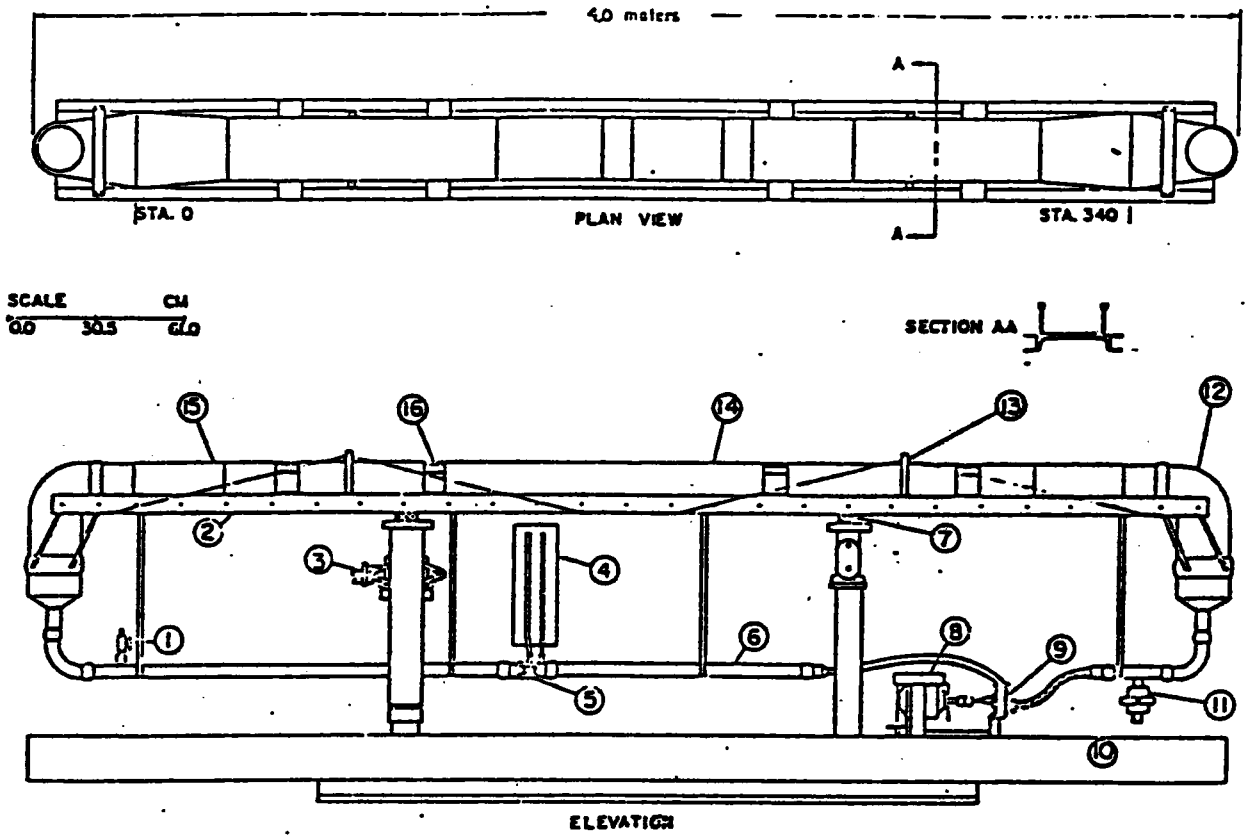
meter tilting-recirculating flume (Figure 25). Measurements were obtained over a plane glass bed and over a bed of sediment similar in character to that observed in the Merrimack River. In each experimental run, the turbulent velocity structure was monitored using hot-wire probes and compared with the field measurements obtained by NAI (p. 35). The comparisons provided a basis for adjustment of the laboratory flows so that experimental conditions remained dynamically similar to the velocity field observed in the Hooksett Pond study area (see Section A). Mean velocity was measured by means of a Venturi flowmeter (Figure 25) and by Rhodamine dye injection prior to each test run.

2) 1976

The primary objective of the 1976 investigation was to determine the behavioral response of viable shad larvae to the range of streamflow/velocity and sediment-water interfacial or substrate conditions characteristic of the Merrimack River. Since successful completion of these preliminary observations necessarily required an available supply of viable larvae, the behavioral studies were supplemented by a series of experiments intended to develop satisfactory laboratory rearing and handling procedures.

a) Egg Culture Procedures

Fertilized shad eggs were obtained and delivered in the same manner as in 1975 and reared in plexiglass hatching jars. These jars and the general culture method are described more fully in a later section. Six jars were employed in a redundant two channel system. Generally, three jars were placed in each channel. Tap water, which had been previously dechlorinated by aging several days, was continuously circulated from a large-volume segmented reservoir through the channels and associated hatching jars. No fungicides or bacterial inhibitors were employed, but complete segregation between channels was maintained at



LEGEND:

1. Drain and filtration trap
2. Aluminum support beam
3. Scissors jack
4. Standing liquid manometer
5. Venturi flowmeter
6. 3.8 cm. return line
7. Resilient shock mounts
8. Dayton 1/2 H.P. Varidrive
9. Labawco centifugal pump
10. Safety catch box
11. Ball type dump
12. Modified 15 cm. glass elbows
13. Adjustable support brace
14. Glass channel test section
15. Convergent entrance and diffuser section
16. Aluminum side supports

Figure 25. Turbulence flume outline drawing. Merrimack River Anadromous Fisheries Investigations, 1976.

all times. Water temperature and ambient light levels were held constant during the incubation period. Lighting was provided by the in-place laboratory fixtures equipped with General Electric F-40-GO gold fluorescent tubes. Water temperatures, maintained constant during each incubation period, were allowed to increase slightly as the study progressed. The initial batch of eggs, delivered on June 1, 1976, was reared at approximately 16°C while the final lot was held at 18.5°C. This increase in rearing temperature was intended to follow ambient water temperature increases at the Connecticut River spawning area and minimize thermal shock effects.

b) Larvae Culture

Following each hatch, the yolk sac larvae were transferred from the hatching jars to one of four 20 gal aquaria. Constant water temperatures were maintained in each of the four rearing aquaria. Temperatures over the study period remained at 19.5°C ± 0.5°C. Light conditions were varied with two aquaria on a diurnal light-dark cycle and two maintained in near total darkness. The source and character of the lighting was the same as that applied to the jar culture setup.

The different illumination levels applied to the rearing aquaria were intended to assess larval photosensitivity and determine the influence of light levels on feeding. Initial observations indicated that larvae favored low light levels and tended to congregate in shadows. It was hypothesized that these conditions represented minimum stress levels and favored feeding habitat. Laboratory conditions were established to begin tests of the accuracy of this hypothesis.

Throughout the rearing period a regular feeding and water quality schedule was maintained. Two basic diets were applied: a natural blend of freshwater plankton, and a commercially prepared food, Tetramin Baby Fish Food E. Freshwater plankton were obtained from a small pond adjacent to Avery Point. Food was presented every three

hours with two tanks (one light cycled, one continuously dark) receiving the plankton and the remaining two the commercial diet. Concurrent water quality observations were obtained to monitor pH and ammonia levels in each tank. These data indicated that maintenance of low ammonia levels (< 500 ppb) required twice daily exchanges of approximately 25% of each tank's volume. This exchange rate was maintained throughout the study period.

As a corollary to this study, the gut contents of larval shad seined from the Connecticut River in Sunderland and Hatfield, MA, were investigated to determine foods consumed under natural conditions. Larvae captured in the field on 23 June 1976 were preserved in buffered 5% formalin, stained with Rose Bengal, and returned to the NAI marine lab in Portsmouth, NH. In the laboratory, specimens were eviscerated and their gut contents identified to the lowest practical taxa and enumerated. For comparison, plankton samples taken from the Avery Point Pond with a No. 20 mesh Nitex plankton net were also analyzed.

c) Shad Egg and Larvae Transport

The behavioral responses of larval shad to varying velocity and substrate conditions were conducted in the 4.0 m tilting recirculating flume (Figure 25) used in the 1975 egg transport studies. A varietal sedimentary bed was placed along the main channel; sediments ranged in texture from medium sands to gravel and were arranged alternately so that an organism moving downstream would be exposed sequentially to each type. The flume was filled with dechlorinated tap water and water temperatures were held equal to those prevailing in the rearing tanks. Light levels were constant for all observations with illumination provided primarily by the in-place laboratory fixtures.

Each series of observations was initiated by manually transferring individual larvae from the rearing tanks to the flume. Initial observations placed primary emphasis on substrate response. Zero velo-

city conditions were maintained. Following the completion of the substrate response observations, a low velocity flow was established in the flume and each organism's ability to and interest in maintaining position was assessed. As a final consideration, some of the fall velocity and transport studies conducted during 1975 were repeated in 1976 for verification.

Plate 2 depicts some aspects of the transport and fall velocity investigations.

b. Results

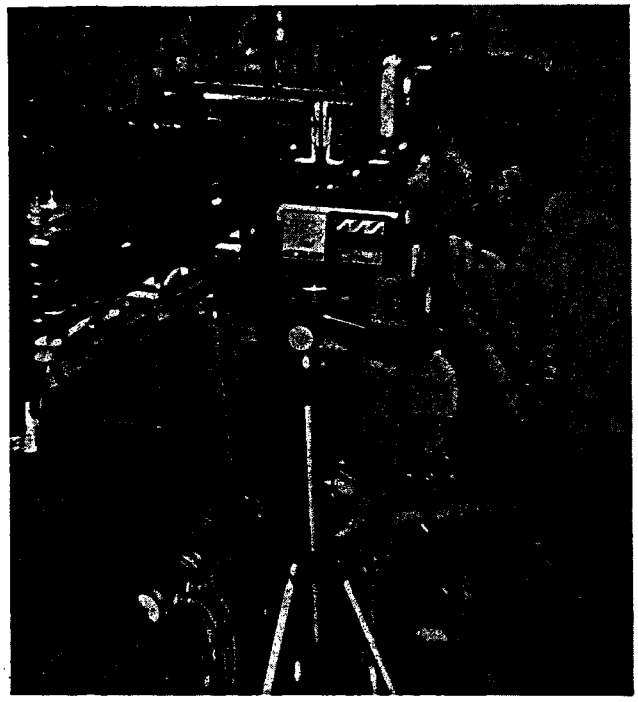
1) 1975

a) Fall Velocity

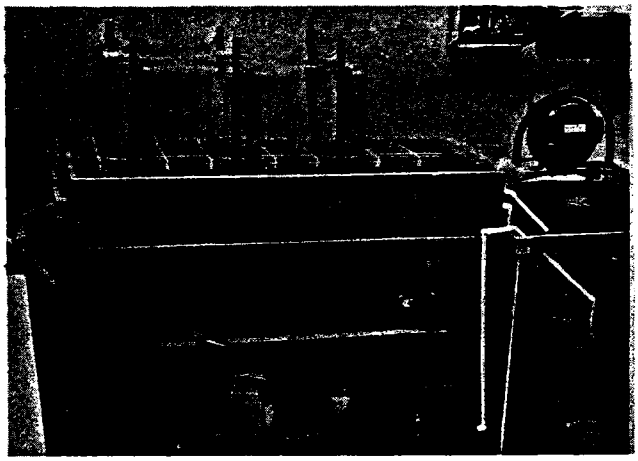
(1) Viable Eggs

Viable shad egg fall velocity in fresh water averaged 1.25 cm/sec (t = 21.0°C). Velocity varied little with the age of the egg; maximum values (1.38 cm/sec) occurred just after fertilization and subsequent water hardening (Figure 26). Velocities decreased uniformly from this value to 1.2 cm/sec approximately 15 hr after fertilization. Subsequent measurements indicated a slow velocity increase to 1.3 cm/sec at 35 hr followed by a general decrease to 1.18 cm/sec just prior to hatching.

Fall velocities varied only slightly in response to variations in water temperature; a 10°C temperature decrease resulted in a 10% fall velocity decrease. These data indicate that under the usual thermal conditions suitable for shad spawning (temperatures ranging between 14°C and 21°C) typical water temperature variation will have no significant effect on transport characteristics.



(a)



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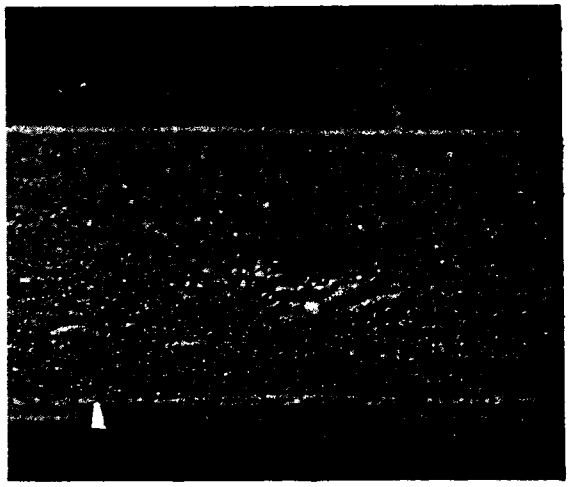


(c)

(d)

Plate 2. Egg transport and larval behavior investigations, University of Connecticut Marine Sciences Center, Avery Point: (a) observing eggs and larvae in test flume; (b) redundant circulating water system with hatching jars; (c) living (clear) and dead (opaque) eggs [mean diameter ≅ 2.5 mm] sheltering in substrate depression under low velocity conditions; (d) living and dead eggs undergoing suspended-load transport under high velocity conditions. Merrimack River Anadromous Fisheries Investigations, 1976.

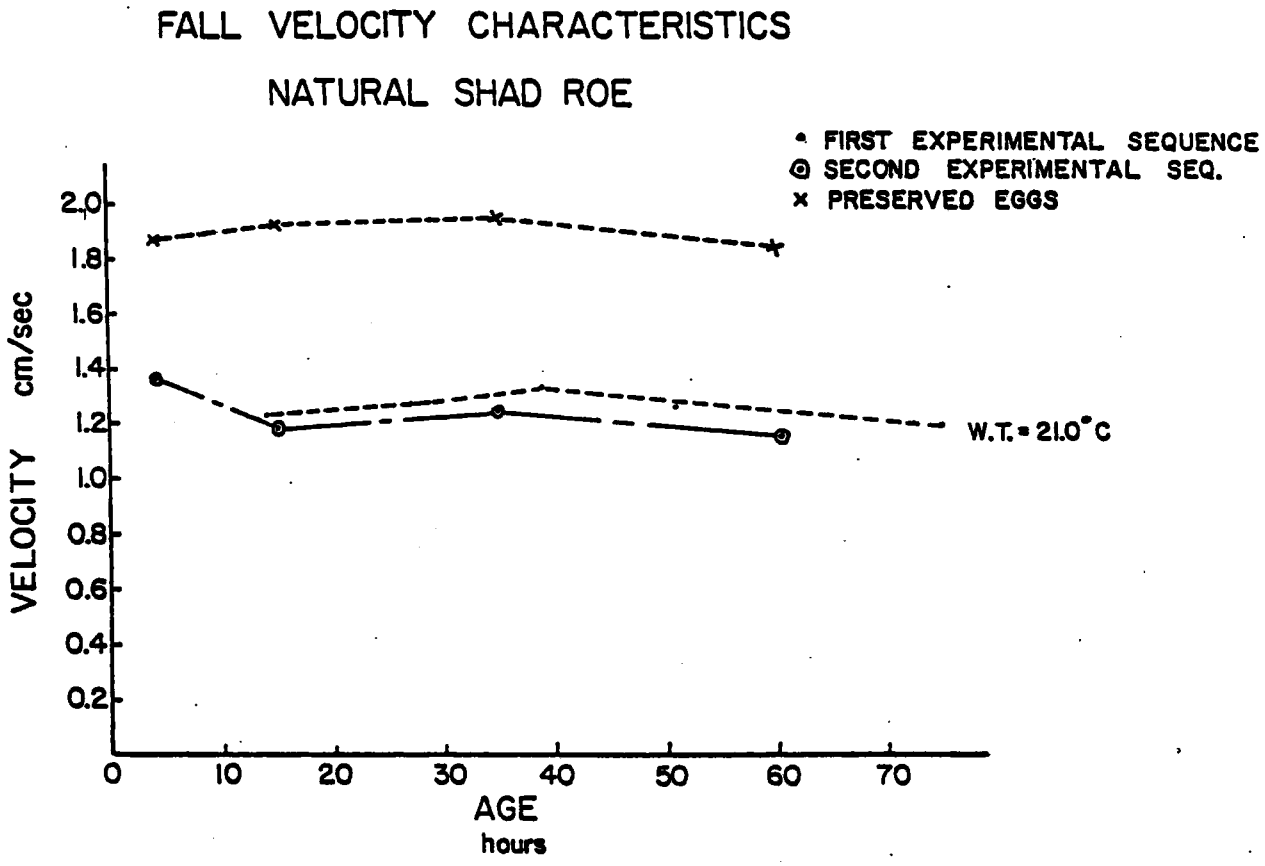


Figure 26. Shad egg fall velocity vs. age. Merrimack River Anadromous Fisheries Investigations, 1976.

(2) Preserved Eggs

The fall velocity of fertilized shad eggs preserved in a 5% formalin solution averaged approximately 1.9 cm/sec. The values were consistently higher than the 1.2 cm/sec reported by Walburg and Nichols (1967) and the $\bar{x}$ = 1.25 cm/sec observed for viable eggs. The application of these values to transport studies therefore requires great interpretive care.

b) Transport Characteristics

(1) Viable Eggs

Laboratory observations indicated that relatively low velocities were required to initiate movement and maintain transport of viable shad eggs. Over a plane glass bed, flow velocities of approximately 3 cm/sec were sufficient to initiate motion. Particles rolled along the bed in a steady uniform progression. The eggs moved individually with no indication of any adhesion or neighbor effects. The character of movement over the bed of sediment was somewhat more complex.

Initiation of motion over a bed of sediment occurred at a velocity of approximately 4-5 cm/sec. In the absence of bed-forms or obstructions movements were similar to those observed over the glass bed with the eggs rolling along the bed in a steady downstream progression. There was no apparent adhesion to the sediment or interaction with neighboring eggs. This bed load phase continued until the velocity reached approximately 10 cm/sec. At this point "hops" or saltations began. Further velocity increases resulted in a transport consisting of both bed load and suspended load components.

The influence of bed-forms along the sediment-water interface on transport conditions varied with the character of the individual

features. Low frequency sediment ripples of small amplitude caused minor variations in transport. Increasing amplitude or frequency favored flow separation on the downstream or lee side of the ripples. When this occurred, eggs tended to collect in these backwater areas. Similar results were observed in depressions or behind obstructions (rocks, debris, etc.) (Plate 2). Laboratory observations indicated that optimum sheltering conditons were realized when the bed features had dimensions on the order of 10 to 100 times the mean diameter of the shad eggs. Significant sheltering, for example, was observed in depressions 4.0 cm in diameter and 1.0 cm in depth and behind long-crested bed-forms 20 cm in wavelength and 2.0 cm high. Significantly larger features tended to permit rapid transit of the eggs or resulted in complete burial due to sidebank instability.

The presence of bedforms suitable for sheltering can significantly alter the downstream flux of eggs. Laboratory observations indicated that velocities sufficient to cause egg movement along the sediment bed (5-10 cm/sec) were generally unable to dislodge sheltered eggs. Removal from shelter under these conditions was typically the result of collisions between intruding and sheltered eggs. Significant removal of eggs from shelter required velocities in excess of 15 cm/sec. Under these conditions the suspended load represented a major component of the total transport and noticeably fewer eggs had the opportunity to find shelter. Some sheltering continued, however, until velocity levels exceeded the critical erosion velocity of the sediment (> 20 cm/sec).

Analysis of all flume data indicated no significant variation in transport characteristics during the development period. The slight variations in fall velocity, noted previously, failed to produce measurable alterations in critical velocity levels.

c) Artificial Eggs

Data concerning the transport characteristics of artificial eggs (Stira *et al.*, 1976) are extremely limited. Three runs with eggs simulating both water-hardened and non-hardened, freshly spawned eggs were attempted. Of the two lots of eggs, the clear "water-hardened" eggs fell at a velocity of 1.1 cm/sec, which was closer to that of the natural eggs (1.25 cm/sec); the green, "non-water hardened" eggs fell at the rate of 1.6 cm/sec. Examination of the artificial egg's transport characteristics in the flume showed that both lots were somewhat adhesive. Following introduction into the flow the clear eggs rapidly acquired a coating of sand grains that effectively limited motion. The green eggs were somewhat less subject to sediment adhesion but were generally found to provide a poor transport analogue of natural shad eggs.

d) Larvae

Cursory observations on the behavior of newly-hatched pro-larvae suggested that they may be somewhat demersal. In the presence of current, the larvae tended to orient themselves in an upstream direction along the bottom and were able to maintain their position in the presence of currents of up to 20 cm/sec (≈ .4 kn).

2) 1976

a) Larval Food Habits

A total of fifteen Connecticut River shad larvae ranging in total length from 8 to 23 mm were examined for food habits. The sizes of the specimens examined and the gut contents of each are contained in Appendix Table D2. In general, younger stages of copepods (copepodites, nauplii) and occasional unicellular green and bluegreen algal cells

dominated the gut contents of those 8-11 mm larvae which had been feeding. However, eight of the 12 larvae analyzed in this size range had guts less than 1/4 full, indicating either sporadic feeding at these young ages or that readily digestable materials, consumed earlier in the day (samples were taken mid-day), had already been digested. The presence of several zooplankton exoskeleta is further evidence of this possibility.

Larger larvae (12-14.5 mm) consumed larger zooplankton stages in addition to the nauplii and copepodites consumed by the smaller larvae. Neither of the two larvae examined had guts less than 1/4 full, and no phytoplankton was present (although it may have been digested).

The largest larvae examined, 23 mm, had been feeding on immature insects up to 4 mm in length and a cladoceran (1 mm TL). Partially digested phytoplankters found in the gut of this specimen (Appendix Table D2) may have been ingested incidentally.

Analysis of Avery Point Pond plankton samples revealed a comparable, but not identical, phytoplankton and zooplankton composition (Appendix Table D3). The desmid *Scenedesmus* and blue-green alga *Anabaena* dominated the phytoplankton; these algae were not present in the gut samples. The diatom *Fragellaria*, present in the gut content samples, was also present in the pond water. Most importantly, the pond water was virtually teeming with copepod nauplii of the same general size as those found in the gut samples. There were also many cladocerans present in the pond water samples. In general, the pond's plankton community probably represented an adequate food source for larval shad. In addition, many of the animals present in the plankton samples were reported by Maxfield (1953) to constitute important larval shad food items.

IV. SUMMARY AND CONCLUSIONS

The restoration of American shad to the New Hampshire portion of the Merrimack River has prompted some concern among state and federal agencies as to the likely negative effects of Merrimack Station on certain of the species' life history phases. As a result, Merrimack Stations's NPDES permit was modified to include a requirement for special studies to assess the likelihood of significant negative interaction between Merrimack Station's once-through cooling system and American shad eggs, larvae, and juveniles. Studies completed to date have (1) delineated current velocities near the plant intakes and discharge and temperature distributions throughout Hooksett Pond; (2) numerically modelled current velocities throughout Hooksett Pond under a range of discharge conditions typical of anticipated spawning season conditions; (3) determined downstream transport characteristics of developing eggs and, to a lesser extent, characterized several aspects of early larval behavior including their apparent ability to withstand downstream transport; (4) determined egg and larvae tolerance to rapid temperature increases through laboratory bioassay, *in situ* bioassay, and literature review; and (5) attempted to synthesize this information into an accurate assessment of potential pump entrainment and thermal shock death for American shad eggs and larvae should the restoration of a spawning adult population to Hooksett Pond eventuate. An attempt to determine the responses of juvenile shad to the discharge using radio telemetry failed when no juveniles could be captured for study.

Based on physical data collected and analyzed as part of this investigation; laboratory observations, and on-going entrainment sampling programs at existing powerplants, the probability of entraining significant numbers of American shad eggs directly in the Merrimack Station cooling water flow 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

significant proportion of total river volume. At discharge levels high enough to effect significant removal of eggs from shelter, the intake's zone of influence, in terms of cross-stream distance and the proportional volume of the cooling water flow are proportionally, very small and, therefore, so is the likelihood of entrainment. The likelihood of significant egg entrainment in the thermal plume is similarly 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 would typically 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. Although data from existing powerplants suggest that larval pump entrainment is not apt to be significant, it cannot be dismissed in its entirety due to the larvae's apparent surface and streamside orientation. Similarly, momentum entrainment may be experienced by larvae undergoing downstream transport. Water temperatures within the thermal plume's warmest areas are generally cooler than the lethal levels determined for larvae, but lethal levels may be approached should unusually warm and dry periods occur during late June-early July.

In conclusion, studies conducted to date have attempted to address the four issues required by Merrimack Stations's NPDES permit. Specifically, (1) river current patterns in the vicinity of the plant have been measured and the likelihood of egg entrainment in the thermal discharge has been determined; (2) the effect of such entrainment for various probable periods of exposure has been determined, noting both lethal and sublethal effects; (3) the condition of juvenile shad hatched (a) within the plume and (b) outside the plume from eggs drifted through the plume was addressed only through the immediate post-hatching stage.

No attempt was made to differentially track survivorship through later stages; and (4) the behavioral patterns of juvenile shad in relation to the thermal plume has not been determined, as noted earlier.

V. ACKNOWLEDGEMENTS

NAI and PSCoNH thank the individuals representing agencies involved in the Merrimack and Connecticut River Anadromous Fish Restoration Programs for their aid in providing eggs for this study. The assistance of Peter Oatis, Massachusetts Division of Fish and Wildlife and Jon Greenwood, New Hampshire Fish and Game Department, is particularly acknowledged. Dr. Roger J. Reed, Massachusetts Cooperative Fishery Unit and Alexis Knight, U. S. Fish and Wildlife Service provided technical assistance. Robert J. Stira, formerly a graduate student at the Massachusetts Cooperative Fishery Research Unit, provided the artificial eggs and Dan LeBlanc, Massachusetts Division of Fish and Game, provided the hatching jars utilized in these investigations. Dr. Reed also made larvae available for study and permitted direct observation of Connecticut River field work.

b) Larval Culture

Culture methods employed in this study resulted in a maximum post-hatching survival of approximately 21 days. Detailed observations indicated that the shad progressed through the yolk sac stage and attained a maximum length of 10-12 mm. Despite this apparent progress in all cases mortality occurred precipitously after 14 to 21 days. Variations in light levels or diet produced no measurable differences in this response. Larvae were examined regularly with the aid of hand lens and dissecting microscope. At no time was food observed in the gut of the larvae despite high aquarium food concentrations. The ultimate cause of this apparent feeding failure and resulting mortality remains uncertain.

c) Transport Observations

(1) Eggs

A limited series of observations were obtained to re-determine the fall velocity and flow entrainment characteristics of developing eggs. The procedures employed were identical to those applied in 1975. Fall velocities of viable eggs averaged 1.2 cm/sec (WT = 19.8 C) and again varied only slightly during the development period. No substantive differences were found between the transport characteristics observed during 1976 and those evaluated in 1975.

(2) Larvae

In all cases observed, viable larval shad displayed an obvious disaffinity for the sediment-water interface. An apparent tactile repulsion was evidenced over all types of sediment tested. Organisms displayed only minor variations in this response as a function of age. One and two day old yolk sac larvae, displaying limited sustained swim-

ming ability, tended to contact the bottom more frequently and swam less predictably than older organisms. The older, stronger larvae simply avoided the bottom and tended to congregate along the walls of the flume and near the surface. This substrate response differs substantially from that observed during the 1975 egg transport studies (p. 65). The greater number of observations recorded during suggests that the newly hatched larvae observed in 1975 were in a severely weakened state and that their behavior was not representative of normal larvae.

When exposed to flow, larval shad generally responded first by aligning themselves parallel to the flow and the longitudinal axis of the channel. The next common response was a general migration towards the low velocity region in the immediate vicinity of the surface. Some organisms appeared to favor the low velocity region adjacent to the walls of the flume. In either of these two positions larvae could maintain position despite relatively high-velocity average flows. Most moved alternately into and out of the low velocity boundary regions. Organisms moving toward the center of the channel were easily entrained and showed only limited ability to withstand even the lowest velocity flows (3 cm/sec) for prolonged periods, but observations indicated that organisms could sustain swimming speeds well above this level for short periods of time. Occasionally an organism would move rapidly upstream against a 3-5 cm/sec flow. This speed was not sustained and eventually the individual would either retreat to a boundary area or be re-entrained and moved downstream. The rates of downstream transport varied widely. Some larvae would be entrained momentarily before retreating back into the low velocity regions. Others would remain within the core of the flow and be transported rapidly downstream.

After the first two days of development observed transport characteristics varied little with age. The limited swimming ability of the early prolarvae caused these individuals to be transported rapidly downstream. Swimming ability developed rapidly however and within one to two days following hatching most larvae were able to seek out and

maintain position within the low velocity regions. Beyond this period, observations over the next 14 days indicated no substantial response alterations to free-stream flow conditions.

2. Field Bioassay

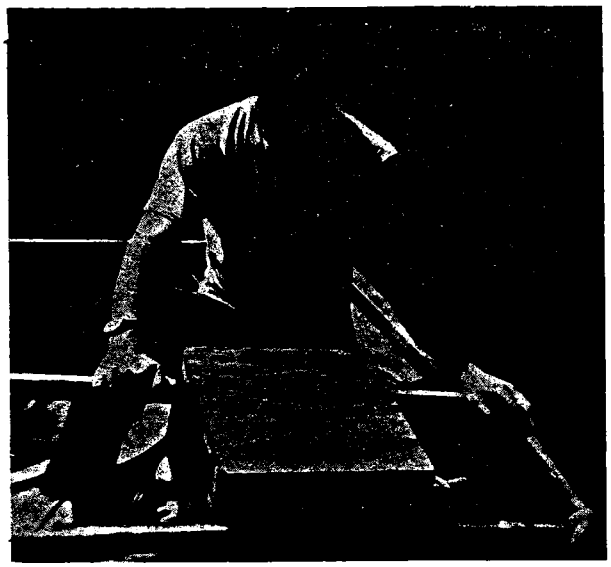
a. Methods of Study

The general procedure was to drift developing shad eggs through the Merrimack Station thermal discharge, anchoring some within the mixing zone and some in the "far-field". Hatching success and survivorship after treatment were compared to "control" eggs which had been moved through a river area not influenced by the thermal discharge. Such parameters as exposure temperatures (both during the drift and throughout the developmental period) and egg density were then used to statistically explain differences noted. Some of the procedures and equipment employed are depicted in Plate 3 a,b.

1) Egg Procurement and Maintenance

a) 1975

Fertilized shad eggs for use in the field bioassays were obtained and transported from the Connecticut River, Holyoke, MA in the same manner as was described for the transport and fall velocity studies (page 53). Upon arriving at the Merrimack River the fertilized eggs were divided approximately equally among 4 floating hatching boxes (Carlson, 1968) located at Station N-10 (Figure 1). Eggs were usually in the river by approximately 0400 of the morning following fertilization. A small sample was usually taken to determine initial fertilization success. As many dead eggs as possible were manually removed from the boxes prior to test initiation. Each group of eggs was im-



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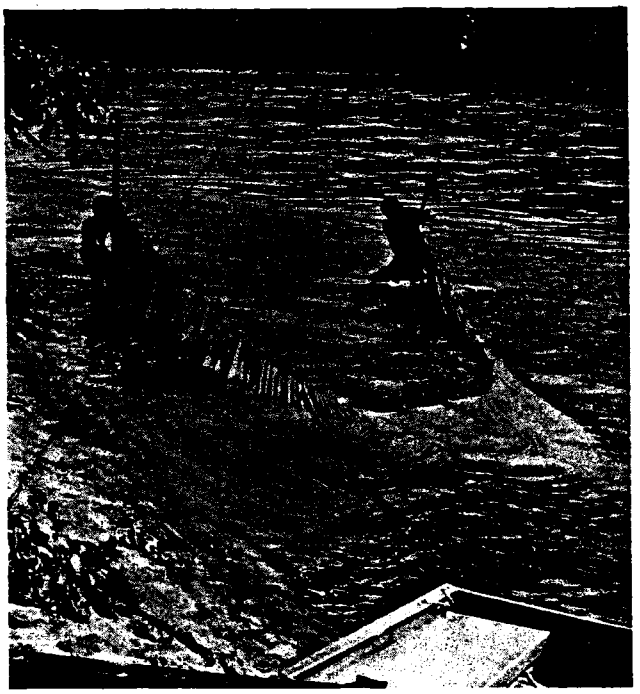

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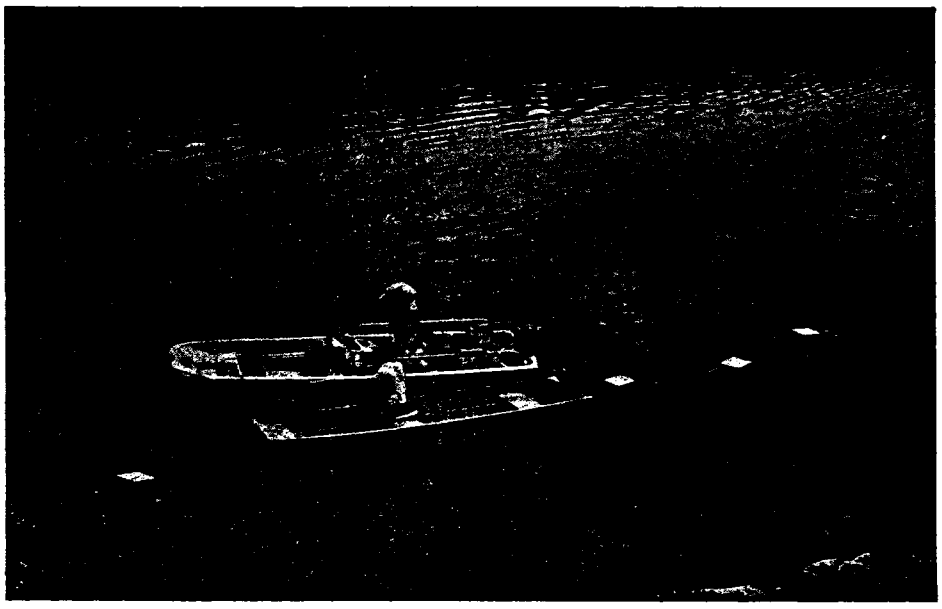
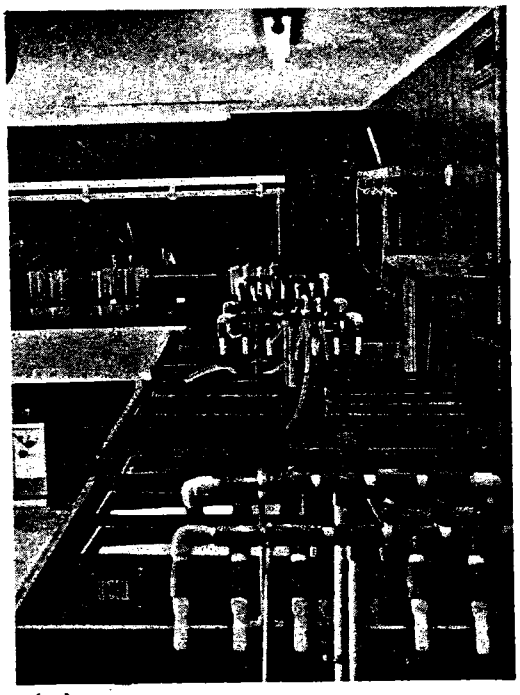


(b)

Plate 3. (a) Hatching box employed in field bioassays. (b) preparing boxes for downstream drift. (c) seining larval shad in a Connecticut River eddy in Hatfield, MA. Merrimack River Anadromous Fisheries Investigations 1976.

(a)



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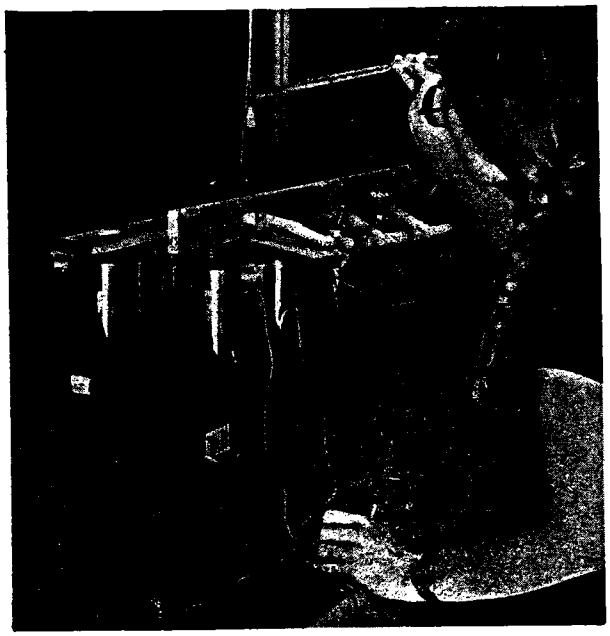


(d)

(c)

Plate 4. Merrimack Station bioassay laboratory: (a) 24-channel printing digital temperature recorder; (b) water baths w/aquaria and, in background, hatching jars; (c) hourly post-thermal shock inspection of baskets for dead eggs and/or larvae; (d) periodic removal of dead eggs from culture jars. Merrimack River Anadromous Fisheries Investigations, 1976.

mersed in dilute malachite green solution as a precaution against fungus at least once before being used in tests.

b) 1976

Egg procurement procedures remained identical for 1976. Stock boxes were maintained at Station N-5 (Figure 1) instead of N-10 to minimize travel time.

2) Continuous Temperature Monitoring

a) 1975

Continuous temperature recorders were maintained at Stations N-10-W, S-4-W and S-17-W (Figure 1) throughout the duration of the field bioassay program. Each recorder consisted of two thermistor probes, moored surface and bottom approximately 75 ft from the west bank, connected to a RUSTRAK 2-channel strip-chart recorder. The recorders were serviced weekly. Strip charts were later interpreted using a Numonics digitizing system. Daily minima, maxima, means and standard deviations were computed.

b) 1976

For 1976, the N-10 recorder was moved to the new control site at Station N-5 (Figure 1). Only surface temperatures were monitored. Computational procedures remained unchanged from 1975.

3) Test Procedures

Data describing the details of each experiment and the test animals used are contained in Tables 4 and 5.

TABLE 4. STARTING DATES FOR THE NINE EGG BATCHES UTILIZED IN THE FIELD BIOASSAY PROGRAM. EGGS WERE FERTILIZED BETWEEN 2100 AND 2400 ON THE EVENINGS INDICATED AT HOLYOKE, MA. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

	MAY				JUNE																	
	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975						1		2		3														
1976		4		5			6	7										8		9				

a) 1975

(1) Series No. 1

The procedure, in general, involved a simulation of eggs drifting at the surface and bottom through the thermal discharge to mixing zone (S-4) and a far-field (S-17) locations. Twelve egg boxes were rigged and weighted in pairs to be moored in duplicate, surface and bottom, at Stations N-10 (control), S-4 and S-17. One pair designated for S-17 was equipped with thermistor probes wired to a boat-mounted RUSTRAK to record the surface and bottom temperatures encountered during the drift. Approximately 35 ml (1000 eggs) of eggs were placed in each of the 12 paired boxes. The boxes designated for S-4 and S-17 were suspended from a 14 ft boat equipped with a 7.5 hp motor and drifted downstream, using the motor at idle for directional guidance, to their designated locations. Upon reaching their respective stations, the boxes (2 pair per station) were anchored near the continuous temperature recorders. Upon completion of the drift series, control boxes

TABLE 5. FIELD BIOASSAY EXPERIMENTS CONDUCTED DURING 1975 AND 1976. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DRIFT NO.	EGG BATCH NO.*	START OF EXPERIMENT			END OF EXPERIMENT		
		DATE	TIME (EDT)	EGG AGE†	DATE	TIME (EDT)	EGG AGE†
1975							
1	1	6-04-75	1145	36	6-06-75	1300	84
2	2	6-06-75	1500	40	6-10-75	1500	136
3	3	6-09-75	1415	88	6-11-75	1415	136
1976							
4	4	6-02-75	1200	86	6-07-76	1430	167
5	4	6-04-76	1100	136	6-07-76	1430	167
	5			86	6-09-76	1030	165
	6			14	6-09-76	1030	142
6	6	6-09-76	1200	135	6-11-76	1400	193
	7			39	6-12-76	1430	97
7	8	6-17-76	0930	61	6-18-76	1500	98

*as defined in Table

†approximate hrs since fertilization

were towed for about 15 min upstream of the plant and returned to the temperature recorder at N-10.

The eggs in this first test series did not hatch on schedule due to a sharp temperature drop during the exposure period. All eggs and larvae were removed from the boxes and preserved in 5% buffered formalin. It was noted at this time that fungus problems were severe in the boxes moored at the bottom.

(2) Series No. 2

Due to the problems experienced with fungus in the Series 1 bottom boxes, all Series 2 boxes were rigged in groups of 4 to be drifted at the surface. Thermistors were attached to two boxes designated for S-17. Approximately 20 ml of eggs (approximately 550 eggs) were placed in each of the 12 boxes. The drift procedure was identical to that employed in Series No. 1 except that two boats were used to allow controls and treatments to be drifted simultaneously. Eggs and larvae were collected and preserved in the same manner as described for Series No. 1.

(3) Series No. 3

The third series was run in the same manner as Series No. 2 except that fewer boxes were used. Eggs were difficult to obtain at this time; the Connecticut River spawning run was nearly completed. Eggs were stocked at a rate of 15-20 ml (400-500 eggs) per box. During the drift phase of this series the "control" pair broke loose from its mooring and entered the area of thermal influence. Since these eggs had come through the plume, they were anchored at Station S-4 as additional treatments rather than being towed back upstream to the control location.

b) 1976

During 1976 four additional drift series using six different egg groups were completed (Tables 4 and 5). The techniques evolved through the third 1975 drift series were employed. Egg boxes were rigged in pairs, dual temperature probes were attached, and the boxes were drifted at the surface to their predesignated locations. Station N-5 (Figure 1) was designated as "control" rather than N-10. The outboard motor at idle was used for directional control when necessary and controls were moved simultaneously using a second boat. Approximately 20 ml of eggs (550 eggs) were used in all tests.

4) Sample Analysis

Each sample was analyzed in its entirety. All eggs and larvae were examined microscopically and enumerated. The following criteria were used in categorization:

a) Larvae

(1) Dead
- (a) Obvious decomposition
- (b) Yolk sac cloudy
- (c) Eyes indistinct or becoming so

(2) Alive
- (a) Smooth, distinct outline without fungus
- (b) Clear yolk sac
- (c) Distinct eyes

(3) Deformed
- (a) Twisted spinal column
- (b) Misshapen yolk sac
- (c) Extremely small specimens

(4) Premature
- (a) Small specimens with abnormally large yolk sacs or incomplete development

b) Eggs

(1) Dead

(a) Decomposition in any state

(b) Broken membrane(s)

(c) Embryo condition, as in larvae (above)

(2) Alive

(a) Intact membranes

(b) No decomposition

(c) Live embryo

5) Data Analysis

The following proportions were analyzed statistically for each of the seven test series:

a) $\frac{\text{Live Eggs}}{\text{Total Eggs}}$ and $\frac{\text{Live Eggs}}{\text{Total Eggs and Larvae}}$

b) $\frac{\text{Live Eggs and Larvae}}{\text{Total Eggs and Larvae}}$

c) $\frac{\text{Total Larvae}}{\text{Total Eggs and Larvae}}$ = "Hatching Success"

d) $\frac{\text{Premature Larvae}}{\text{Total Eggs and Larvae}}$ and $\frac{\text{Premature Larvae}}{\text{Total Larvae}}$

e) $\frac{\text{Live Larvae}}{\text{Total Eggs and Larvae}}$ and $\frac{\text{Live Larvae}}{\text{Total Larvae}}$

f) $\frac{\text{Deformed Larvae}}{\text{Total Eggs and Larvae}}$ and $\frac{\text{Deformed Larvae}}{\text{Total Larvae}}$

g) $\frac{\text{Live Eggs at Start}}{\text{Total Eggs at Start}} - \frac{\text{Live Eggs and Larvae at End}}{\text{Total Eggs and Larvae at End}}$

= "Net Change"*

*1976 only

All of the above proportions were analyzed after angular transformation (to the square root - arcsine scale); (Sokal and Rohlf, 1969). Since there is no IBM Fortran function for arcsine, the angular transformation (x) of each proportion (y) was computed in the following manner:

$$x = \text{arctangent} \left\{ \frac{y}{1-y} \right\}$$ (Eves, 1974)

Analysis of variance (Sokal and Rohlf, 1969) was used to test the significance of observed among-location differences in the transformed 1975 data set. Because the initial number of eggs placed in each box was determined by an approximate (volumetric) method, analysis of covariance (Draper and Smith, 1966) was employed to account for variability introduced from this non-treatment source. Accordingly, the variables "Total Eggs and Larvae", "Total Eggs", and "Total Larvae" were employed as covariates in the 1975 data analysis.

For 1976, transformed proportions from both years' experiments were subjected to multiple regression (Draper and Smith, 1966). Time and temperature data from all seven drift series and the continuous monitors was prepared for graphic presentation. From the time-temperature graphs, base temperature (°F), maximum temperature (°F), Δt (°F), and dose (Δ°F-min) were computed. Dosage was computed in the following manner: the total area under each time (x) - temperature (y) curve between points corresponding to the time of the first rapid temperature increase (discharge) and Stations S-4 and S-17 were computed. From each of these figures, which represent the total degree-minutes encountered from the discharge to the test stations, was subtracted the quantity

(time from discharge to either S-4 or S-17) x (ambient temperature)

in min and °F, respectively. The remainder represents dosage in Δ°F-min and, by inference, control (N-5, N-10) dosage = 0. The variables Δt,

maximum temperature, egg age, and calculated dosage were then used in a stepwise procedure to explain observed survivorship variability. SPSS statistical routines (Kim and Kohout, 1974) available at NAI through Boeing Computer Services, Inc., Waltham, MA were employed for all analysis of variance and multiple regression computations.

b. Results

Survivorship results for all 1975 and 1976 field bioassays are combined as a table of means and standard errors in Table 8a-e. Tests of significance and other results are discussed separately. Note: All computations were performed after transformation to the arcsin scale; transformed means ($\bar{y}$) may be converted back to untransformed proportions ($\bar{x}$) in the following manner:

$$\bar{x} = (\text{sine } \bar{y})^2$$

1) 1975

a) Series No. 1

Drift Series No. 1 results are presented in Figure 27a and in Appendix Table D4. Figure 27a illustrates the thermal history encountered by the eggs during the drifting phase of the study. Eggs in the S-4 and S-17 surface boxes experienced a rapid temperature increase of 15°F (from 65 to 80°F) followed by steady, cooling over approximately 20 min in the travel from Station 0 to S-4. Some variation was then experienced by the surface groups, followed by a period of cooling. The final 50 min of the drift to S-17 exposed eggs in surface boxes to near-continuous +2.5°F (67.5°F) temperatures. Eggs in the bottom boxes were exposed to considerably less temperature variation; bottom temperatures increased gradually from 65° to 67°F between Station 0 and S-17 (Figure

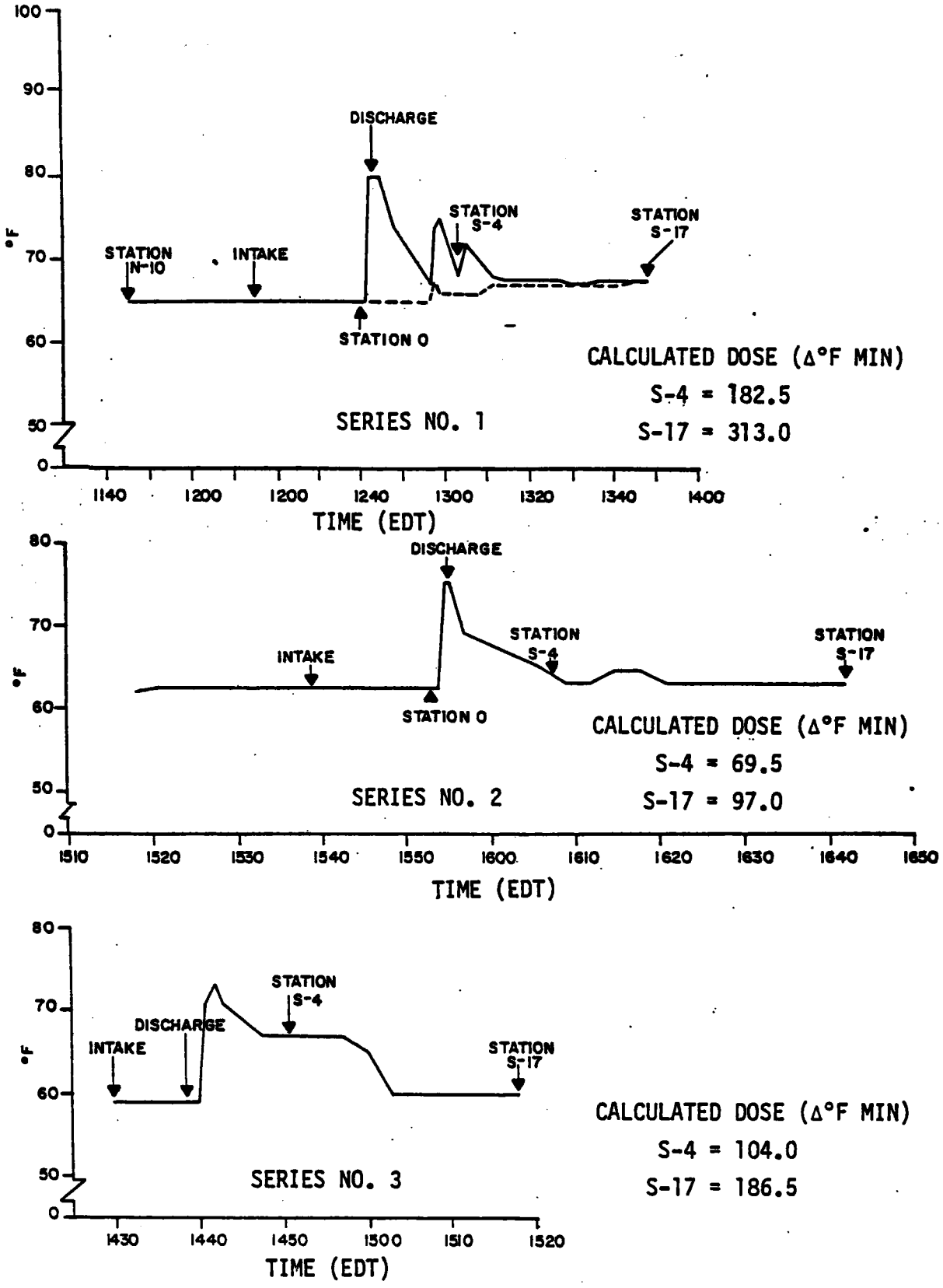


Figure 27. Time-temperature histories experienced by drifting eggs in Series Nos. 1, 2, and 3. Merrimack River Anadromous Fisheries Investigations, 1976.

27a). S-4 and S-17 calculated dosages were 182.8 and 313.0Δ°F-min, respectively.

Temperatures at the 3 mooring stations (N-10, S-4, S-17) during the field bioassays are presented in Figure 28. As stated previously (page 74), surface and bottom ambient temperatures fell and water levels rose (Appendix Figure A2) during Series No. 1. In addition, Unit II went down for maintenance during the experiment (Figure 28). Temperatures below 60°F were recorded consistently toward the end of the experiment, which extended the development period of the eggs considerably and necessitated termination of the experiment before all eggs had hatched.

Surface-bottom temperature differences were most apparent at Station S-4 (Figure 28b); these never exceeded 5°F. Station S-17 was generally isothermal, about 1-2°F warmer than N-10 (Figure 28c).

Statistical analysis of the Series 1 bioassay (Table 6; Appendix Table D4) revealed the following: the covariates Total Eggs and Larvae, Total Eggs, and Total Larvae together were sometimes significant ($p < .05$), indicating that the initial number of eggs per box may have affected survivorship. After correcting for this effect, further analysis revealed significant (p usually < .01) differences in survivorship between surface and bottom boxes, with higher survival at the surface. Similarly, the proportion of premature and deformed (Appendix Table D4) larvae was greater in bottom boxes ($p < .01$). No observed differences between locations were significant ($p > .05$).

Because of the falling water temperatures (Figure 28) and the resultant termination of the experiment before complete hatching had occurred, the proportion of living eggs and larvae (Live Eggs and Larvae/Total Eggs and Larvae) (Table 6) is probably the most representative data from this series. As this table illustrates, the depth effect was highly significant ($p < .001$) whereas the station effect was not ($p > .05$). The 2-way interaction was also not significant ($p > .05$); how-

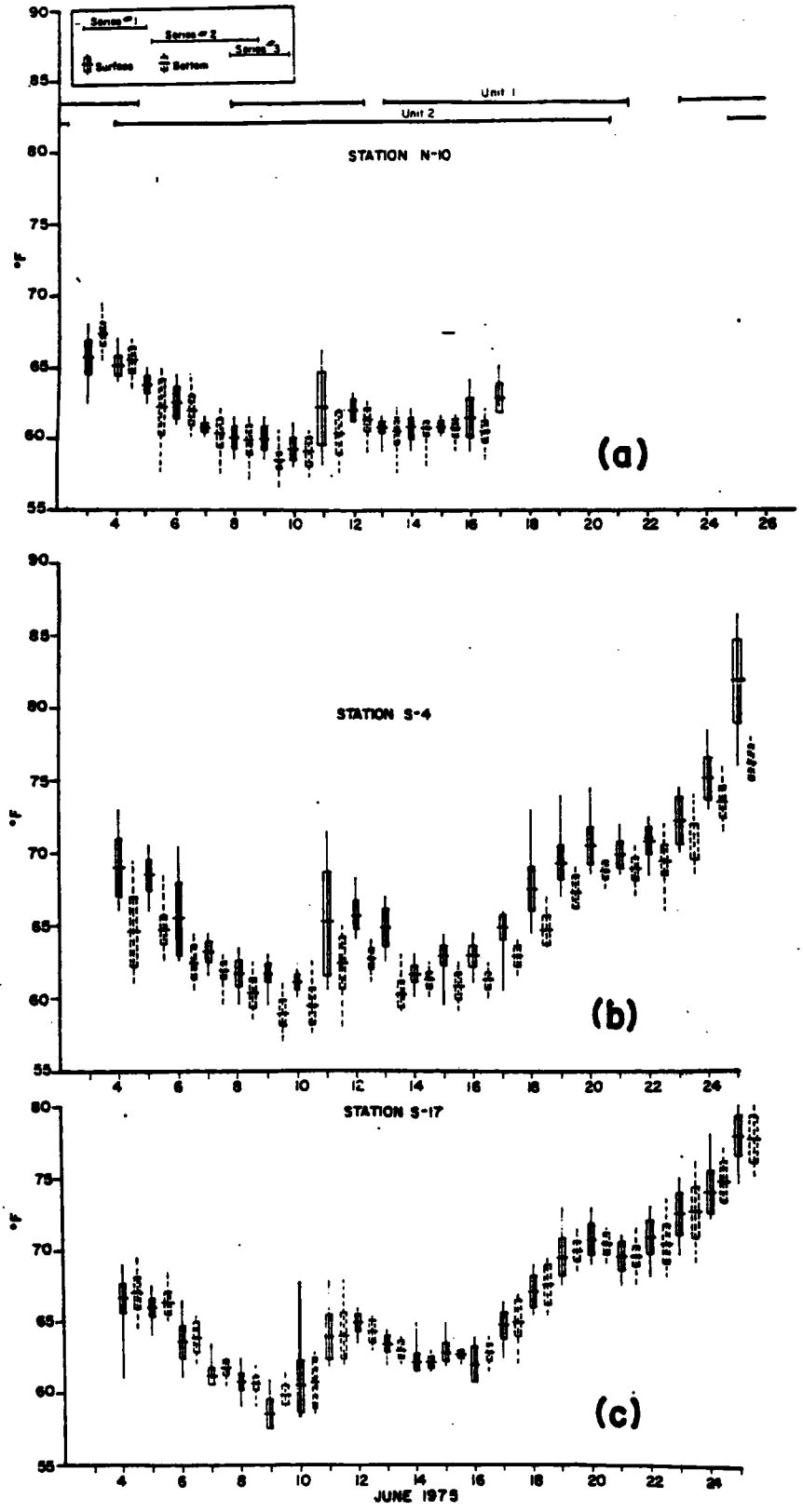


Figure 28. Daily means, ranges, and standard deviations of N-10, S-4, and S-17 surface and bottom temperatures during June, 1975. Data based on continuous monitor records. Duration of Bioassay Series 1-3 and Merrimack Station on-line status are also indicated. Merrimack River Anadromous Fisheries Investigations, 1976.

TABLE 6. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Live eggs and larvae)}}{\text{(Total eggs and larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.034	2.897	NS
Total eggs and larvae	1	0.043	3.672	NS
Total eggs	1	0.040	3.395	NS
Total larvae	1	0.049	4.199	NS
Main Effects	3	0.246	20.885	0.05
Station	2	0.025	2.104	NS
Depth	1	0.719	61.041	0.001
Interactions	2	0.045	3.861	NS
Station x Depth	2	0.045	3.861	NS
Explained	8	0.116	9.884	0.05
Residual	6	0.012	---	---
Total	14	0.072	---	---

Multiple Classifications; Grand Mean = 0.66

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.05	0.00
S-4	4	0.05	0.10
S-17	4	-0.13	-0.09
Depth			
Surface	9	0.18	0.19
Bottom	6	-0.27	-0.29
Multiple R^2	---	---	0.839
Multiple R	---	---	0.916

ever, its magnitude relative to the depth effect was small. In general, the factors analyzed accounted for greater than 90% of the data's variability.

b) Series No. 2 and 3

Figure 27b and c illustrates the temperatures encountered by the developing eggs of Series 2 and 3. As in Series No. 1, the greatest temperature rise experienced was less than 15°F to a maximum temperature of 75°F. Calculated S-4 dosages were 69.5 and 104.0Δ°F-min and S-17 dosages 97.0 and 186.5Δ°F-min in Series 2 and 3, respectively. One-way analysis of variance was performed on these data; the small number of observations precluded the use of the covariance analyses used for Series No. 1. As a result, the analyses accounted for only 2 to 52% of the data's variability (Table 7). Main effects (stations) were not significant for any dependent variable tested in either series.

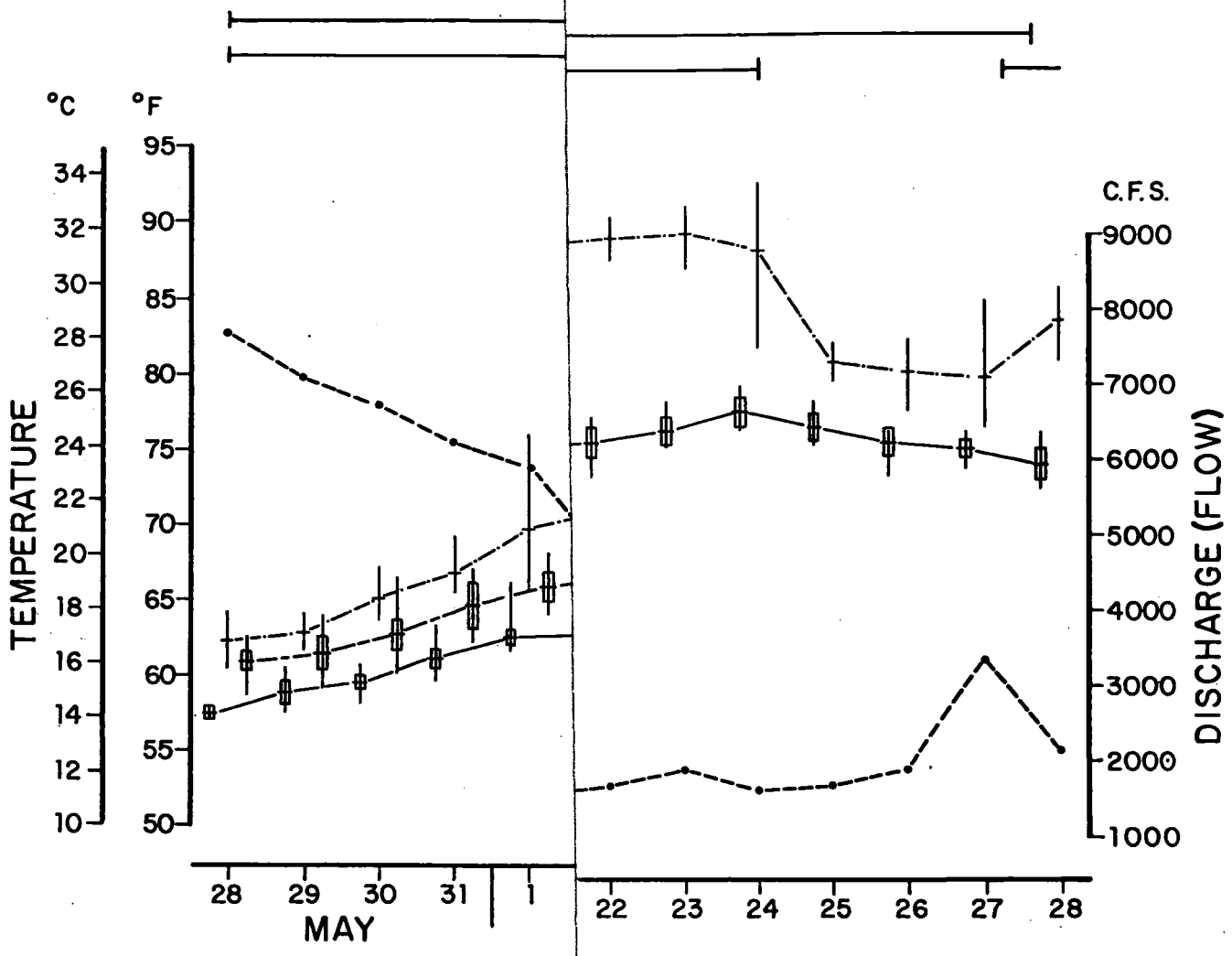
2) 1976

Ambient temperature, discharge, and plant operating status for the periods corresponding to the 1976 drift bioassays are displayed in Figure 29. As this figure illustrates, flow was declining and temperature rising throughout the experimental period. Temperature differences among stations relative to plant on-line status were highly apparent, especially when discharge was low (note S-4 temperature change from 23-28 June relative to Unit 2 status). An equipment failure ended S-17 data output on 12 June. Finally, as in 1975 (Figure 28), Unit II went down for maintenance during an important period in the experiments (4-11 June; Figure 30); only Series 7 was run with Unit II operational for its entirety.

TABLE 7. TABLE OF MEANS, DEVIATIONS, AND COEFFICIENTS OF VARIATION, FIELD BIOASSAY SERIES #2 AND #3. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

VARIABLE	RUN NO. 2 (N = 13)					RUN NO. 3 (N = 6)				
	GRAND MEAN	DEVIATION FROM GRAND MEAN			R^2	GRAND MEAN	DEVIATION FROM GRAND MEAN			R^2
		N-10	S-4	S-17			N-10	S-4	S-17	
Deformed Larvae / Total Larvae	0.03	0.03	-0.03	-0.01	0.185	0.13	-0.04	-0.01	-0.05	0.324
Deformed Larvae / Total Eggs & Larvae	0.01	0.01	-0.01	0.00	0.135	0.06	-0.02	0.00	0.02	0.293
Live Eggs & Larvae / Total Eggs & Larvae	0.29	-0.10	0.12	0.01	0.227	0.42	-0.02	0.00	0.02	0.084
Live Eggs / Total Eggs & Larvae	0.03	0.02	-0.03	0.02	0.228	0.21	-0.11	0.03	0.08	0.520
Live Eggs / Total Eggs	0.04	0.02	-0.04	0.02	0.220	0.24	-0.12	0.04	0.08	0.478
Total Larvae / Total Eggs & Larvae (Hatching success)	0.37	-0.13	0.16	0.01	0.320	0.48	0.02	0.03	-0.04	0.307
Live Larvae / Total Larvae	0.23	-0.01	0.01	0.00	0.034	0.26	0.00	-0.01	0.01	0.135
Live Larvae / Total Eggs & Larvae	0.28	-0.11	0.13	0.01	0.253	0.38	0.00	0.01	-0.01	0.23

Note: data have been transformed using Angular Transformation (Sokal and Rohlf, 1969). See text p. 77 for explanation



ns and ranges for stations N-5, S-4, and
tor records (standard deviations indicated
June, 1976. Mean daily Garvin's Falls
ay Series Nos. 4-7, and Merrimack Station
ted. Merrimack River Anadromous
6.

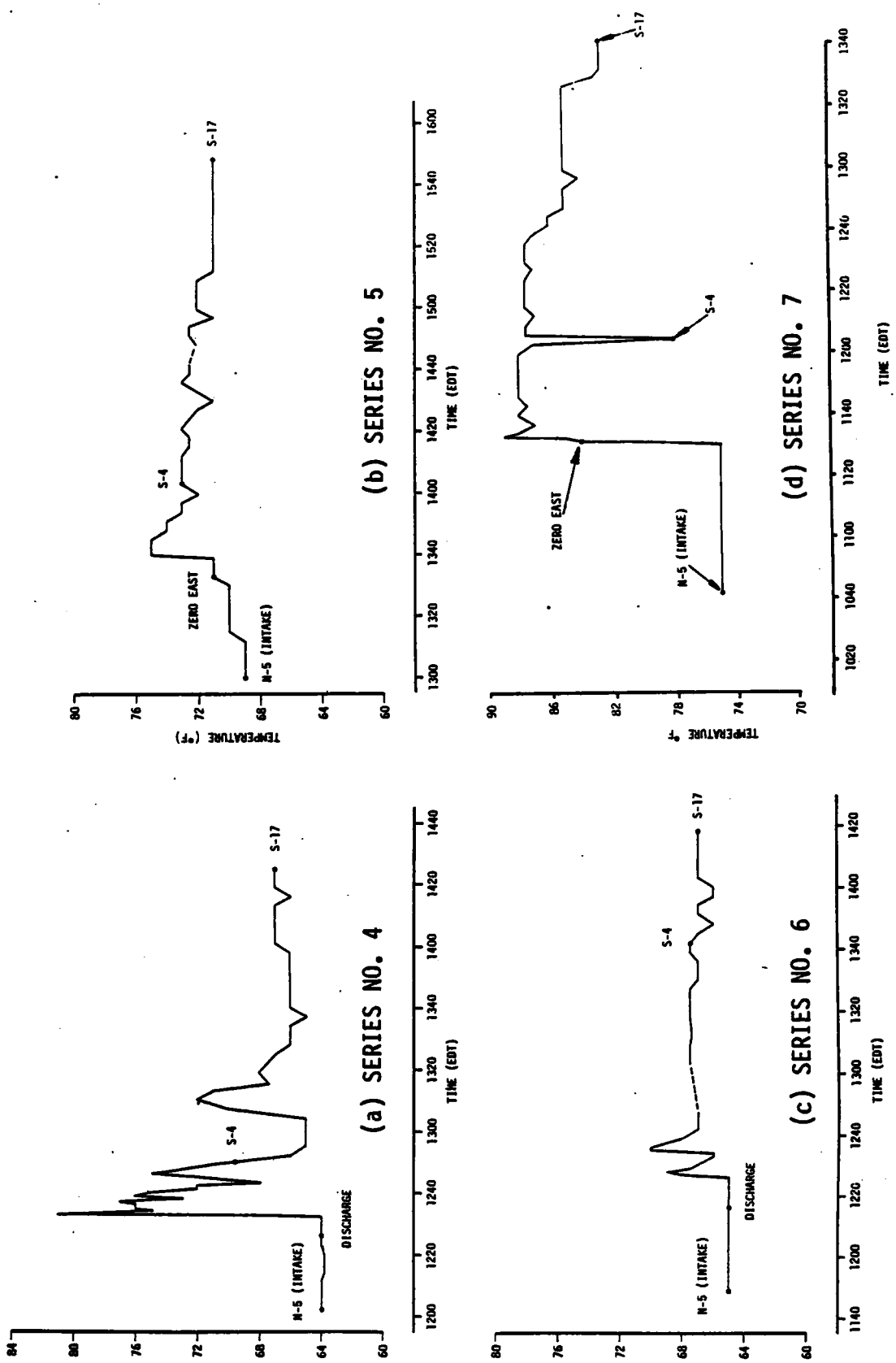


Figure 30. Time-temperature histories experienced by drifting eggs in Series Nos. 4-7. Merrimack River Anadromous Fisheries Investigations, 1976.

Results of physical measurements for each drift series are described in the next four paragraphs. All 1976 biological results are discussed together.

a) Series No. 4

Figure 30a illustrates the time-temperature conditions experienced by the Series 4 86-hr old eggs. Upon reaching the discharge, the eggs experienced a rapid 19°F increase from 64 to 83°F. This was followed by a 20-30 min cooling to 69°F in the transit to S-4. Eggs drifted to S-17 from S-4 experienced erratic temperature changes of up to ±5°F over a period of about 1 hr. They were moored at S-17 about 2 hr after being moved from N-5, and the final temperature was 66°F (+2°F). S-4 and S-17 calculated dosages were 178.0 and 36.1.0Δ°F-min, respectively.

b) Series No. 5

Because only Unit 1 was operating at the start of this experiment (Figure 29), the 136, 86 and 14 hr-old eggs used in this experiment experienced relatively minor temperature shock when compared to other series (Figure 30b). Temperatures increased from 65 to 69°F at the discharge. This increase was followed by a 5 min cooling to 66°F, another rapid temperature increase to 71°F, and a subsequent 5 min cooling to 67°F. Temperature then increased steadily from 67 to 68°F in the approximately 1 hr it took to reach S-4. Temperature then fluctuated ±1°F during the 40 min it took to drift from S-4 to S-17. Final S-17 temperature was 67°F (+2°F) and calculated S-4 and S-17 dosages were 184.0 and 246.0 Δ°F-min, respectively.

c) Series No. 6

As was the case for Series 5, Unit II was not operational at the start of this experiment (Figure 29). The 135 and 39 hr old eggs experienced a gradual temperature increase from 69 to 71°F during the 40 min it took to travel from N-5 to the discharge (Figure 30c). The temperature then increased rapidly from 69 to 75°F at the discharge and cooled gradually to 73°F over the 40 min drift to S-4. The drift from S-4 to S-17 took approximately 1 hr 40 min, and temperatures varied ±2°F. Final S-17 temperature was 71°F (+2°F), and computed dosages were 144.7 and 441.7 Δ°F-min at S-4 and S-17, respectively.

d) Series No. 7

The 61 hr old eggs used in this experiment were subjected to the most severe thermal conditions experienced by any test group (Figure 30d). Temperature was constant at 77°F during the 50 min drift from N-5 to the intake; it then rose almost instantaneously to 93°F, a change of +16°F. Temperature was then relatively constant at 92 ± 1°F for the 30 min drift from the discharge to S-4. At S-4 the temperature dropped sharply to 79°F; apparently the discharge was confined to the central and eastern portion of the channel at S-4, leaving the recorder and mooring station considerably less affected. After mooring at S4, the eggs moved further downstream experienced another rapid increase from 79 to 92°F. Gradual cooling from S-4 to the final 87°F (Δt = 10°F) S-17 temperature took place over a period of 35 min. Calculated dosages at S-4 and S-17 were 420.0 and 1444.5 Δ°F-min, respectively, the highest of any drift experiment.

e) Biological Findings

Biological data from all seven 1975 and 1976 drift bioassays are presented as a table of means and standard errors (Table 8a-e).

TABLE 8a . MEAN AND STANDARD ERROR[+] OF TRANSFORMED PROPORTION OF SUCCESSFULLY HATCHING EGGS AT THREE DRIFT STATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		STATIONS			
DRIFT	BATCH	N-10	S-4	S-17	ALL
1	1	0.495(0.051)	0.658(0.056)	0.689(0.012)	0.614(0.043)
2	2	0.170(0.037)	0.524(0.138)	0.386(0.078)	0.360(0.066)
3	3	--[*] --	0.499(0.030)	0.433(0.056)	0.477(0.195)
4	4	0.902(0.308)	1.125(0.193)	1.210(-0-)	1.053(0.131)
5	4	0.697 (-0-)	0.948(-0-)	-- --	0.822(0.126)
	5	1.278 (-0-)	1.412(0.159)	1.166(-0-)	1.317(0.088)
	6	0.785 (-0-)	1.084(-0-)	0.932(-0-)	0.934(0.086)
	All	0.920(0.181)	1.214(0.134)	1.049(0.117)	1.079(0.091)
6	6	1.181(-0-)	1.339(-0-)	1.165(-0-)	1.229(0.055)
	7	1.044(-0-)	1.177(-0-)	1.054(-0-)	1.092(0.043)
	All	1.113(0.068)	1.258(0.081)	1.110(0.056)	1.160(0.044)
7	8	1.038(-0-)	0.721(-0-)	0.962(-0-)	0.907(0.095)
	9	0.200(-0-)	0.353(-0-)	0.043(-0-)	0.232(0.063)
	All	0.619(0.419)	0.537(0.184)	0.552(0.410)	0.569(0.159)
All	All	0.647(0.109)	0.805(0.085)	0.695(0.094)	0.725(0.055)

[+] -0- denotes 1 observation; standard error is not calculated.

[*] -- signifies no observations

TABLE 8b. MEAN AND STANDARD ERROR[+] OF TRANSFORMED PROPORTION OF LIVE EGGS AT THREE DRIFT STATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		STATIONS			
DRIFT	BATCH	N-10	S-4	S-17	ALL
1	1	0.948(0.018)	0.660(0.125)	0.436(0.242)	0.681(0.109)
2	2	0.031(0.022)	0.000(0.000)	0.055(0.032)	0.047(0.014)
3	3	--[*] --	0.144(0.024)	0.327(0.023)	0.205(0.042)
4	4	0.165(0.166)	0.000(0.000)	0.201 (-0-)	0.106(0.068)
5	4	0.322 (-0-)	0.000 (-0-)	-- --	0.161(0.161)
	5	0.000 (-0-)	0.000 (-0-)	0.000 (-0-)	0.000(0.000)
	6	0.000 (-0-)	0.000 (-0-)	0.000 (-0-)	0.000(0.000)
	All	0.107(0.108)	0.000 (-0-)	0.000 (-0-)	0.036(0.036)
6	6	0.000 (-0-)	0.524 (-0-)	0.000 (-0-)	0.175(0.174)
	7	1.183 (-0-)	0.000 (-0-)	0.464 (-0-)	0.549(0.344)
	All	0.592(0.592)	0.262(0.262)	0.262(0.232)	0.362(0.192)
7	8	0.000 (-0-)	0.000 (-0-)	0.000 (-0-)	0.000(0.000)
	9	0.937 (-0-)	0.295 (-0-)	0.606 (-0-)	0.613(0.185)
	All	0.469(0.469)	0.148(0.148)	0.303(0.303)	0.306(0.160)
All	All	0.319(0.115)	0.136(0.051)	0.201(0.058)	0.211(0.044)

[*] -- signifies no observation

[+] -0- denotes 1 observation, so standard error is not calculated.

TABLE 8c. MEAN AND STANDARD ERROR[+] OF TRANSFORMED PROPORTION OF LIVE LARVAE AT THREE DRIFT STATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		STATIONS			
DRIFT	BATCH	N-10	S-4	S-17	ALL
1	1	1.219(0.008)	1.203(0.008)	1.154(0.116)	1.192(0.032)
2	2	0.750(0.059)	0.890(0.108)	0.809(0.151)	0.816(0.061)
3	3	--[*] --	0.921(0.041)	1.061(0.219)	0.967(0.069)
4	4	0.429(0.100)	0.474(0.084)	0.629(-0-)	0.487(0.056)
5	4	0.388(-0-)	0.000(-0-)	-- --	0.194(0.194)
	5	0.740(-0-)	0.731(0.078)	0.541(-0-)	0.686(0.058)
	6	1.013(-0-)	0.909(-0-)	0.646(-0-)	0.856(0.109)
	All	0.714(0.182)	0.409(0.204)	0.593(0.052)	0.633(0.101)
6	6	0.294(-0-)	0.421(-0-)	0.330(-0-)	0.348(0.037)
	7	1.203(-0-)	0.837(-0-)	1.390(-0-)	1.144(0.162)
	All	0.749(0.455)	0.629(0.209)	0.860(0.530)	0.746(0.193)
7	8	0.826(-0-)	0.394(-0-)	0.000(-0-)	0.407(0.238)
	9	1.047(-0-)	0.000(-0-)	0.000(-0-)	0.349(0.349)
	All	0.937(0.110)	0.197(0.197)	0.000(-0-)	0.378(0.190)
All	All	0.787(0.082)	0.731(0.078)	0.747(0.114)	0.753(0.051)

[+] -0- denotes 1 observation; so the standard error is not calculated

[*] -- signifies no observation

TABLE 8d. MEAN AND STANDARD ERROR[+] OF TRANSFORMED PROPORTION OF TOTAL LIVE EGGS AND LARVAE AT THREE DRIFT STATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		STATIONS			
DRIFT	BATCH	N-10	S-4	S-17	ALL
1	1	0.038(0.003)	0.041(0.003)	0.029(0.002)	0.036(0.002)
2	2	0.023(0.002)	0.050(0.020)	0.038(0.007)	0.037(0.007)
3	3	--[*] --	0.040(0.004)	0.048(0.006)	0.043(0.003)
4	4	0.037(0.011)	0.028(0.002)	0.044(-0-)	0.035(0.005)
5	4	0.120(-0-)	0.000(-0-)	-- --	0.060(0.060)
	5	0.138(-0-)	0.122(0.037)	0.068(-0-)	0.112(0.022)
	6	0.069(-0-)	0.065(-0-)	0.045(-0-)	0.060(0.008)
	All	0.109(0.021)	0.077(0.032)	0.056(0.011)	0.083(0.016)
6	6	0.028(-0-)	0.074(-0-)	0.048(-0-)	0.050(0.013)
	7	0.145(-0-)	0.128(-0-)	0.170(-0-)	0.147(0.012)
	All	0.086(0.059)	0.010(0.027)	0.109(0.061)	0.099(0.023)
7	8	0.055(-0-)	0.043(-0-)	0.000(-0-)	0.033(0.017)
	9	0.118(-0-)	0.036(-0-)	0.047(-0-)	0.067(0.026)
	All	0.086(0.032)	0.040(0.004)	0.023(0.023)	0.050(0.016)
All	All	0.061(0.012)	0.054(0.009)	0.049(0.010)	0.055(0.006)

[+] -0- denotes 1 observation, so standard error is not calculated

[*] -- signifies no observation

TABLE 8e. MEAN AND STANDARD ERROR[+] OF TRANSFORMED CHANGE IN THE PROPORTION OF TOTAL LIVE EGGS AND LARVAE BEFORE AND AFTER EACH DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		STATIONS			
DRIFT	BATCH	N-10	S-4	S-17	ALL
1	1	0.503(0.001)	0.503(0.001)	0.503(0.000)	0.503(0.000)
2	2	0.458 (0.000)	0.456(0.002)	0.457 (0.000)	0.457(0.001)
3	3	--[*] --	0.503 (0.000)	0.502 (0.000)	0.503(0.000)
4	4	0.527(0.001)	0.527(0.001)	0.527 (-0-)	0.527(0.000)
5	4	0.527 (-0-)	0.528 (-0-)	-- --	0.526(0.002)
	5	0.555 (-0-)	0.556(0.002)	0.558 (-0-)	0.556(0.001)
	6	0.523 (-0-)	0.523 (-0-)	0.524 (-0-)	0.523(0.001)
	All	0.534(0.010)	0.541(0.009)	0.541(0.018)	0.538(0.006)
6	6	0.547 (-0-)	0.546 (-0-)	0.546 (-0-)	0.546(0.001)
	7	0.600 (-0-)	0.601 (-0-)	0.599 (-0-)	0.600(0.001)
	All	0.573(0.027)	0.573(0.028)	0.573(0.026)	0.573(0.012)
7	8	0.586 (-0-)	0.586 (-0-)	0.587 (-0-)	0.586(0.001)
	9	0.118 (-0-)	0.036 (-0-)	0.047 (-0-)	0.067(0.026)
	All	0.352(0.234)	0.311(0.275)	0.317(0.270)	0.327(0.117)
All	All	0.490(0.029)	0.491(0.026)	0.482(0.033)	0.488(0.016)

[+] -0- denotes 1 observation, so standard error is not calculated

[*] -- signifies no observation

Regression results are contained in Table 9 (all batches) and Appendix Table D5 (each batch separately).

Batch-by-batch stepwise regression analyses (Appendix Table D5) revealed few statistically significant relationships and there were no obvious trends. Of the 35 relationships computed only the following were significant ($p < .05$), with the sign (±) of the independent variables indicating direction of effect:

BATCH	DEPENDENT VARIABLE	INDEPENDENT VARIABLES IN RELATIONSHIP
1	Hatching success	calculated dose (+)
1	Proportion of live eggs	calculated dose (-)
3	Proportion of live eggs	calculated dose (+)
6	Net change in proportion of live eggs and larvae	age (+), calculated dose (+)

Generally, the number of observations within each batch was insufficient to detect significant relationships. For this reason, the data were pooled to compute the relationship presented in Tables 8a-e and 9. Hatching success variability (Table 8a; Table 9, line a) among all experiments was explained by age, Δt, and maximum exposure temperature, in order of importance ($R^2 = .408$). Age and maximum temperature had a positive effect on hatching success, with only Δt exerting a negative effect. The net result was that in all cases except one hatching success was greatest at Station S-4, the warmest station, than at either S-17 or N-5/10, the control locations (Table 8a). The exception was Batch 8, Drift 7; however, analysis of the Batch 8 data alone revealed no significant relationships between hatching success and any of the temperature-related variables tested, as discussed previously (Appendix Table D5).

Variability in the proportion of the live eggs remaining at the experiment's end (Table 8b, Table 9, line b) was not significantly explained by any of the variables tested ($p > .05$; $R^2 = .136$). Variability in this dependent variable was higher than in others examined, as revealed by the standard errors in Table 8b.

TABLE 9. RESULTS OF STEPWISE REGRESSIONS FOR ALL DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT + V_1 + V_2 + V_3 + V_4	MULTIPLE R	f
Proportion Hatching	-0.61532 + 0.00480 age + -0.05300 Δt + 0.02149 Tmax + ---*	0.639	10.60***
Proportion of Live Eggs	-1.20548 + 0.02059 Tmax + -0.00132 age + -0.00017 dose + -0.00458 Δt	0.369	1.77ns
Proportion of live Larvae	2.80478 + -0.00041 dose + -0.00487 age + -0.02559 Tmax + 0.02510 Δt	0.669	9.09***
Proportion of Live Eggs and Larvae	-0.01064 + -0.00685 t + -0.00201 Tmax + -0.00003 dose + -0.00010 age	0.586	5.88***
Net Change in Proportion of Live Eggs and Larvae	0.87381 + -0.00569 Tmax + 0.00108 age + -0.00004 dose + -0.00070 Δt	0.549	4.85**

*only three variables selected

Variability in the living proportion of larvae present in the boxes at the experiment's end (Table 8c; Table 9, line c) was significantly explained by calculated dose, age at time of temperature shock, maximum exposure temperature, and Δt, in order of importance (R^2 = .448). Dose and age had negative effects, but the magnitude of their coefficients is small; maximum exposure temperature and Δt exerted negative and positive influences of about the same magnitude, respectively (Table 9, line c). The data for Experiment 7 in Tables 8c and 9, line c suggest that the proportion of larvae alive in the boxes after hatching (post-hatching survival) may be negatively affected by exposure to elevated temperatures, especially if the exposure occurs near hatching time.

Variability in the proportion of eggs and larvae alive the end of the experiments was significantly explained by Δt, maximum exposure temperature, calculated dose, and age, in order of importance (Table 8d, Table 9, line d). Although significant ($p < .001$), this relationship did not explain as much total variability as the earlier regressions (R^2 = .343). Generalizations based on this level of confidence are not warranted.

The net change in the proportion of living organisms between the start and end of the experiments (Table 8e; Table 9, line e) must be viewed in reverse when compared to the other dependent variables tested; a positive effect on net change infers decreased survivorship, and a negative effect indicates higher survival. Regression results indicate a significant negative effect due to maximum exposure temperature, a slight negative response to calculated dose, and a slight positive response to egg age at the time of the experiment. As was the case for the proportion of live eggs and larvae, this relationship is significant ($p < .01$) but the total variability explained is comparatively low (R^2 = .301).

Generally, stepwise regression analyses combining the results of all seven field bioassay experiments produced significant ($p < .01$)

explanation of observed variability for all dependent variables except the proportion of live eggs at the end of the experiments (Table 9). Standard errors associated with the means of these variables also indicate substantial precision considering the rather imprecise nature of the experiments as a whole. However, this apparent success must be viewed with caution. First, R^2 was > .40 only for hatching success and the proportion of live larvae. These low proportions of explained variability indicate that even in the best cases more than half of the observed variability was attributable to causes other than age and the three temperature variables tested. Effects due to such unmeasured variables as location-specific water quality, physical stress in the transport process, and other phenomena not related to Merrimack Station are implicated. Second, the three temperature variables (calculated dose, maximum temperature, Δt) tested are highly correlated, making it difficult to truly separate the effects of each. And finally, egg transport investigations, discussed previously (p. 60), indicate that studying Merrimack Station's thermal effects on eggs drifted near the surface may be only an academic exercise; this topic is discussed in more detail in a later section.

In conclusion, the field bioassays were conducted to meet Merrimack Station's NPDES permit requirements. Results suggest, but do not strongly indicate, that exposure of eggs near hatching time to the Merrimack Station thermal discharge when it is at its warmest and subsequent retention of eggs in surface waters of substantially elevated temperature may affect post-hatching survival. Hatching success, the dependent variable required for study by Merrimack Station's NPDES permit, was unaffected in the seven experiments conducted during 1975-1976. The imprecise nature of the field experiments and high degree of correlation among independent variables makes broad application of those findings unwarranted. Laboratory study, where extraneous variability can be more readily controlled, is probably a more meaningful method for determining thermal tolerance levels.

3. Laboratory Bioassay

The laboratory bioassay program was designed to complement the field bioassay program in determining more precisely the thermal tolerance of American shad eggs and larvae. Specifically, the laboratory study was included to remove the variability introduced by weather, plant failures, and other uncontrollable events which might effect survivorship.

a. Methods of Study

1) Laboratory Set-up

Generally, the methods employed were modifications of those developed by Schubel (1974) and co-workers. This method was selected (a) because it had already used successfully with American shad and (b) so that data would be directly comparable to that generated in Maryland (Schubel, 1974; Schubel and Koo, 1975; Koo, 1976).

All laboratory bioassays were conducted in a 10 x 30 ft mobile facility located just north of the Unit No. 1 intake house at Merrimack Station (Figure 1). The major components of this mobile laboratory included a once-through running river water system with temperature control and a multi-channel continuous temperature monitoring system.

a) Water System and Related Equipment

(1) 1975

The once-through water system essentially pumped ambient water from the river to an elevated, divided head box within the mobile laboratory. From the head box gravitational flow distributed the water to 6 controlled-temperature water tables and, then, back to the river.

Temperature control was achieved through the use of 6 Neslab Model SWHX non-contaminating heat exchangers equipped with 2000 watt stainless steel immersion heaters and solid-state thermostats. River water was pumped via a 12 GPM iron pump located on the river bank and a foot valve and strainer assembly anchored 2 ft off the river bottom 40 ft offshore. All piping was either polyethylene water supply tubing or Van-Lab flexible clear vinyl laboratory tubing. All connections were of polyethylene.

Water flow from the pump was regulated by an iron valve immediately prior to entering the divided head box. Within the divided head box, 1/2 of the water was cooled with a Neslab Model PBC-75 3/4 hp refrigeration unit (7200 BTU hr^{-1}). This was necessary because the river water was warmed slightly above ambient while being pumped to the laboratory. Water then flowed to 6 water subsystems: each of Systems 1-5 consisted of six 5-gallon glass aquaria and a 4' x 3'6" x 7" deep water table with standpipe drain. System 6, which was used primarily for stock maintenance, was similar except that the aquaria were of 20 gal capacity and the water table measured 4' x 8' x 7" deep with two standpipes. Water flowed directly to each aquarium, regulated through a system of pinchclamps, and overflowed into the water tables; the water surrounding each aquarium helped maintain thermal uniformity among the 6 tanks in each subsystem. The standpipe drains, connected to a return flow collecting pipe, conducted the water back to the Merrimack River.

(2) 1976

For 1976, the water system and laboratory were modified in an attempt to relieve some of the water quality and temperature control problems experienced during 1975. All plumbing was replaced with rigid PVC pipe and a series of PVC valves and drains. The gravity-feed head box employed during 1975 was replaced with a standard water supply-type storage tank with pressure switch and accumulator, and a larger (up to 20 gpm) pump was installed. Water was delivered to the laboratory at a

continuous rate of 12 gpm and 25-40 psi. The smaller pump was retained as a standby. It was installed in the water system in parallel with the main pump and equipped with its own foot valve and strainer assembly and differential pressure switch (Figure 31). The standby pump's pressure switch was set for operation at pressures indicating a main system failure. An Aquafine Model SL-1 ultraviolet sterilization unit was installed in the system downstream of the pressure accumulator in attempt to control the growth of bacteria, fungus, and brown algae. Two Neslab PBC-75 coolers and a Neslab SW-HX heat exchanger were installed in the "cold half" of the water system to provide better ambient temperature maintenance. Unlike 1975, the coolers and heat exchanger were set up so that the refrigeration coils did not contact the circulating water. In addition, the PBC-75 compressors were relocated outside the laboratory so that their heat rejection would not raise the air temperature inside. Finally, the entire laboratory structure was air conditioned so that temperatures inside remained at 70°F ± 5° throughout the study period.

All laboratory windows were covered with black plastic and General Electric F 40 GO gold fluorescent tubes were installed to minimize the amount of visible blue light emissions. Perlmutter and White (1962) cited Hamdorf's (1960) results demonstrating lethal effects on developing salmonid eggs caused by exposure to light of 4500-5000 Å (visible blue-violet). Perlmutter and White (1962) suggested pink fluorescent lights for hatcheries. However, review of GE's published emission spectra (GE, 1968) revealed that pink tubes emit considerable ultraviolet light whereas gold tube emissions are nearly all in the green, yellow and orange range determined to be the safest for developing embryos (Hamdorf, 1960). The gold laboratory lights were kept on continuously; with the blackening of windows, illumination remained constant.

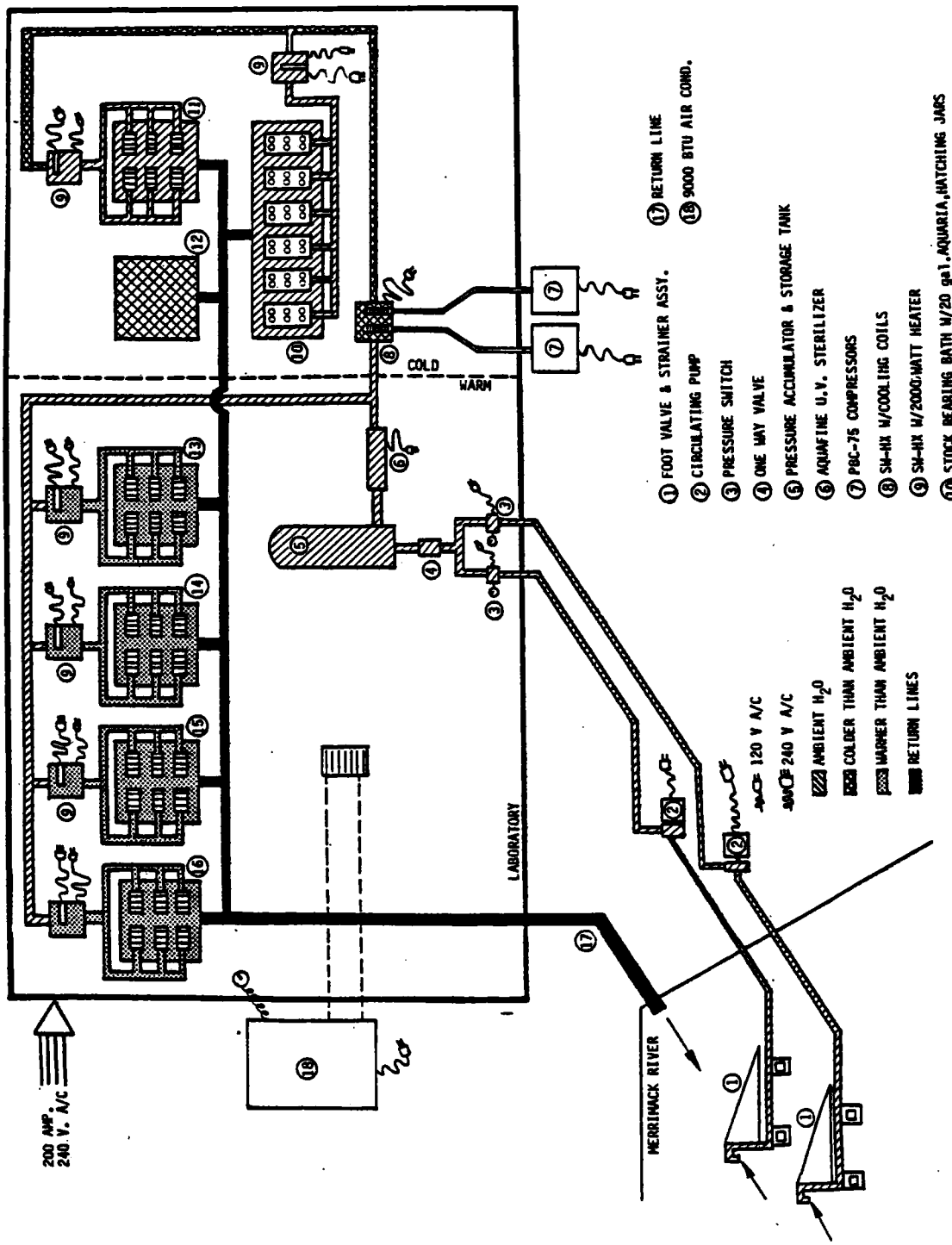


Figure 31. Schematic diagram of 1976 bioassay laboratory water system and related equipment, Merrimack River Anadromous Fisheries Investigations, 1976.

b) Stock Maintenance

(1) 1975

Initially, all eggs and larvae used in the laboratory bioassay program were obtained from the Connecticut River in the manner described previously (page 53) and maintained in a manner similar to that employed by Schubel (1974). In this procedure, System 6, containing the 20 gal aquaria, was set up to maintain the ambient Merrimack temperature at the time the eggs were brought into the laboratory. Developing eggs were placed in 27.3 x 16.9 x 13.5 cm deep wood-framed nylon mesh baskets which floated in the tanks. Developing eggs and larvae in the other systems (treatment) were maintained in smaller (17.1 x 7.0 x 5.8 cm deep) floating baskets of similar construction. At least one aerating stone was placed in each tank to ensure water circulation and prevent thermal stratification.

(2) 1976

For 1976 basket culture was replaced by jar culture for the maintenance of stock test animals. Standard plastic hatchery culture jars were obtained from the Sandwich, MA Hatchery (Mass. Div. Fish. Game). These were set up in the following 3-layered system (Figure 32): up to six jars were placed in each of up to six 20 gal aquaria located within the large stock-rearing water table (System 6) (Figure 31). Water circulation in the jars was controlled, using pinchclamps, at a rate just sufficient to maintain gently rolling egg motion (Leach, 1925). Water overflowed from the jars into the 20 gal aquaria and then into the water table. Aerating stones in the 20 gal aquaria maintained circulation and prevented stratification. Upon hatching, larvae were prevented from leaving the hatching jars by 333μ mesh placed around the overflow (Figure 32). After all larvae had hatched, they were transferred to 5 gal aquaria with at least two aerating stones per aquarium.

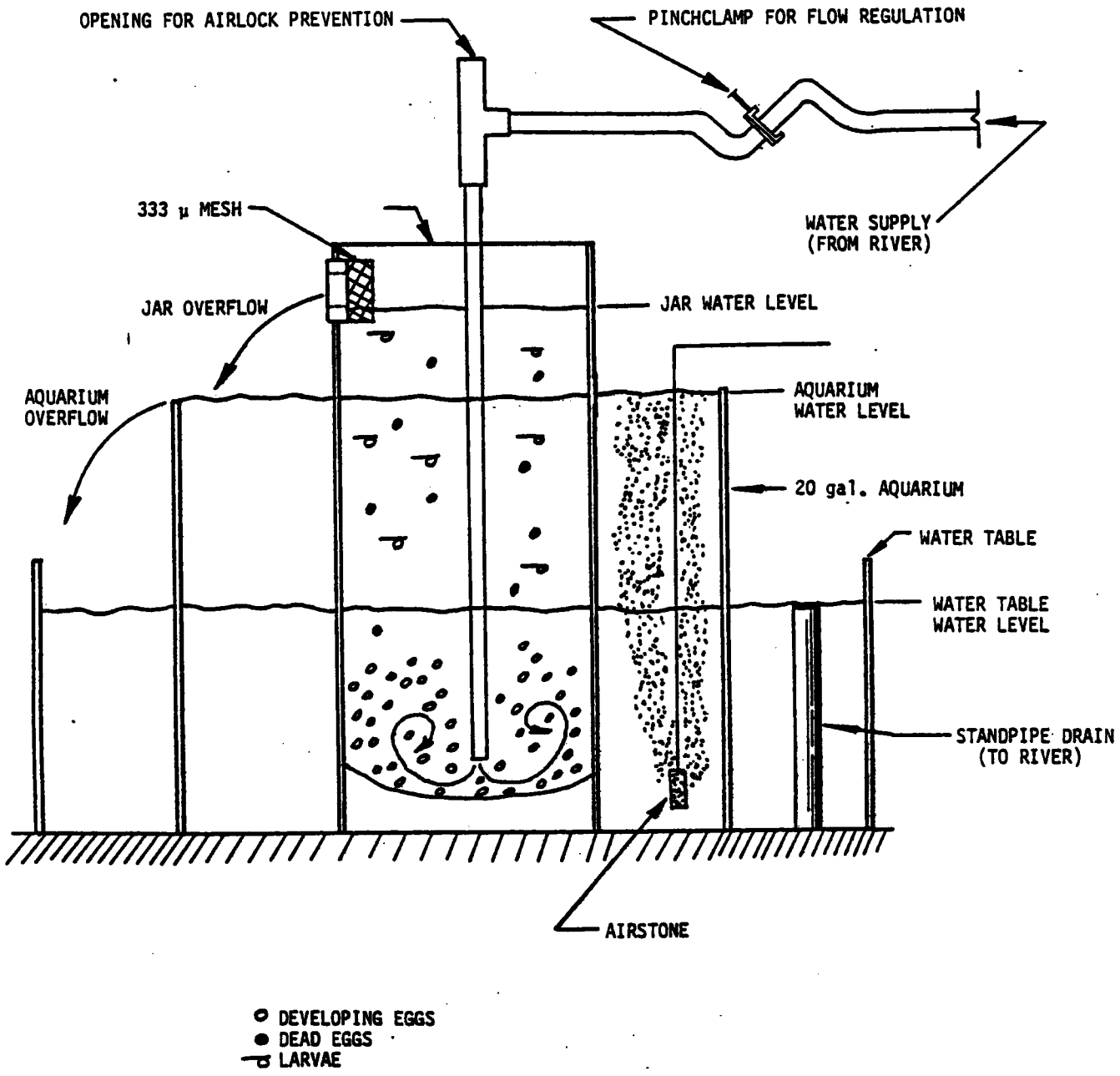


Figure 32. Jar culture setup for American shad. Merrimack River Anadromous Fisheries Investigations, 1976.

As in the behavioral studies [Section 1.a.2)b)] attempts were made at feeding larvae a variety of potential foods including powdered commercial fish food, live and frozen newly-hatched brine shrimp, and natural plankton. Brine shrimp were cultured in the laboratory using battery jars with airstones, and natural plankton was circulated constantly from the river through the water system.

c) Temperature Monitoring

Continuous temperature monitors were maintained in 4 of the 6 aquaria within each of the 6 systems. These monitors consisted of thermistor probes wired to a Kaye Model 8000 24-channel printing digital recorder. The laboratory temperature monitoring system remained unchanged for 1976.

2) Test Procedures

a) 1975

Immediately prior to testing, living larvae were transferred from river hatching boxes to the test baskets. Generally, testing involved establishing the 5 test systems at pre-determined elevated temperatures and immersing the test baskets containing approximately 20 eggs or larvae in the heated baths for short periods followed by gradual cooling to simulate the temperature shock experienced by eggs and larvae entrained in the thermal plume and cooling water at Merrimack Station. First, baskets were transferred quickly from ambient to test temperatures. Then, after the prescribed test period (usually 10 minutes), approximately 1/2 of the water in the 5.5 gal tanks was emptied and then the entire tank, containing the baskets, was immersed in a bath containing ice and water. When the temperature in the tanks cooled to approximately 2°F above ambient (simulating far-field conditions) the baskets were transferred to a system maintaining +2°F conditions.

Controls were removed from the ambient system and replaced; others were transferred from ambient to +2°F to simulate far-field effects only. Dead animals were removed at regular intervals and recorded. Experiments were terminated when all organisms had perished.

In all, 4 test runs were attempted during 1975. Due to problems involving the laboratory systems, larvae were taken from river hatching boxes for these tests. In addition, a test to determine the rate at which dead eggs become opaque was performed. Shad eggs normally turn from their normal living, translucent state to opaque shortly after death. To determine how rapidly this occurs and whether or not the onset of opacity represents a useable end point in a bioassay series, the following procedure was utilized: Approximately 20 living eggs were transferred from ambient to a test basket. The eggs were sacrificed by immersing this basket in 120°F for 5 minutes. The basket was then returned to ambient and observed until all eggs were recognizably opaque.

b) 1976

Laboratory procedures and experimental protocol remained similar from 1975 to 1976, but several improvements were made. The most important change was that egg and larval survivorship was monitored continuously, and dead animals were removed hourly for the duration of the experiments. This added greatly to the data's precision and reduced the spread of fungus. A 2-cell flashlight provided added illumination for identifying and removing dead eggs and larvae. Also in 1976, stock maintenance within the laboratory provided sufficient quantities of test animals; use of hatching box eggs and larvae, necessitated by engineering and logistic problems in 1975, was not necessary during 1976.

c) General

During the 2 years of experiments eggs and larvae ranging in age from 14 to 328 hr (since fertilization) were subjected to Δt's of up to 24°F (maximum temperature = 99°F) for durations as long as 30 min. Detailed data describing each experiment and the test animals used are contained in Tables 10 and 11. Plate 4 depicts some of the equipment and procedures used in the laboratory investigations.

TABLE 10. STARTING DATES FOR THE 13 EGG BATCHES UTILIZED IN THE LABORATORY BIOASSAY PROGRAM. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

	MAY				JUNE																
	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975																				A	B		C	
1976	1		2					3				4	5			6		7		8			9	10

b. Results

1) 1975

a) Egg Opacity Tests

Eggs were generally identifiable as "opaque" within 10 min after removal from the 120°F bath (15 min from initial immersion). Some opacity could be detected 5 min after removal. Opacity was, therefore, determined to be a sufficiently accurate indicator of egg death for future studies.

TABLE 11. LABORATORY BIOASSAY EXPERIMENTS CONDUCTED DURING 1975-1976. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

EXP	EGGS/ LARVAE	DATE	BATCH*	AGE+	AMBIENT t (°F)	Δt (°F)	Tmax (°F)	DURATION (MIN)
1A	1**	06-25-75	A	236	75	8,12,20,24	87,83,95,99	10
1A	1**	06-25-76	C	164	75	8,12,20,24	87,83,95,99	10
2A	1**	06-27-75	A	284	72	4,8,15	76,80,87	10
2A	1**	06-27-75	C	212	72	4,8,15	76,80,87	10
3A	1**	06-30-75	C	257	75	4,12	79,92	10,20
4A	1**	07-01-75	B	328	78	6.5,16	84.5,94	10
4A	1**	07-01-75	C	280	78	6.5,16	84.5,94	10
1	e	06-02-76	1	110	62	3,7,13,21	65,69,75,83	20
1	e	06-02-76	2	38	62	3,7,13,16	65,69,75,78	10
2	e	06-03-76	2	61	62	4,8,14,17	66,70,76,79	20
2	e	06-03-76	3	14	62	4,8,13,17	66,70,75,79	20
3	e	06-04-76	2	84	62	4,8,13,21	66,70,75,83	30
3	e	06-04-76	3	39	62	5,9,16,19	67,71,78,81	30
4	e	06-06-76	4	59	64	4,9,16,20	68,73,80,84	30
5	1	06-08-76	3	132	63	5,9,14,16	68,72,77,79	20
5	1	06-08-76	3	136	64	5,10,14,18	69,74,78,82	10
6	1	06-09-76	3	159	66	5,8,13,18	71,74,79,84	20
6	1	06-09-76	3	159	66	5,8,13,18	71,74,79,84	10

(Continued)

TABLE 11. (Continued)

EXP	EGGS/ LARVAE	DATE	BATCH*	AGE+	AMBIENT t (°F)	Δt (°F)	Tmax (°F)	DURATION (MIN)
7	l	06-10-76	5	132	67	5,7,13,17	72,74,80,84	10
7	e	06-10-76	6	62	68	6,8,18,28	74,76,86,96	20
7	e	06-10-76	6	63	69	5,8,17,27	74,77,86,96	30
8	l	06-11-76	6	83	68	6,9,18,24	74,77,86,92	20
8	e	06-11-76	7	37	68	6,9,18,25	74,77,86,93	20
9	l	06-12-76	3	228	66	6,10,14,17	72,76,80,83	20
10	e	06-14-76	8	61	65	6,10,14,25	71,75,79,90	20,30
10	l	06-14-76	7	112	66	7,9,14,23	73,75,80,89	20
11	l	06-15-76	7	131	66	6,9,14,17	72,75,80,83	20
11	l	06-15-76	8	87	68	6,9,13,27	74,77,81,95	20
12	l	06-16-76	7	160	70	7,9,13,17	77,79,83,87	20
13	l	06-17-76	8	130	69	6,9,14,17	75,78,83,86	20
13	l	06-17-76	3	351	69	8,10,14,17	77,79,83,86	20
14	l	06-18-76	8	158	69	7,10,14,17	76,79,83,86	20
14	l	06-18-76	9	88	70	6,9,12,16	76,79,82,86	20

*As defined in Table ____

+hrs since fertilization

**All 1975 larvae from hatching boxes

b) 1975 Bioassay Experiments

The results of the four laboratory bioassay series are displayed graphically (Figures 33 through 35) in terms of survivorship over time.

(1) Experiment 1A

In Experiment 1A control mortality was low for both larvae groups and they responded measurably to treatments (Figure 33). The younger 164 hr old larvae responded in a more typical pattern than did the 236 hr old larvae. That is, control, Δ8°, and Δ12°F survivorship was approximately equal for the young larvae whereas Δ8 and Δ12F mortality was greater for the old. The Δ8 mortality was even greater than the Δ12 in this instance. Mortality was substantially higher at Δ20 and Δ24 for both young and old larvae groups (Figure 33). In both instances mortality increased to the point where the experiment's usefulness ended approximately 20 hr after temperature shock.

(2) Experiment 2A

In Experiment 2A the 284 hr old larvae yielded survivorship curves which were typical; control survivorship was higher than that of the Δ4F group, and the mortality at Δ4 was less than at Δ15F (Figure 34). However, control survival in one instance was poor; many larvae died within the first 2 hr. In addition, variability among replicates was considerable (but not enough to mask treatment effects). Survivorship among the younger 212 hr old larvae in Experiment 2A was more replicable (Figure 34). Some larvae escaped from one of the control baskets, however, so there was no replication for that group. Generally, control and Δ8F groups were similar and, as in Series No. 1, there was higher mortality in the Δ15F group and mortality increased in both young and old groups after 20 hr.

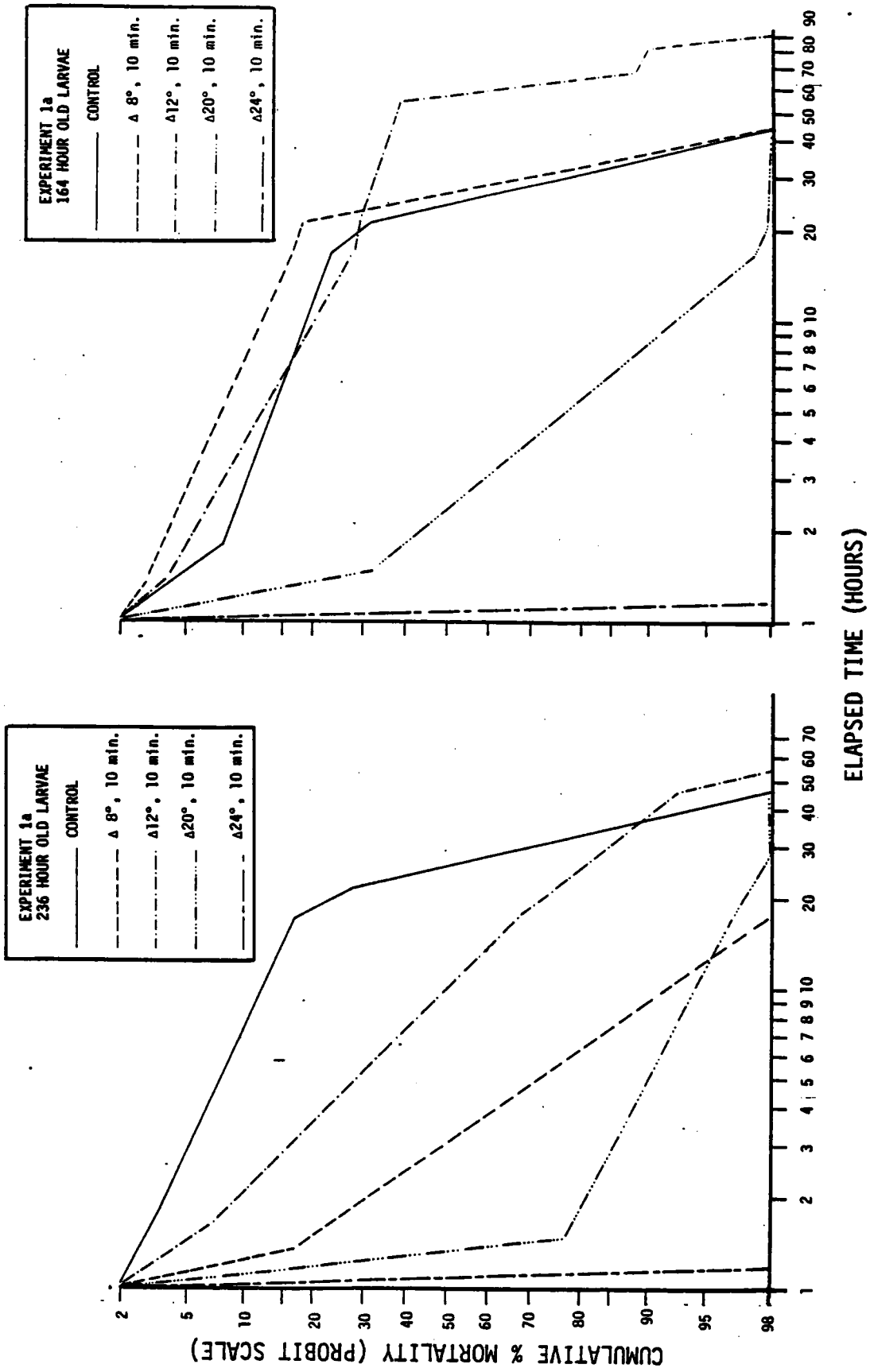


Figure 33. Cumulative mortality/survivorship, Experiment 1A (Probit vs. time). Merrimack River Anadromous Fisheries Investigations, 1976.

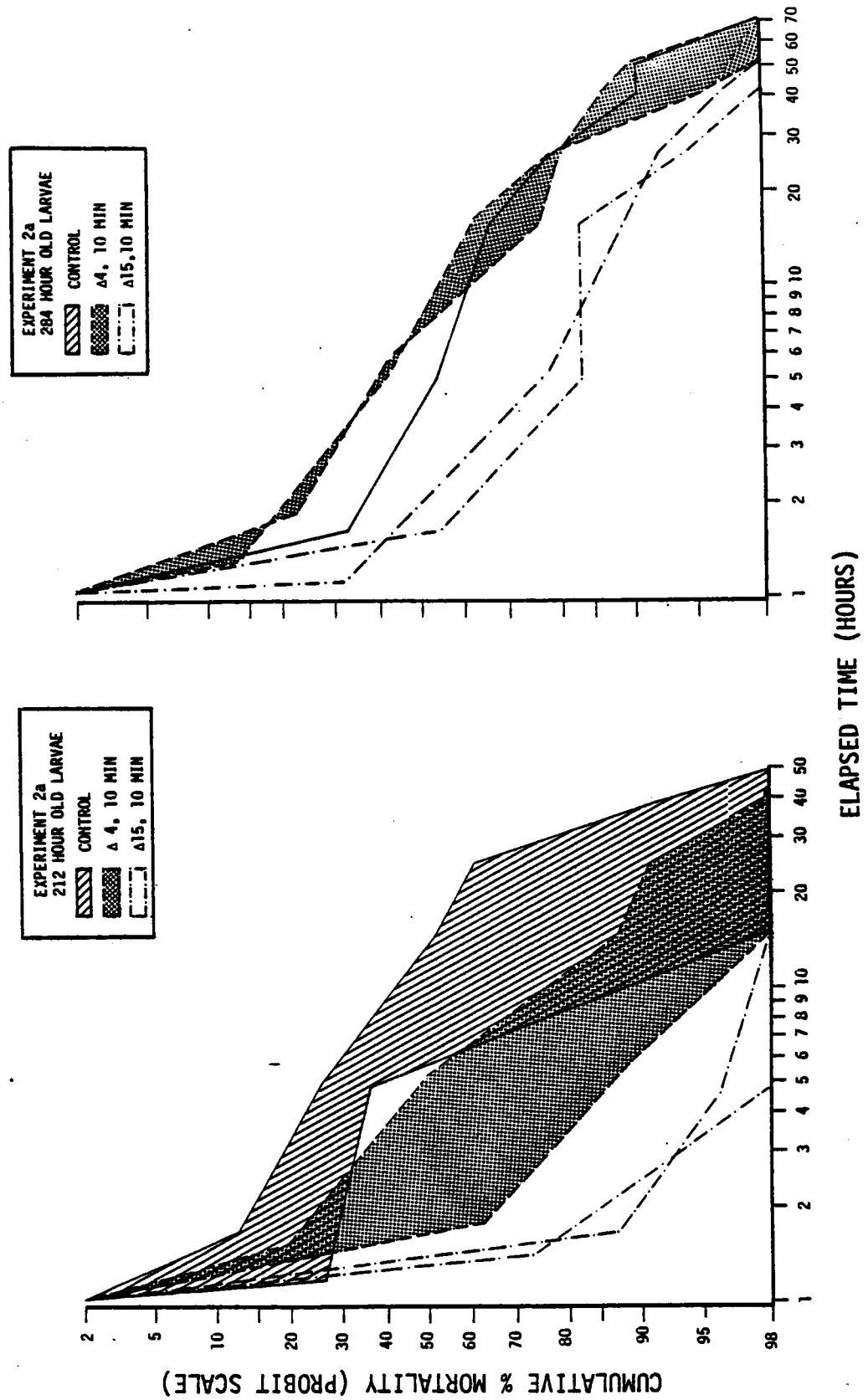


Figure 34. Cumulative mortality/survivorship, Experiment 2A (Probit vs. time). Merrimack River Anadromous Fisheries Investigations, 1976.

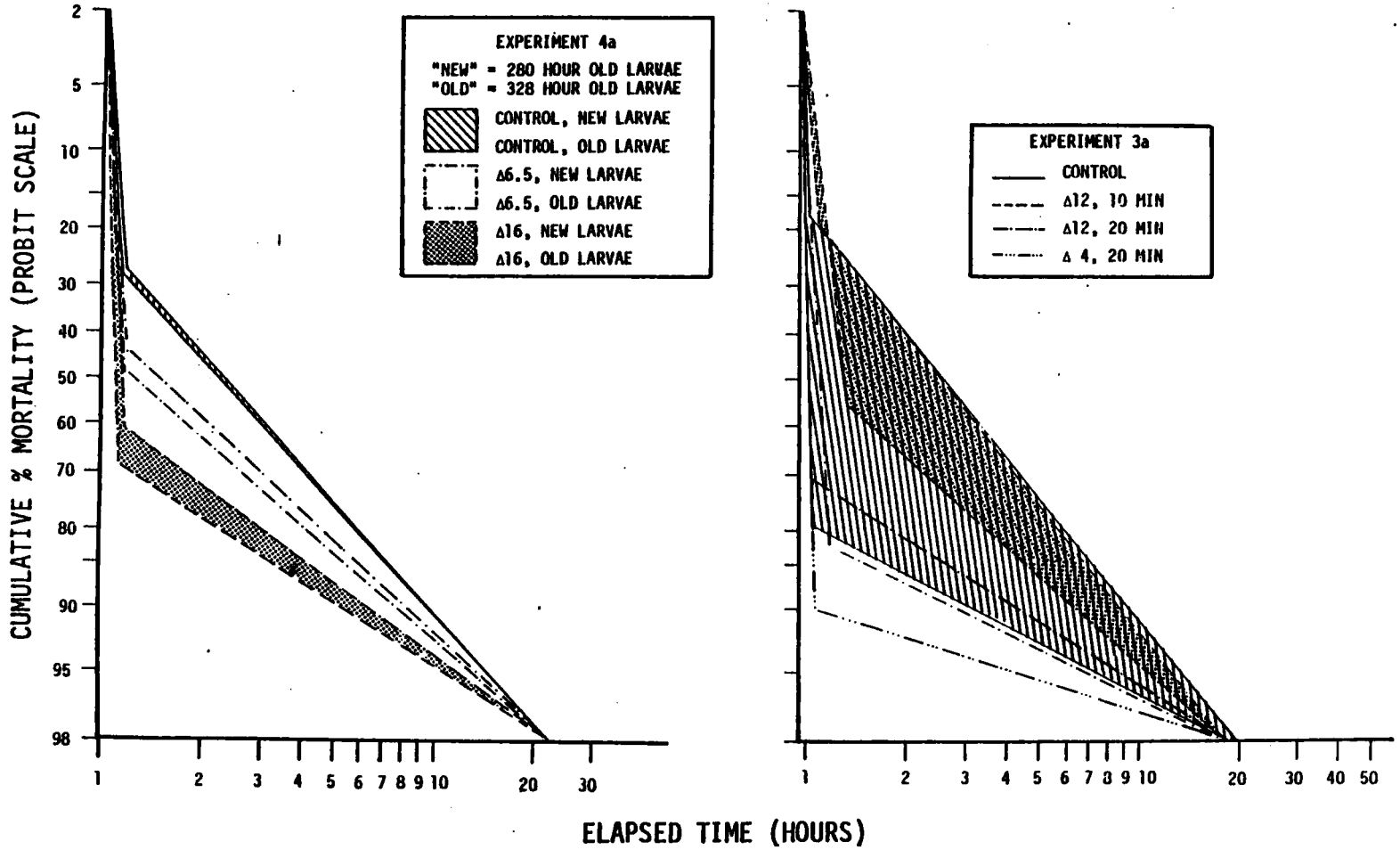


Figure 35. Cumulative mortality/survivorship, Experiments 3A and 4A (Probit vs. time). Merrimack River Anadromous Fisheries Investigations, 1976.

(3) Experiments 3A and 4A

In both series survivorship was poor for both control and treatment groups from the start (Figure 35). Although the poor survival of controls make application of these results questionable, a recognizable pattern of increased survivorship with lower exposure temperature was evident in Experiment 4A.

c) General

Percent survivorship 1.5 hr after treatment was plotted as a function of Δt and actual maximum temperature ($T_{max} = T_{base} + \Delta t$) for Batch A and B larvae (Table 10) (Figure 36). In all four instances this yielded a line with a slight negative slope for the most part followed by a steeply sloping line at higher temperature/Δt combinations.

2) 1976

a) 1976 Bioassay Experiments

Laboratory bioassay experiments conducted during 1976 are summarized in Table 11. The following descriptions briefly discuss each experiment, special circumstances or procedures that may have been used, and the general results of each temperature shock series. Figures 37 through 50 represent survivorship curves generated by each experimental series.

(1) Experiment 1

Batch 1 and 2 eggs 110 and 38 hr old were subjected to thermal increases ($\Delta t \leq 21°F$) for 20 and 10 min, respectively. Prior to this experiment, there was difficulty maintaining water flow through the

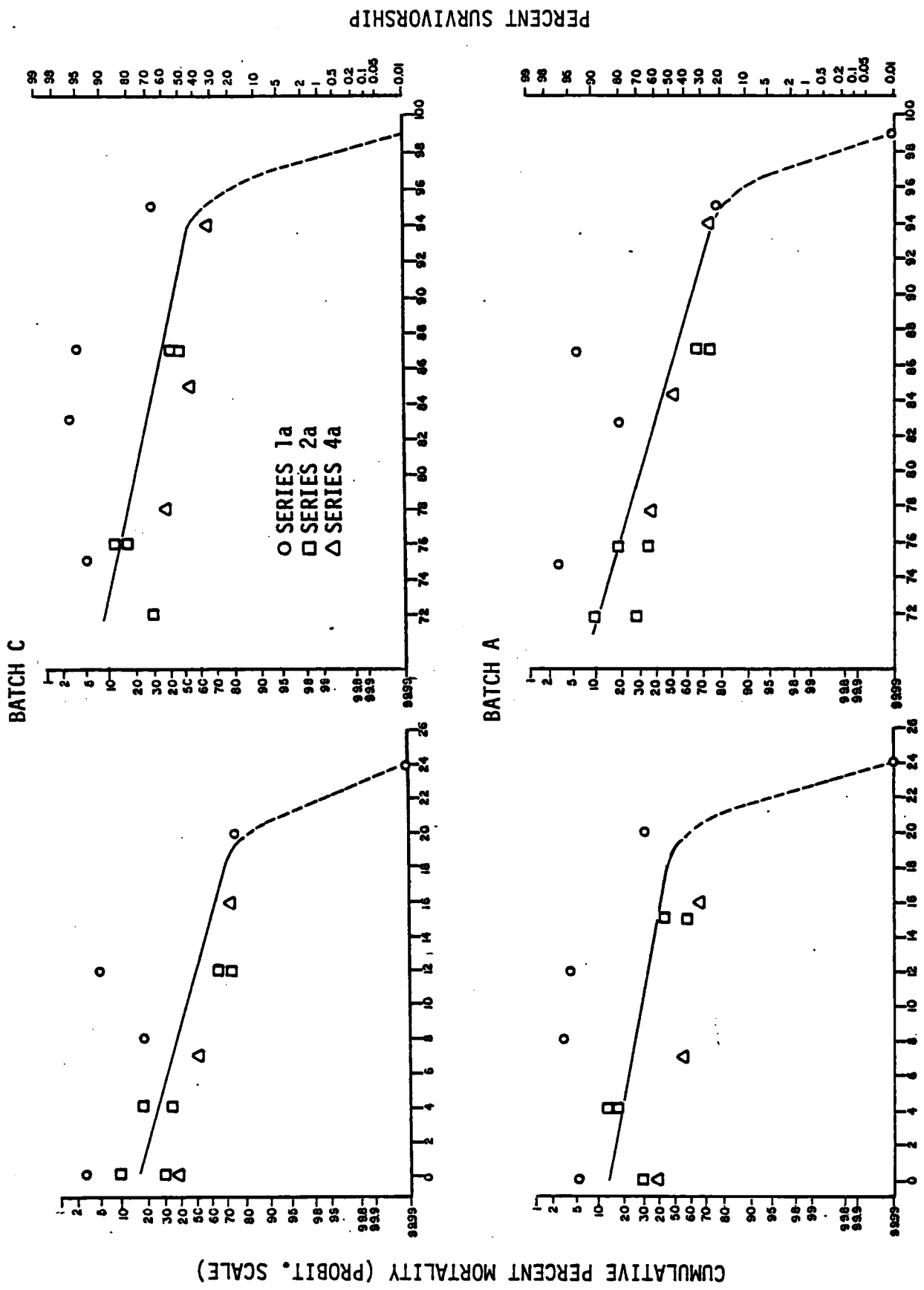


Figure 36. Cumulative mortality vs. temperature change and maximum exposure temperature for Batch A and C larvae. Merrimack River Anadromous Fisheries Investigations, 1976.

hatching jars containing each egg stock, and many eggs died before the experiment began. However, only clear, healthy-looking eggs were used in the test series. Batch 1 survivorship (Figure 37a) was greatest for the control groups and the eggs subjected to the highest thermal increases ($\Delta t \geq 13°F$). Mortality was highest in the eggs exposed to $\Delta t < 7°F$. Batch 2 survival was inconsistent within a given thermal treatment (Figure 34b); survival was greatest in one control basket and in those subjected to $\Delta t > 16°F$. In both Experiment 1 test series, the longest survival time was approximately 132 hr after thermal shock.

(2) Experiment 2

Batch 2 and 3 eggs 61 and 14 hr old were exposed to $\Delta t \leq 17°F$ for 20 min. In both series, survivorship replicability among baskets was poor (Figures 38a,b). The Batch 2 test showed no relationship between thermal dosage and mortality rate; longest survival was 141 hr. Batch 3 control mortality was unexpectedly high compared to the treatment groups; maximum survival was 154 hr after thermal shock.

(3) Experiment 3

This experiment was essentially a repetition of Experiment 2 using a 30-min exposure time. Batch 2 eggs, 84 hr old, were at the hatching stage. Although 20 eggs were placed in each basket, all but three were lost from Basket #16 ($\Delta t = 22°$, Figure 39a) in the Batch 2 test. All procedures were normal in the Batch 3 series; the eggs were 39 hr old. Batch 2 survivorship was better at $\Delta t \geq 13°$ than controls or at other test temperatures (Figure 39a). All groups survived at least 63 hr, but not more than 130 hr. With the exception of one control basekt, the Batch 3 treatment egg groups displayed similar survivorship curves, with total mortality occurring between 123 and 141 hr (Figure 38).

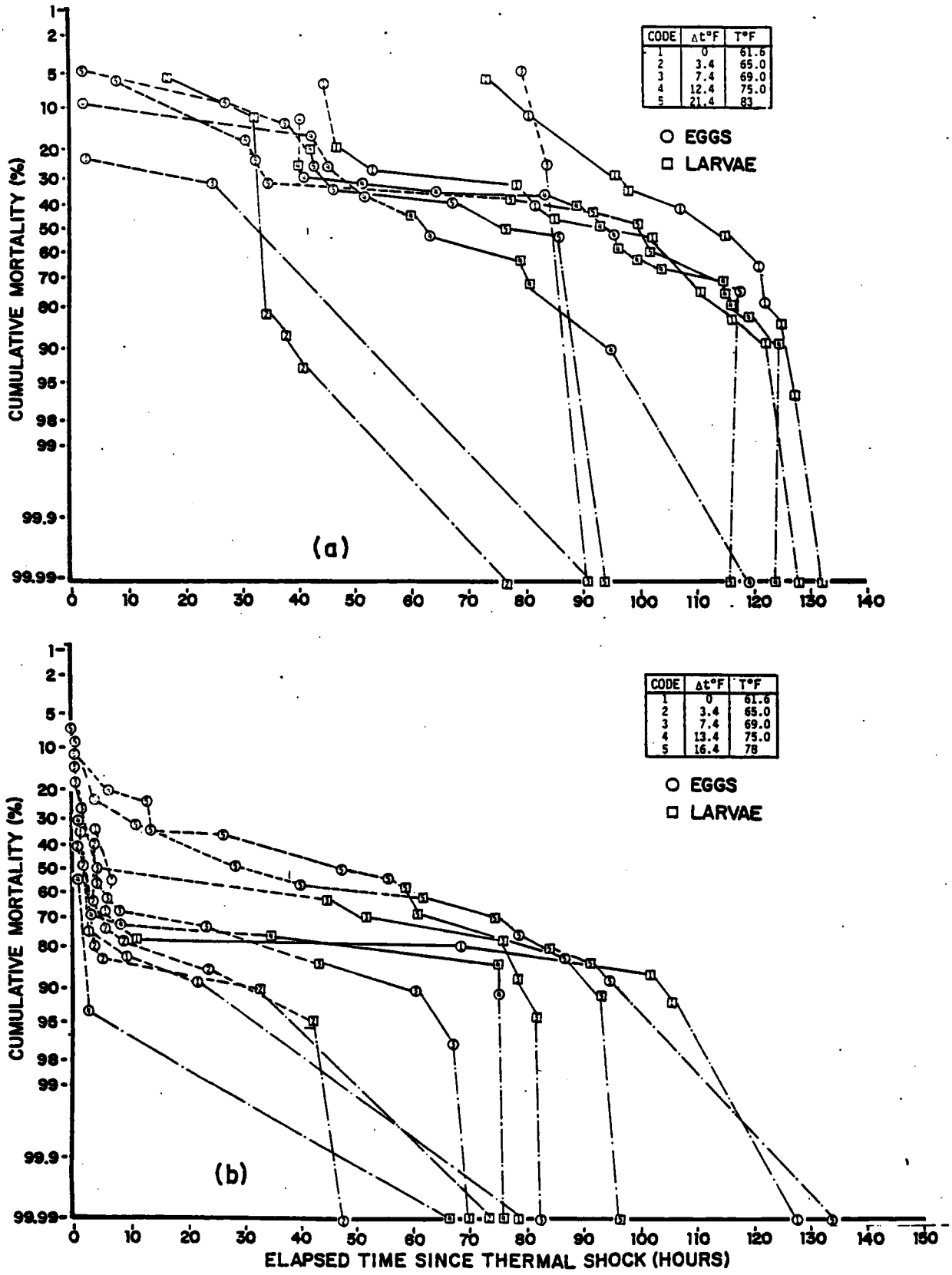


Figure 37. Bioassay Experiment 1 cumulative mortality over time. (a) Batch 1 eggs 110 hr. old. (b) Batch 2 eggs 38 hr. old. Line change from dash to solid indicates 1st appearance of larvae. Broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

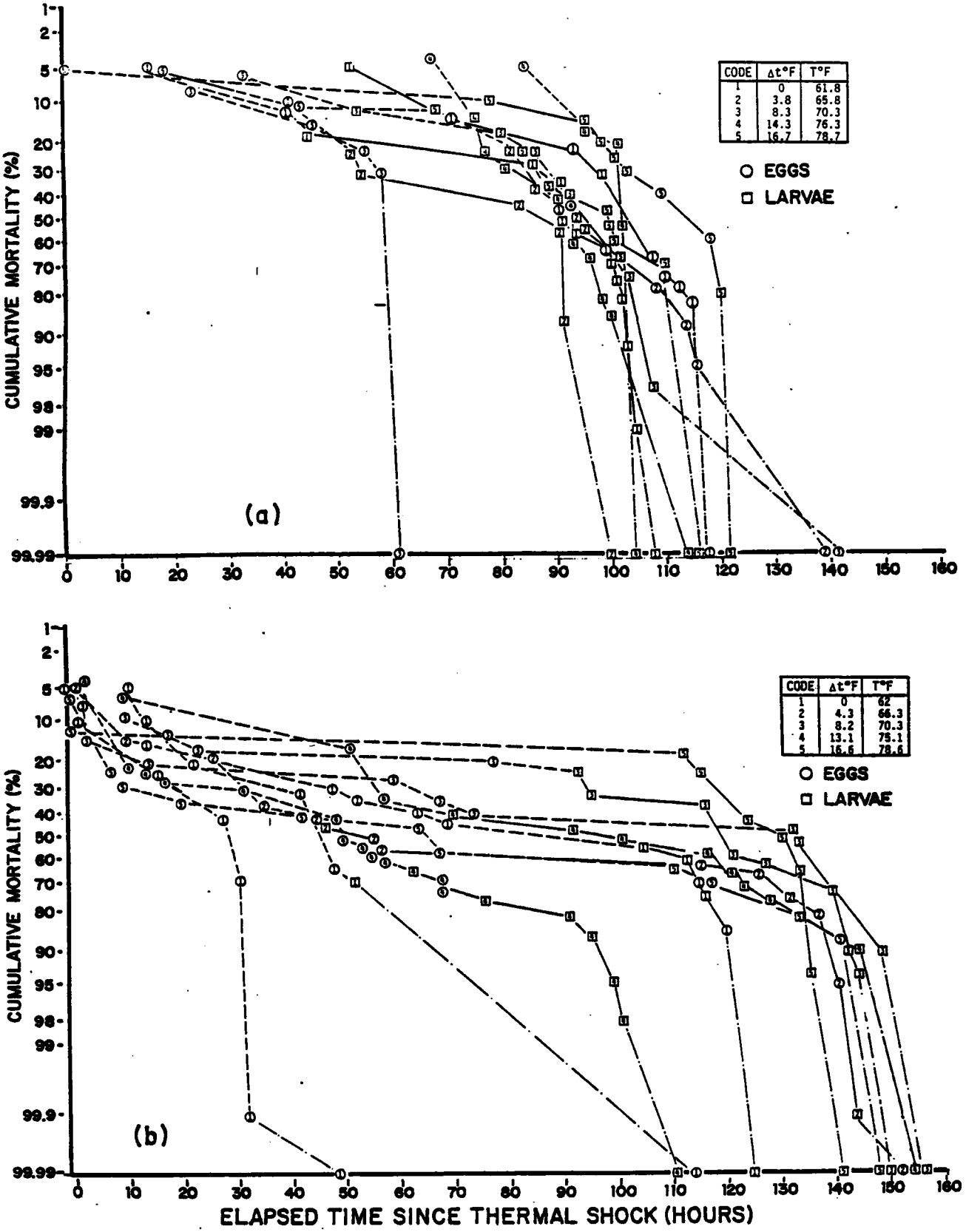


Figure 38. Bioassay Experiment 2 cumulative mortality over time. (a) Batch 2 eggs 61 hr. old. (b) Batch 3 eggs 39 hr. old. Line change from dash to solid indicates 1st appearance of larvae. Broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

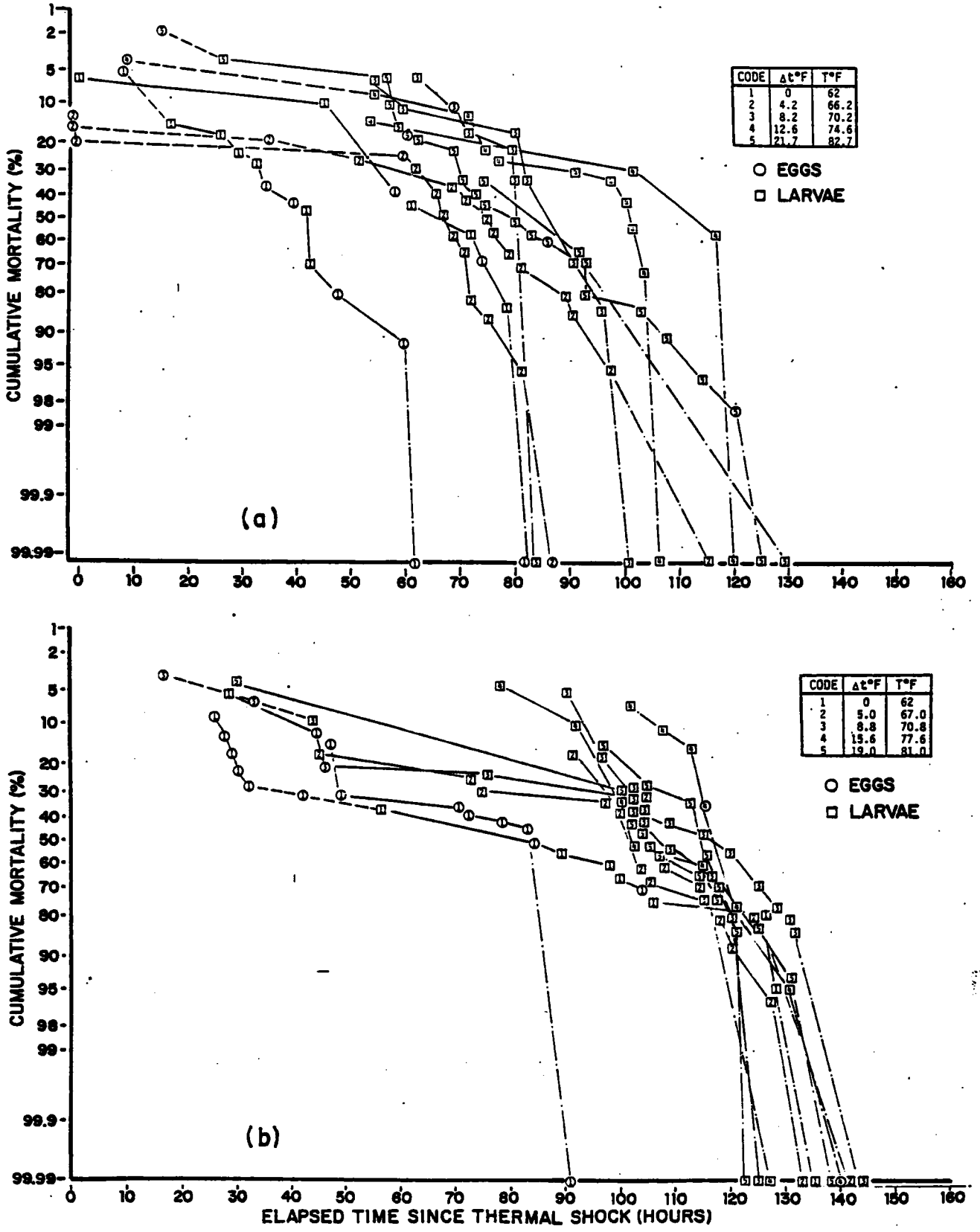


Figure 39. Bioassay Experiment 3 cumulative mortality over time. (a) Batch 2 eggs 84 hr. old. (b) Batch 3 eggs 39 hr. old. Line change from dash to solid indicates 1st appearance of larvae. Broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

(4) Experiment 4

Batch 4 eggs, 59 hr old, were subjected to $\Delta t \leq 20°$ for 30 min. Only ten eggs were used per basket because egg number was limited in this batch. Survival curve replicability was poor (Figure 40), and there was no apparent relationship between mortality rate and thermal dosage. Total mortality occurred between 80 and 120 hr after exposure for all groups.

(5) Experiment 5

Batch 3 larvae, 132-136 hr old, were exposed to $\Delta t \leq 18°$ for 10 and 20 min in two test series. Replicability was poor in both tests, with no apparent correlation between mortality rate and thermal dosage (Figure 41a, b). Compared to previous experiments using eggs, this experiment showed that larval mortality occurred at a much faster rate; total mortality occurred within 22 hr in the 20-min exposure series and within 45 hr in the 10-min series.

(6) Experiment 6

The procedures used in this experiment were the same as in Experiment 5, except that the Batch 3 larvae were 159 hr old. In a 20-min exposure series, controls survived better than the treatment groups (Figure 42a). Control larvae survived between 50 and 70 hr whereas all others died within 32 hr of thermal exposure ($\Delta t \leq 18°F$). In a 10-min exposure series, most groups survived less than 8 hr, although one control group survived 49 hr, and one $\Delta t = 13°$ group survived 41 hr (Figure 42b).

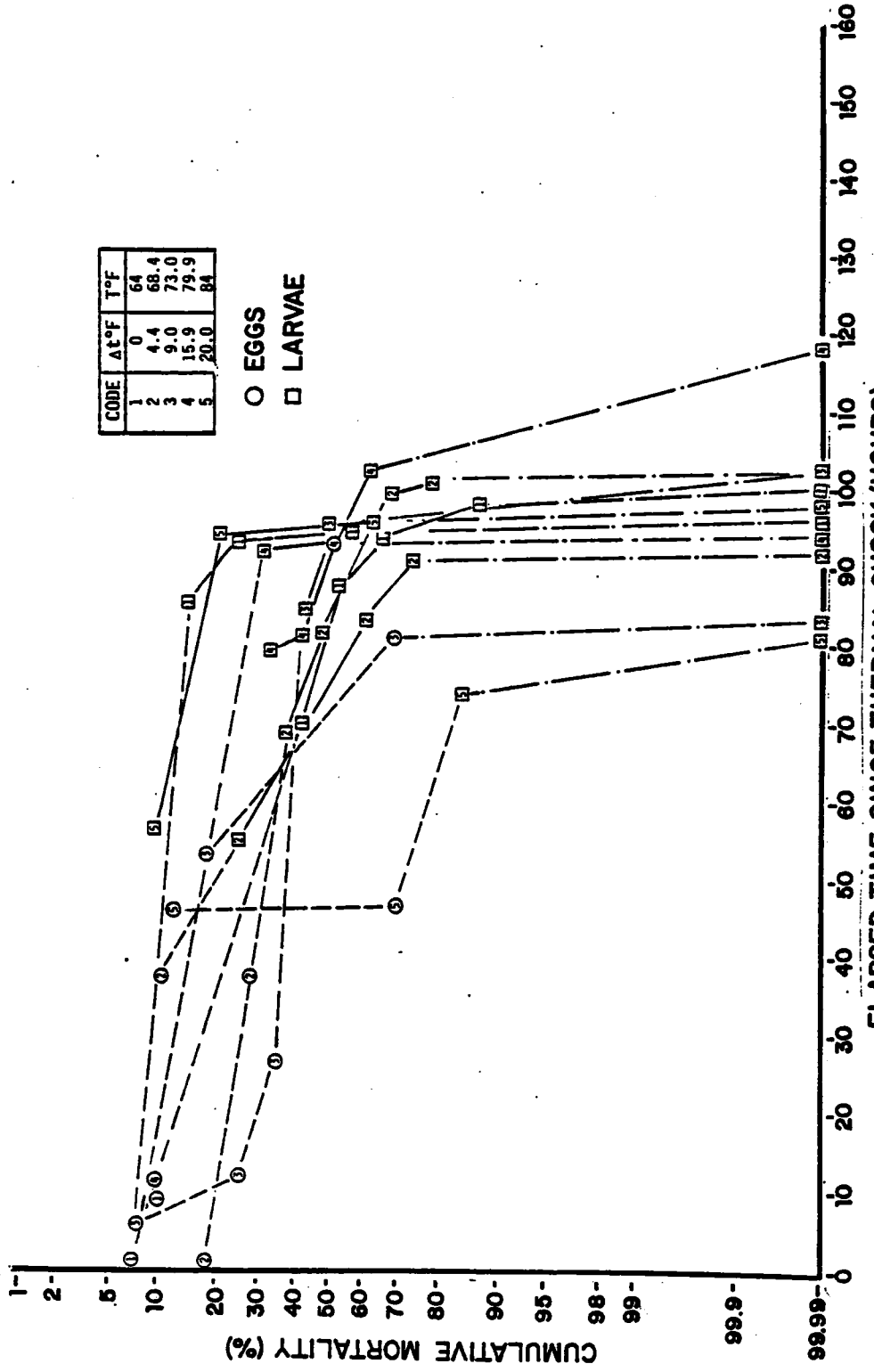


Figure 40. Bioassay Experiment 4. Batch 4 larvae 59 hr. old. Line change from dash to solid indicates 1st appearance of larvae. Broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

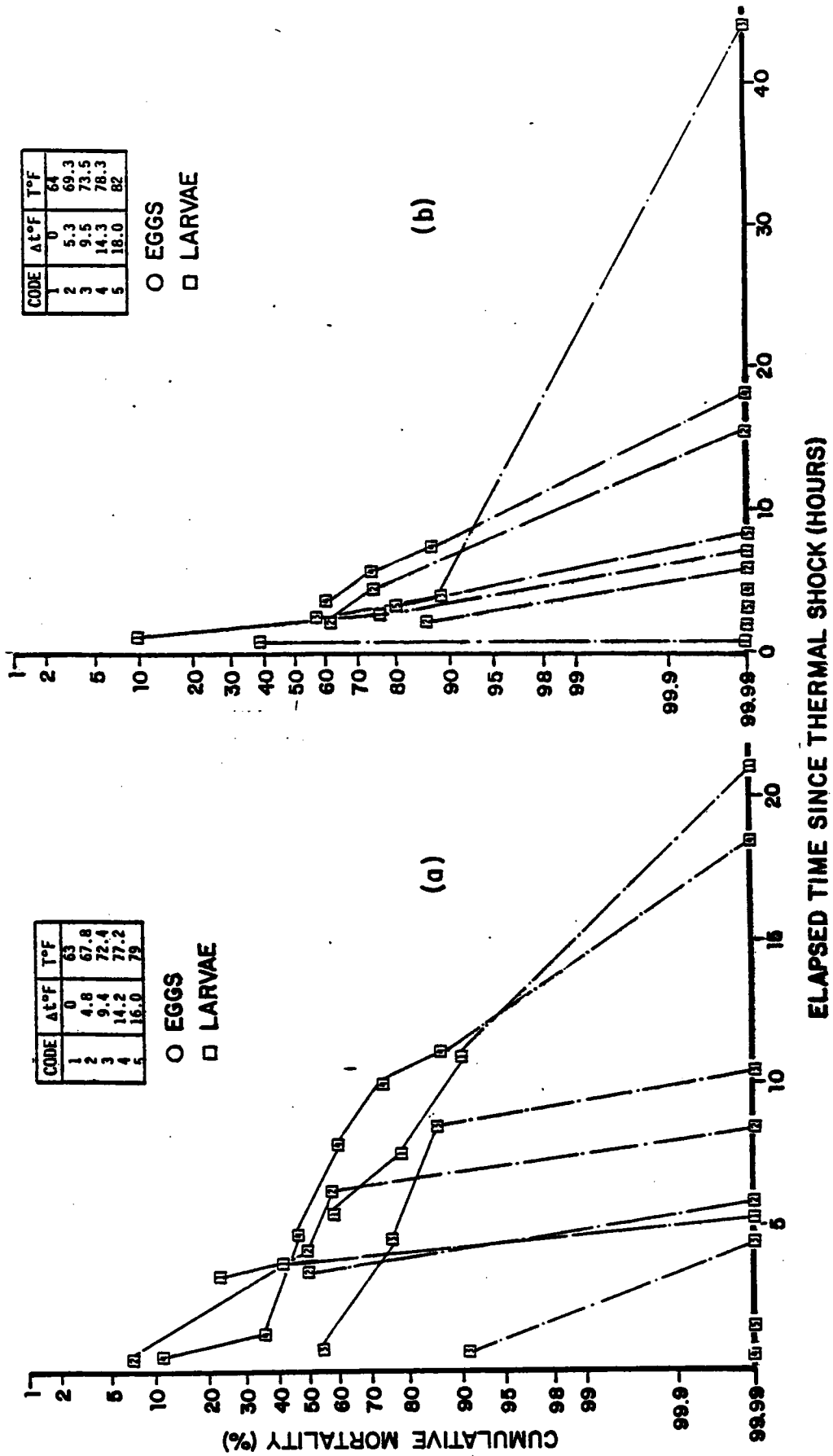


Figure 41. Bioassay Experiment 5. Batch 3 larvae, 132-136 hr. old. (a) 10 min exposure. (b) 20 min exposure. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

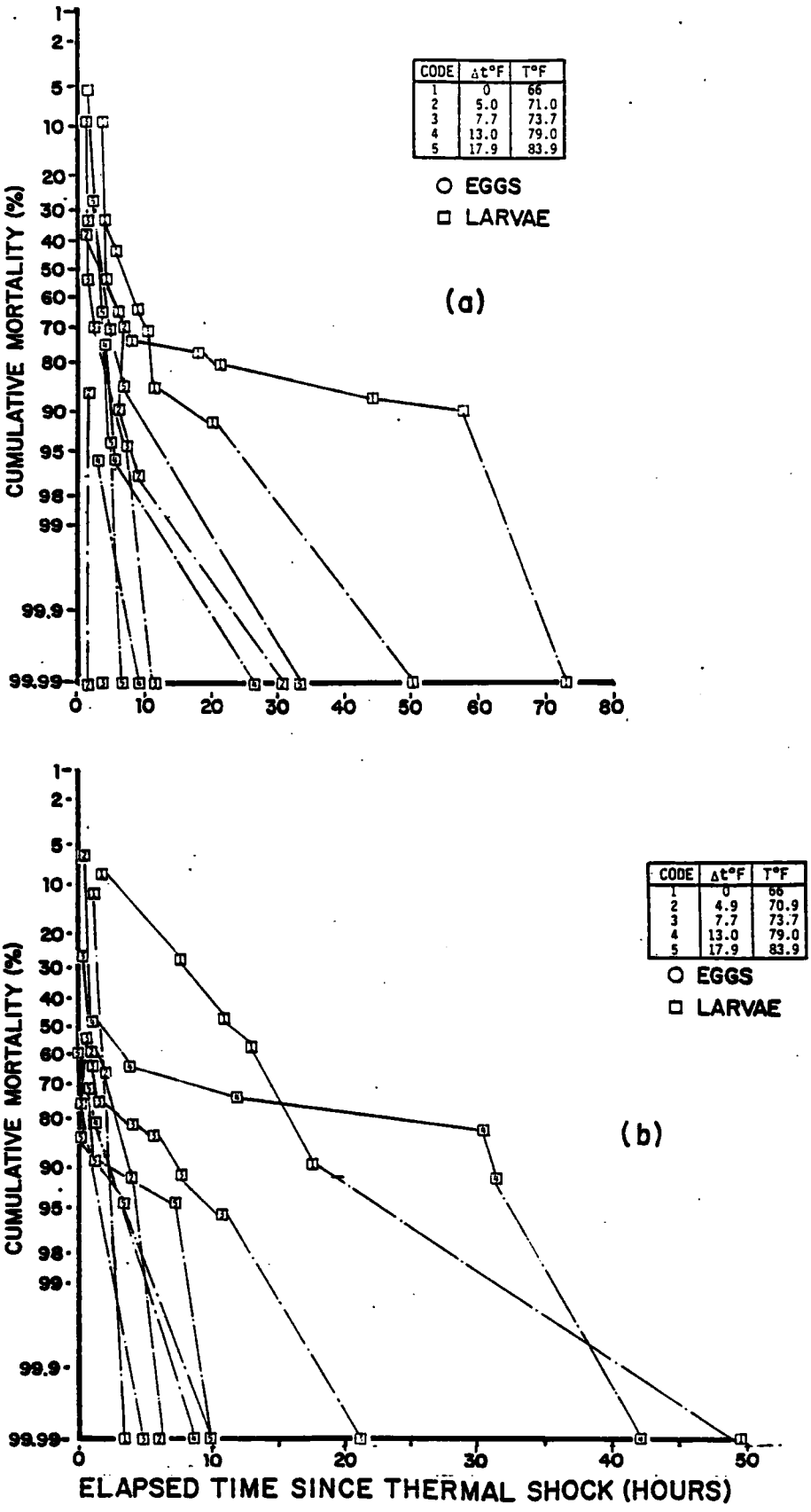


Figure 42. Bioassay Experiment 6. Batch 3 larvae 159 hr. old. (a) 10 min exposure. (b) 20 min exposure. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

(7) Experiment 7

Batch 5 larvae, 132 hr old, were subjected to $\Delta t \leq 17°F$ for 10 min and Batch 6 eggs 62-63 hr old were exposed to $\Delta t \leq 28°F$ for 20 and 30 min. In the larval test series, replicability between baskets was good for all but the $\Delta t = 13°F$ groups (Figure 43a). Survival was highest in the controls and one $\Delta t = 13°F$ group; total mortality occurred within 35 hr for all groups. The two series using Batch 6 eggs, 62-63 hr old, resulted in poor similarity between replicate baskets. The survival curves for the 20-min exposure showed no relationship between mortality rate and thermal dose (Figure 43b). Controls showed both the highest (111 hr) and lowest (56 hr) survival. The survival curves for the 30-min exposure (Figure 43c) indicate a higher mortality rate at higher thermal doses. Eggs subjected to $\Delta t = 27°F$ experienced total mortality within 49 hr of exposure, while those subjected to $\Delta t = 5°F$ survived for up to 116 hr. Mortality was intermediate among controls. This was the first test series to use $\Delta t > 21°F$.

(8) Experiment 8

Batch 6 larvae, 83 hr old, and Batch 7 eggs, 37 hr old, were exposed to $\Delta t \leq 25°F$ for 20 min. Although replicability was good in the larval series, survival was greatest in controls and the $\Delta t = 24°F$ groups (Figure 44a). Survival was high compared to other larval tests, with total mortality occurring between 48 and 78 hr after thermal exposure. Replicability in the egg series was poor for all groups except $\Delta t = 25°F$ (Figure 44b), with the controls and intermediate dosage groups exhibiting both better and worse survival than the highest-dosage group. Total mortality occurred between 90 and 118 hr.

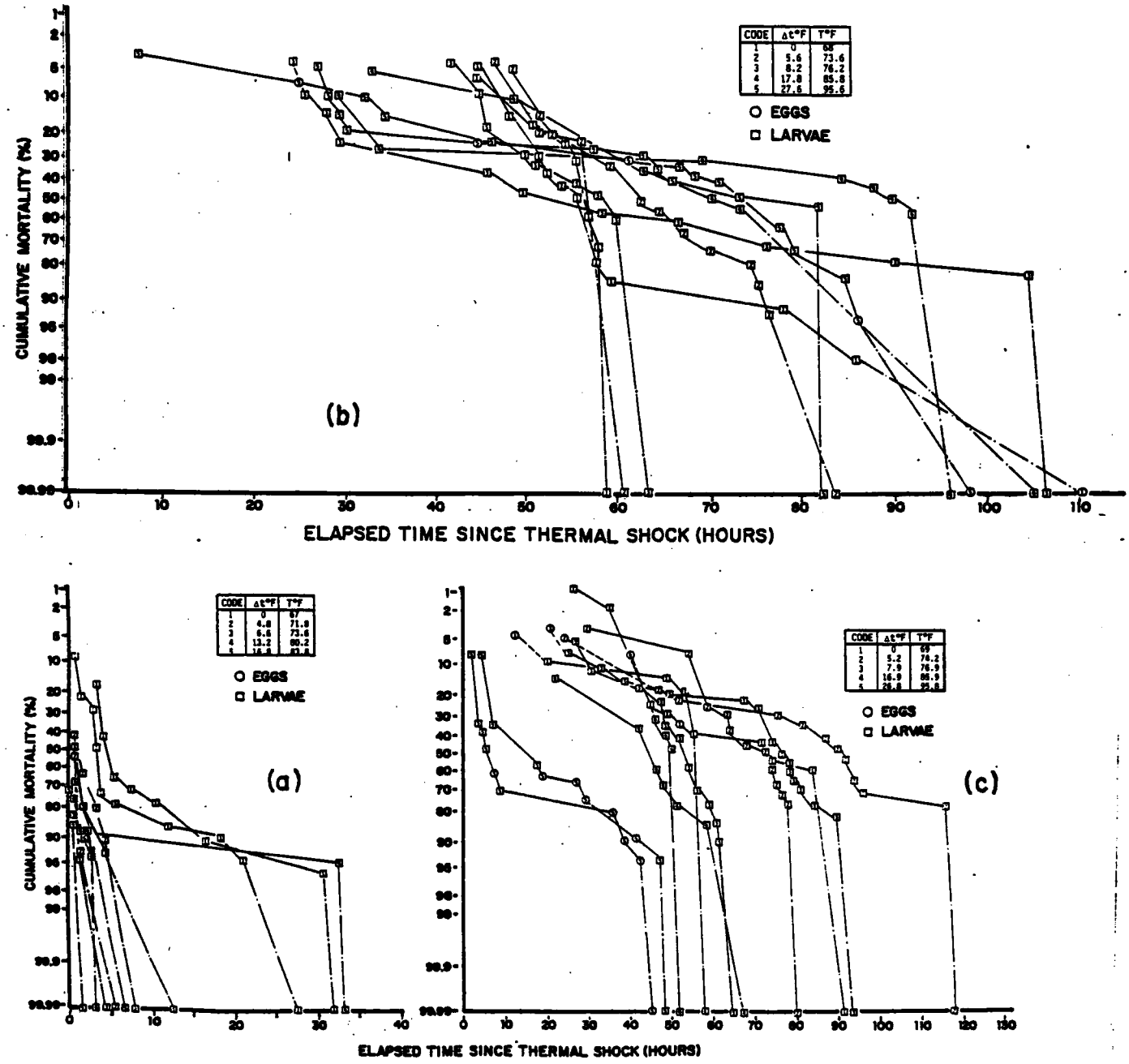


Figure 43. Bioassay Experiment 7. (a) Batch 5 larvae, 132 hr. old, exposed for 10 min. (b) Batch 6 eggs, 62 hr. old, exposed for 20 min. (c) Batch 6 eggs, 62 hr old, exposed for 30 min. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

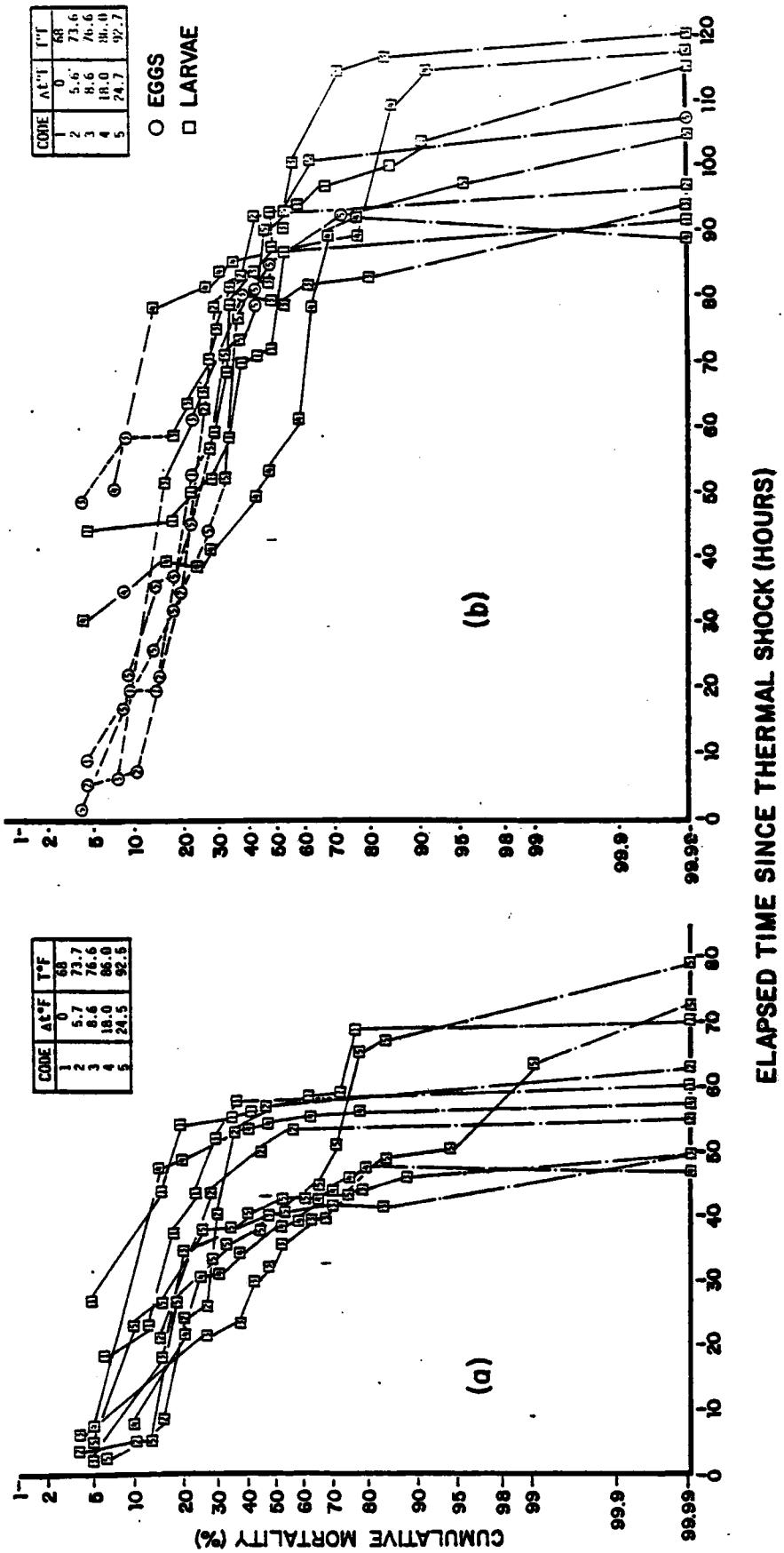


Figure 44. Bioassay Experiment 8. (a) Batch 6 larvae, 83 hr. old. (b) Batch 7 eggs, 37 hr. old. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

(9) Experiment 9

Batch 3 larvae, 228 hr old, were exposed to $\Delta t \leq 17°F$ for 20 min. Replicability was good for all groups except controls (Figure 45). Mortality rates were high, with total mortality occurring within 6 hr for all but one control basket.

(10) Experiment 10

Batch 8 eggs, 61 hr old, were exposed to $\Delta t \leq 25°F$ for 20 and 30 min and Batch 7 larvae, 112 hr old, were subjected to $\Delta t \leq 23°F$ for 20 min. In both egg series survival replicability was poor, and there was no evidence of a relationship between thermal dosage and mortality rate (Figures 46a,b). Total mortality occurred between 50 and 95 hr in both test series, representing a higher mortality rate than observed in the previous egg tests. In the larval test series, mortality was high initially, with live larvae present in only four baskets beyond 6 hr (Figure 46c). Longevity was greatest in control and intermediate dosage ($\Delta t = 9$ and 14°F) groups; complete mortality occurred within 69 hr.

(11) Experiment 11

Batch 7 and 8 larvae, 131 and 87 hr old, respectively, were exposed to $\Delta t \leq 27°F$ for 20 min. Batch 8 larvae were at the hatching stage during this experiment. Batch 7 larvae survival was low among treatment groups ($6°F < \Delta t < 17°F$), but was quite high in the controls (Figure 47a). The 135 hr survival of one control group was the longest observed in any larval test series. Replicability was good in the Batch 8 larvae tests but there was no recognizable pattern between thermal dose and mortality rate (Figure 47b). Complete mortality occurred between 40 and 66 hr after thermal exposure.

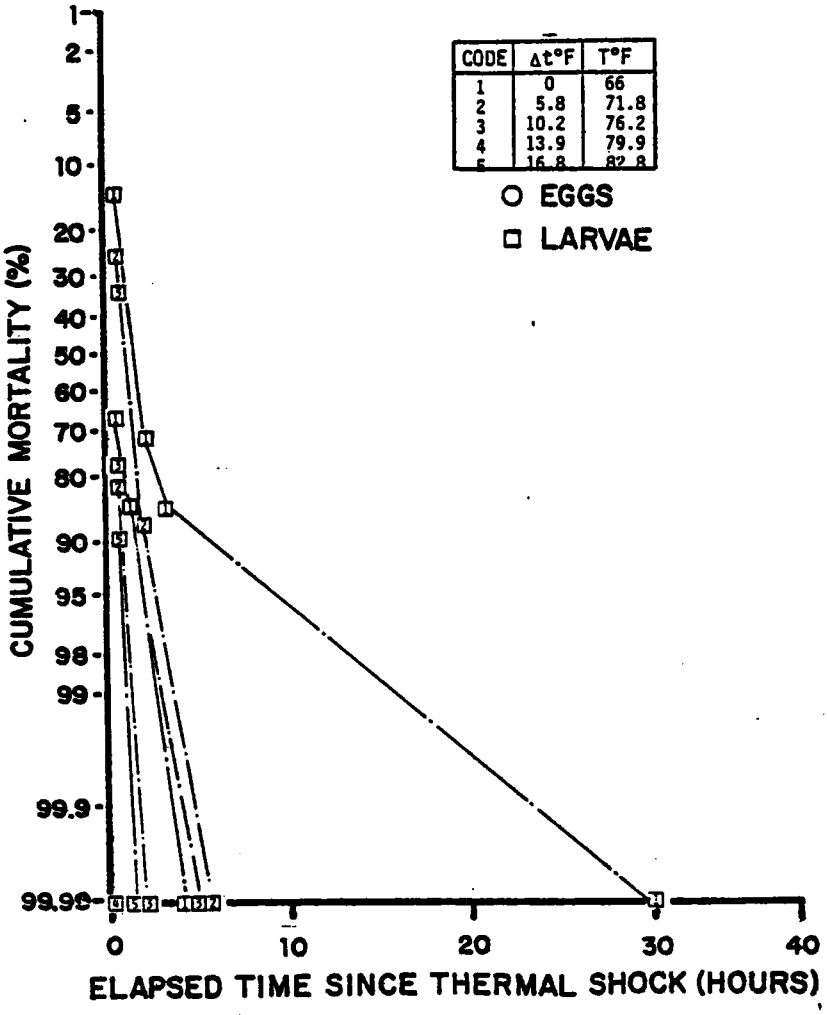


Figure 45. Bioassay Experiment 9. Batch 3 larvae, 228 hr. old, exposed for 20 min. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

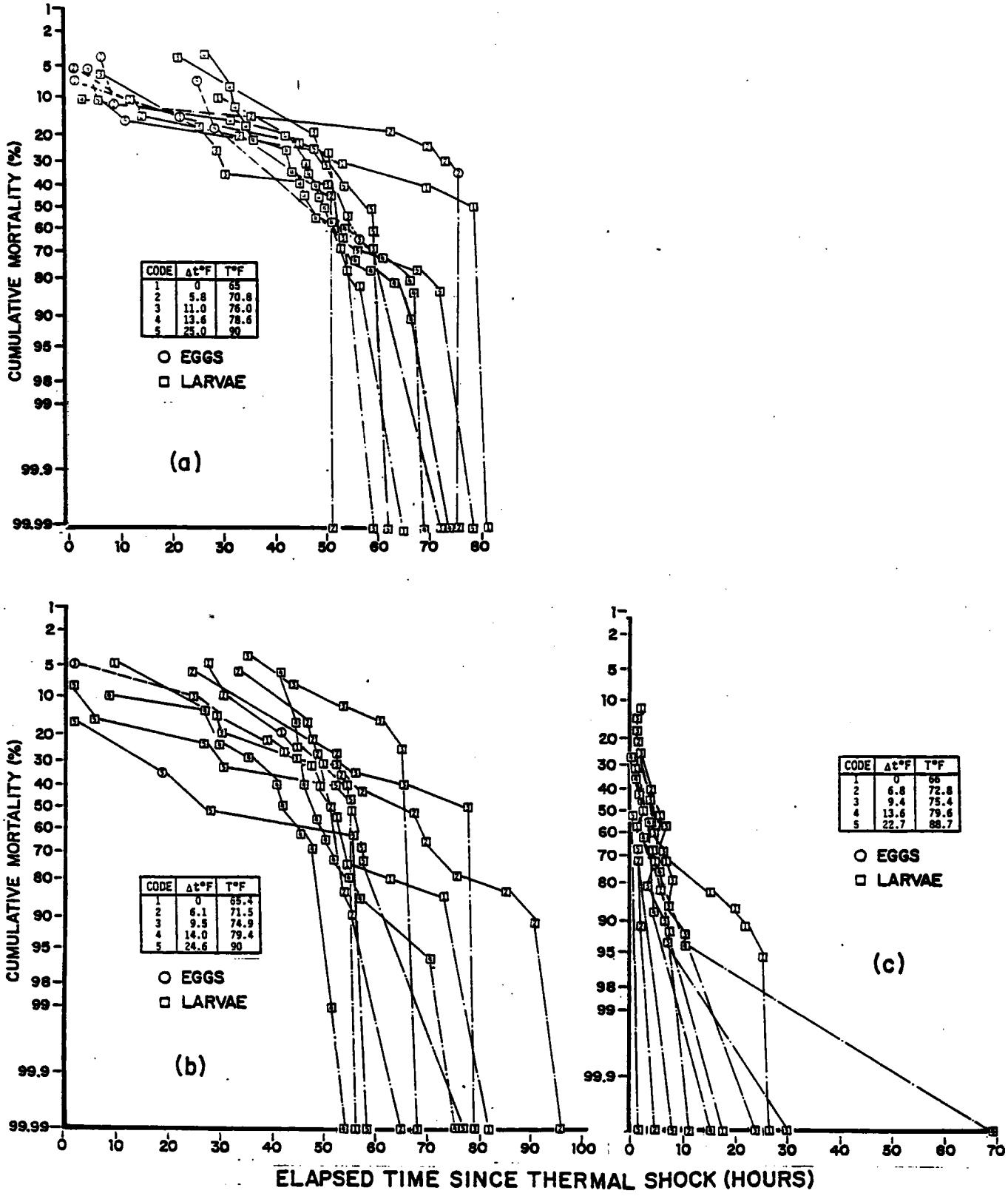


Figure 46. Bioassay Experiment 10. Batch 8 eggs, 61 hrs. old, exposed for 20 min (a) and 30 min (b). (c) Batch 7 larvae 112 hr. old. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

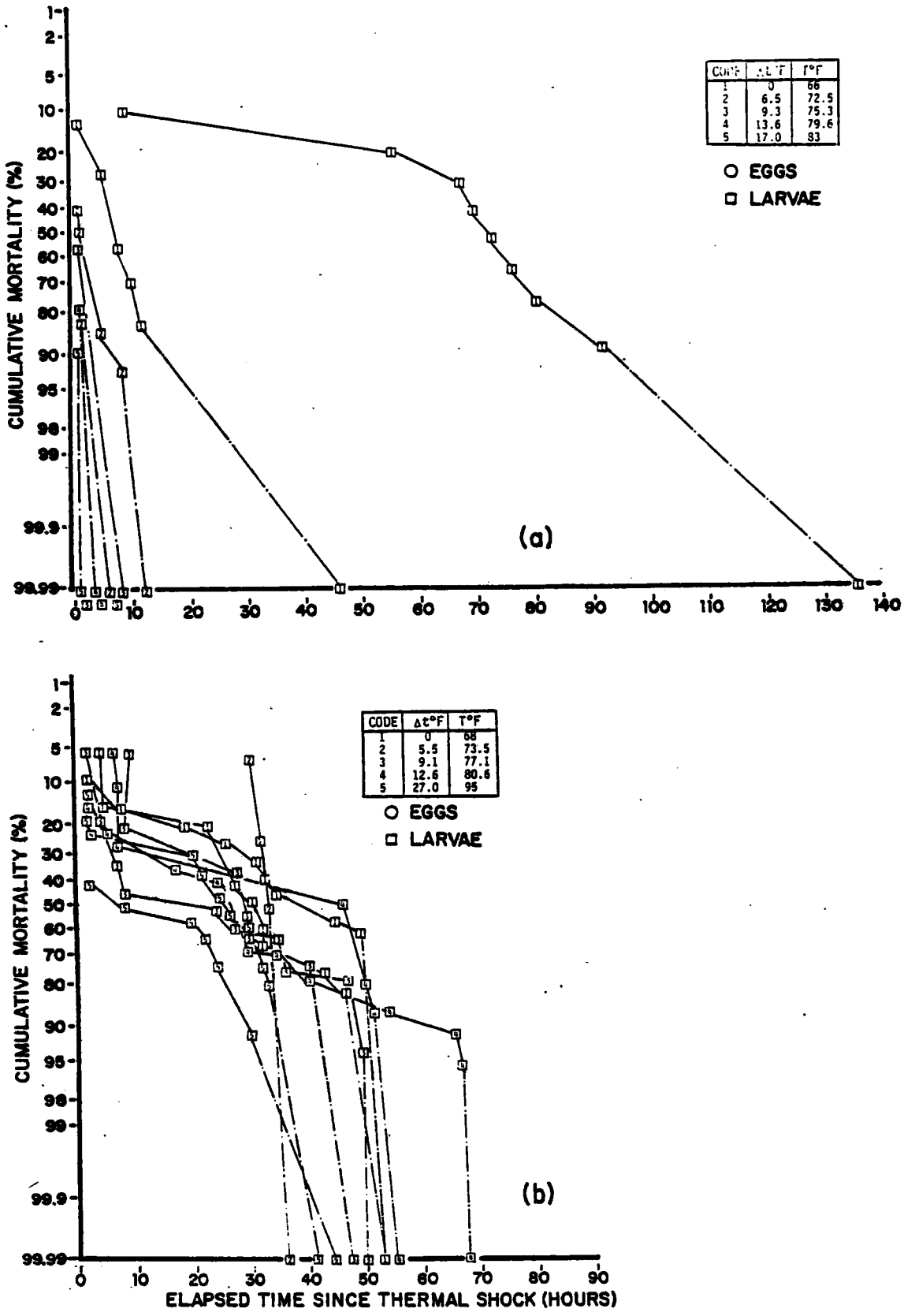


Figure 47. Bioassay Experiment 11. (a) Batch 7 larvae, 131 hr. old. (b) Batch 8 larvae, 87 hr. old. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

(12) Experiment 12

Batch 7, 160 hr old, larvae exposed to $\Delta t \leq 17°F$ for 20 min experienced rapid mortality in all treatment and control groups (Figure 48). All larvae were dead within 8 hr of thermal exposure.

(13) Experiment 13

Batch 8 and 3 larvae, 130 and 351 hr old, were exposed to $\Delta t \leq 17°$ for 20 min. In the Batch 8 series, mortality was high for all but 2 baskets; only one control and one treatment group exposed to $\Delta t = 6°F$ survived beyond 55 hr (Figure 49a). The other larval groups experienced total mortality within 8 hr. The mortality pattern was essentially the same in the Batch 3 larval test series, with only one control and one $\Delta t = 10°F$ basket surviving beyond 42 hr (Figure 49b). All other groups experienced complete mortality within 4 hr of thermal exposure.

(14) Experiment 14

Batch 8 and 9 larvae, 158 and 88 hr old, were subjected to $\Delta t \leq 17°F$ for 20 min. Batch 8 mortality was rapid at all dosage levels. Although controls survived longer than treatment groups, all groups were dead within 7 hr of testing (Figure 50a). Batch 9 larvae, which were at the hatching stage during the test procedure, showed good survival replicability in all groups except $\Delta t = 17°F$ (Figure 50b). With the exception of this basket, the survivorship curves show a distinct direct relationship between mortality rate and thermal dosage. Total mortality occurred within 40 hr of thermal exposure. Batch 9 survivorship curves were the closest to the classic pattern of increased response with dosage observed in the 1976 experiments.

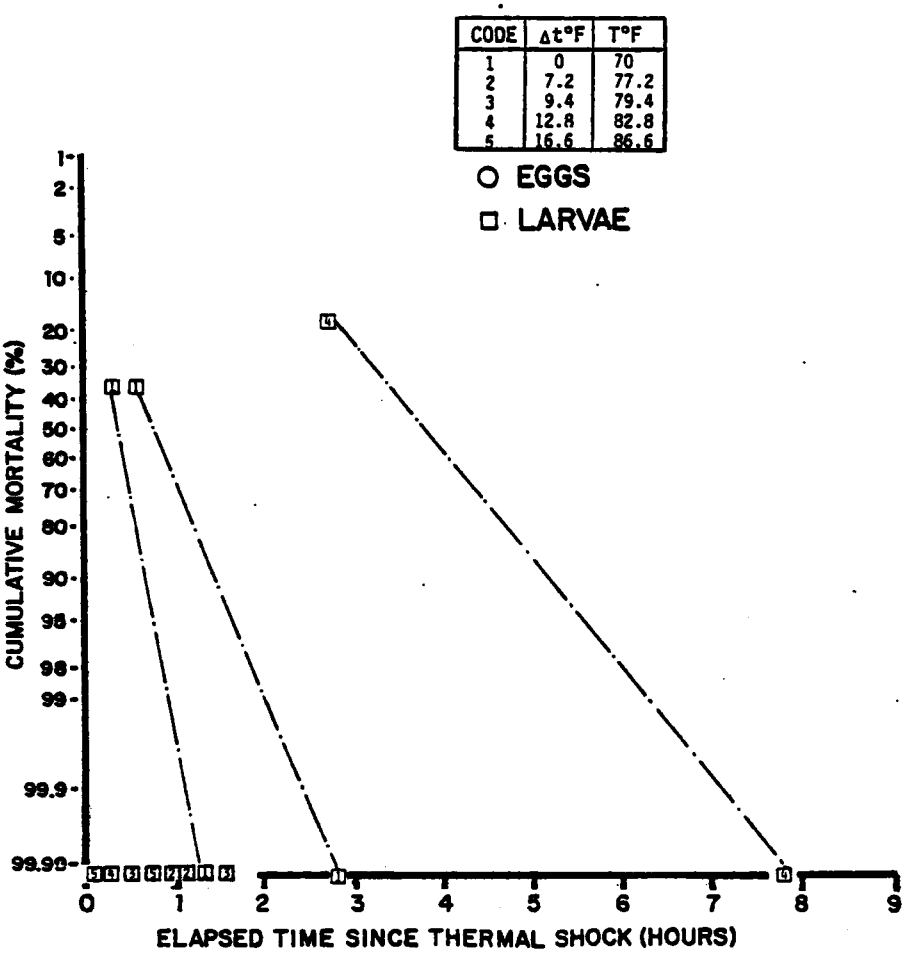


Figure 48. Bioassay Experiment 12. Batch 7 larvae, 160 hr. old, exposed for 20 min. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

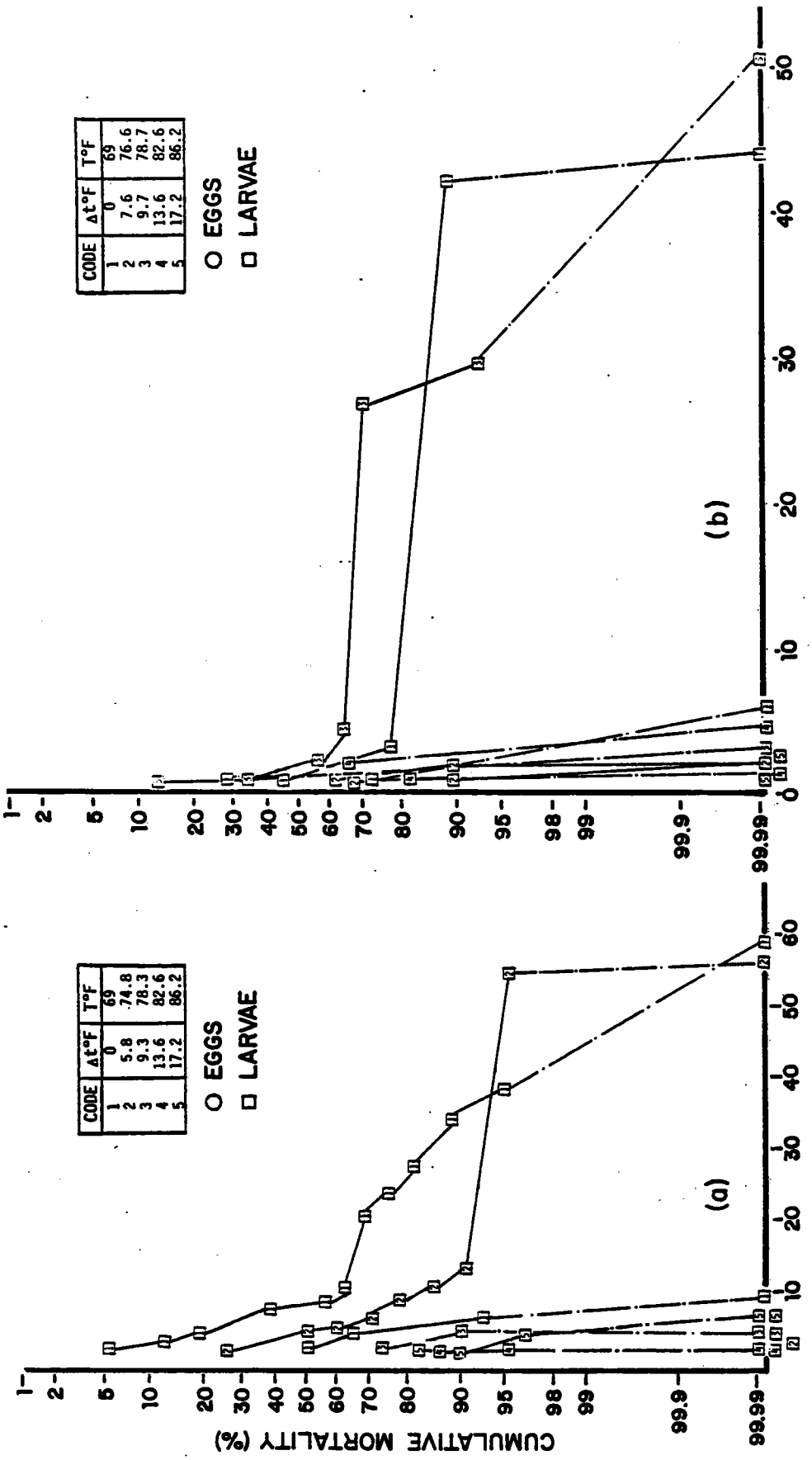


Figure 49. Bioassay Experiment 13. (a) Batch 8 larvae, 130 hr. old. (b) Batch 3 larvae, 351 hr. old. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

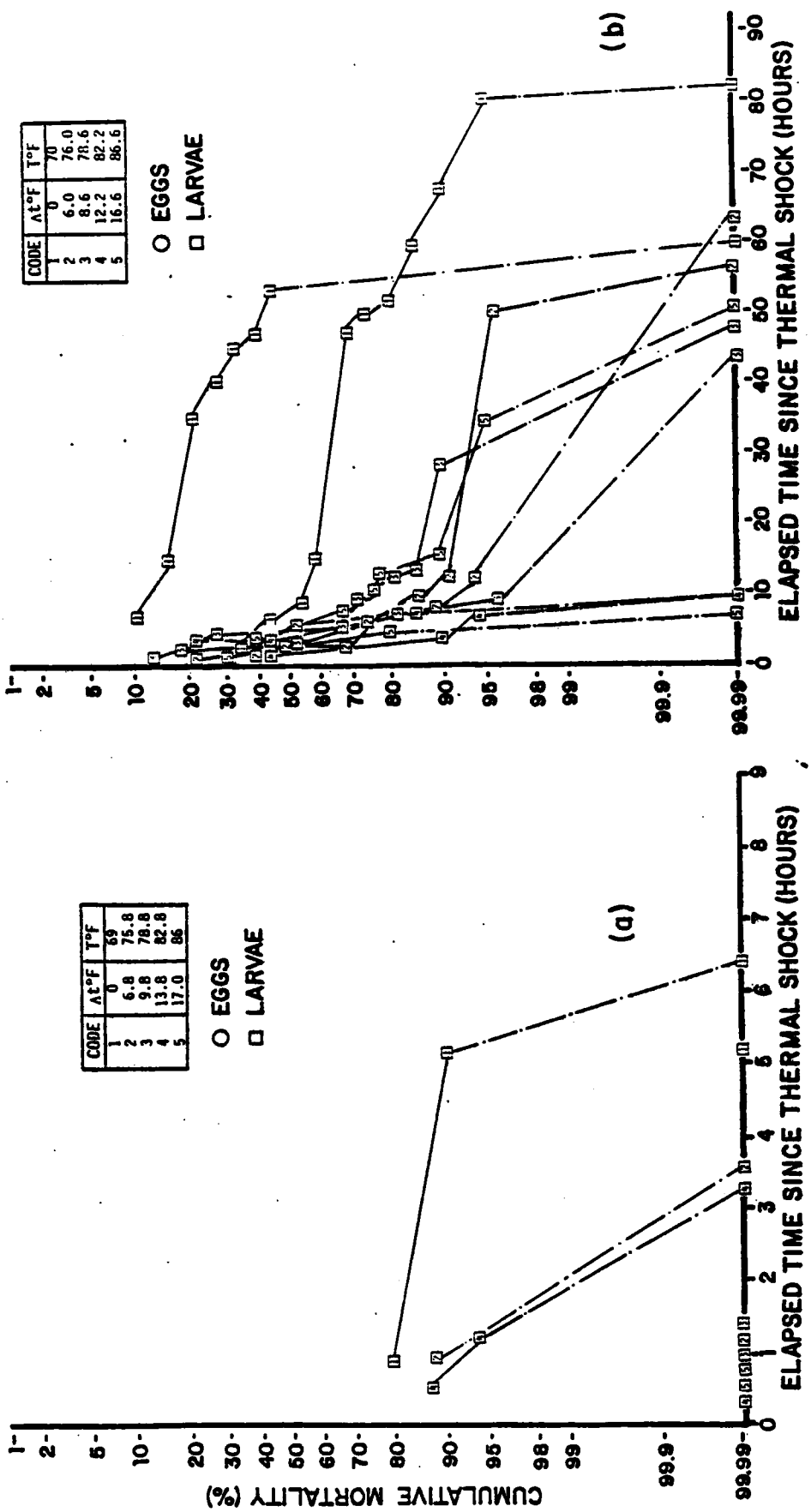


Figure 50. Bioassay Experiment 14. (a) Batch 8 larvae, 158 hr. old (b) Batch 9 larvae, 88 hr old. Change from solid to broken line indicates inferred mortality from time of last live determination. Merrimack River Anadromous Fisheries Investigations, 1976.

b) General

Stepwise multiple regression and analysis of variance (ANOVA) were used for testing laboratory bioassay results. Regression analysis and simple correlation were used to determine the significance of relationships among the following:

INDEPENDENT VARIABLES	DEPENDENT VARIABLES
Acclimation temperature (°F)	Time to 50% mortality (TD50)
Maximum exposure temperature (°F)	Hatching success
Δt (°F)	Survivorship 'n' hr after thermal shock (PAn)
Calculated dose (Δ°F-min)	
Time since fertilization (hr)	

Egg survival percentage was examined at 8, 24, and 48 hr after thermal exposure (PA8, PA24, PA48); larvae were examined at 1, 4 and 8 hr (PA1, PA4, PPA8). Dose was computed in the same manner as described for the field bioassays (p. 77). Analysis of variance was used to determine if variation in calculated dose or exposure time significantly altered survivorship. When significant differences were observed, single degree-of-freedom orthogonal comparisons were used to partition the variation and determine which treatment levels exhibited the observed differences.

(1) Regression Analysis Results

Table 12 and Appendix D6 contain the results of laboratory bioassay stepwise regression. The independent variables age, Δt, ambient temperature, and computed dose were successively added to each equation if F was significant at $\alpha < .01$ and tolerance $\geq .001$. The multiple R^2 indicates the proportion of dependent variable variation that has been accounted for by the included independent variables. F-ratio significance indicates that the slope of the equation is not zero,

TABLE 12. RESULTS OF STEPWISE REGRESSIONS FOR ALL EGG AND LARVAL BATCHES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
LARVAE								
Percent alive at 1 hour	β i.v.[+]	5.41862	-0.00348 age	-0.05806 ambient t	-0.05513 Δt	-0.00014 dosage	.492	11.37***
Percent alive at 4 hours	β i.v.	-0.90489	-0.00312 age	-0.02356 Δt	0.02891 ambient t	0.00019 dosage	.477	10.47***
Percent alive at 8 hours	β i.v.	-2.41363	-0.00274 age	0.04757 ambient t	-0.00876 Δt	-0.00005 dosage	.467	9.92***
Time to 50% death	β i.v.	-0.66885	-0.00085 age	0.01322 ambient t	-0.00006 dosage	-0.00069 Δt	.441	8.59***
EGGS								
Percent alive at 8 hours	β i.v.	1.48308	-0.00005 dosage	-0.00231 Δt	0.00079 age	-0.00139 ambient t	.281	2.02ns
Percent alive at 24 hours	β i.v.	1.32211	-0.00008 dosage	-0.00206 age	-0.00110 Δt	-0.00120 ambient t	.303	2.38ns
Percent alive at 48 hours	β i.v.	2.69488	-0.02624 ambient t	-0.00010 dosage	0.00212 age	0.00085 Δt	.323	2.74*
Hatching success	β i.v.	0.06851	0.01144 ambient t	-0.00004 dosage	0.00080 age	-0.00120 Δt	.099	0.23ns
Time to 50% death	β i.v.	3.19773	-0.03508 ambient t	-0.00312 age	-0.00014 dosage	0.00529 Δt	.509	8.23***

[+] independent variables

* $p < .05$

** $p < .01$

*** $p < .001$

and that there is a true relationship between independent and dependent variables. The equations contained in Tables 12 and D6 are not intended to be prediction functions. Therefore, colinear factors such as calculated dose and Δt were left in the equations to explain as much variability as possible.

(a) Egg Bioassays

Simple correlation coefficients are presented in Appendix Tables D8 and D9 to illustrate the direction and magnitude of relationships between the transformed proportion of live organisms and acclimation temperature, computed dose, Δt, and age. Generally the proportion of living eggs was inversely related to egg age at time of thermal shock. Batch 3 was one exception; there was a direct relationship between age and survivorship, but this group was tested at a younger age (< 40 hr) than the others. Correlations between the proportion of live eggs and Δt and ambient temperature varied among batches. In some cases correlations were very low, indicating that in these experiments mortality was influenced more by unmeasured factors than by either thermal effects or age. When all egg batches were grouped, there was a consistent inverse relationship between proportion of live eggs and calculated dose, Δt, and ambient temperature; this suggests that increased thermal exposure reduced the proportion of live organisms. However, since many of the simple correlation coefficients are low, the implied positive or negative relationships may not be significant. These relationships were further evaluated using stepwise multiple regression.

Many of the egg bioassay regressions indicated no statistically definable relationship between independent and dependent variables, as denoted by non-significant F-ratios. This was particularly true for Batch 2, 4, 7 and 8 egg bioassays (Appendix Table D6).

For Batches 3 and 6, the regressions indicated significant relationships between the dependent variables and the measured independent variables (Appendix Table D6). Ambient temperature, calculated dose, and Δt accounted for 58.2 to 85.9% of the variation in the PA24 and PA48. TD50 and PA8 were also significantly explained by the independent variables age, calculated dose, and Δt. Hatching success was not related to any of the variables monitored.

The relationships between independent and variables were also significant among the Batch 6 egg bioassays. Calculated dose, Δt, and ambient temperature accounted for 40 to 70% of the dependent variable variation. Egg age, which was 62 and 83 hr during these tests, accounted for less than 0.1% of the variation in all dependent variables except PA24, for which it explained 4.9% of the total variation (Appendix Table D6).

With all egg bioassay data combined (Table 12), there was no significant relationship between the four independent variables and either PA8, PA24 or hatching success. Variation in two dependent variables, PA48 and TD50, was significantly related to the independent variables; a maximum of 25.9% of the total variation was accounted for by those variables.

(b) Larval Bioassays

Simple correlation coefficients in the larval bioassays indicated a consistent inverse relationship between dependent and independent variables. Thus, with increasing calculated dose, ambient temperature, or larval age, survival generally decreased. Significant relationships existed in Batch 3, 7, 8 and 9 bioassays and for all larval data combined, but not for either Batch 5 or 6 test series. Among those bioassays where significant relationships existed, the amount of variation explained by any given independent variable varied among batches. However, for Batches 3 and 8, and for all batches

combined, age was the most significant independent variable in terms of accounting for variability among dependent variables (Appendix Table D6; Table 12). Within these batches larvae were tested over a wide age range and survival varied inversely with age. This variable was not as significant in the other batches because of the smaller age range (112-160 hr) over which Batch 7 larvae were tested, and the fact that Batch 9 larvae were tested only once. At older ages, particularly in Batch 3 tests, only the controls survived more than several hr beyond the thermal shock (Table 11). Batch 8 and 9 regressions were exceptional in that multiple R^2 values were higher than usual, indicating that much of the total variation was accounted for by the independent variables.

(2) Analysis of Variance Results

Analysis of variance results are summarized in Appendix Table D7. Significant orthogonal contrasts are presented in Table 13a,b.

(a) Egg Bioassays

Survival of Egg Batches 1, 4 and 7 was tested for differences among thermal exposure groups using one-way ANOVA. None of the dependent variables varied significantly ($p < .05$) among the different exposure temperatures (Table 13). In each of these tests, survival replicability was poor, and survivorship curves gave no evidence of a relationship between mortality and exposure temperature (Figures 38, 41, 45, 45 and 49).

Egg Batch 2, 3, 6 and 8 bioassay results were analyzed using a two-way ANOVA with exposure temperature and duration as factors. Batch 2 eggs, exposed for 10, 20 and 30 min showed significant differences among duration and exposure temperatures for all dependent variables (Table 13). The highly significant interaction terms suggest a synergistic relationship between exposure time and temperature. Partitioning

TABLE 13a. SINGLE DEGREE OF FREEDOM ORTHOGONAL COMPARISONS AMONG EXPOSURE DURATIONS AND TEMPERATURES * FOR EGG BIOASSAYS **. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

TEST SERIES	DUR. (MIN.)	PA8	PA24	PA48	TD50
BATCH 2		2 3 1 4 5	1 2 3 4 5	1 2 3 4 5	2 3 1 4 5
EXPERIMENT 1	10				
EXPERIMENT 2	20				
EXPERIMENT 3	30				
BATCH 6	20	1 2 3 4 5	2 3 1 4 5	1 2 3 4 5	2 3 1 4 5
EXPERIMENT 7	30				
BATCH 8	20	N.S.	N.S.	2 3 1 4 5	N.S.
EXPERIMENT 10	30				

* EXPOSURE TEMPERATURES: 1 = CONTROLS
2,3 = LOWER Δt EXPOSURES
4,5 = HIGHER Δt EXPOSURES

** LINES CONNECT THOSE GROUPS FOR WHICH DIFFERENCES WERE NOT SIGNIFICANT ($p>.05$)

TABLE 13b. SINGLE DEGREE OF FREEDOM ORTHOGONAL COMPARISONS AMONG EXPOSURE DURATIONS AND TEMPERATURES * FOR LARVAL BIOASSAYS **. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

TEST SERIES	DUR. (MIN.)	PA1	PA4	PA8	TD50
BATCH 3 EXPERIMENT 6	10	2 3 1 4 5	N.S.	N.S.	N.S.
	20				
BATCH 5 EXPERIMENT 7	10	2 3 1 4 5	N.S.	2 3 1 4 5	2 3 1 4 5
BATCH 6 EXPERIMENT 8	20	N.S.	N.S.	N.S.	1 2 3 4 5
BATCH 7 EXPERIMENT 10	20	2 3 1 4 5	2 3 1 4 5	2 3 1 4 5	N.S.
EXPERIMENT 11					
EXPERIMENT 12					
BATCH 8 EXPERIMENT 11	20	1 2 3 4 5	1 2 3 4 5	N.S.	N.S.
EXPERIMENT 13					
EXPERIMENT 14					
BATCH 9 EXPERIMENT 14	20	N.S.	N.S.	1 2 3 4 5	N.S.

* EXPOSURE TEMPERATURES: 1 = CONTROLS
2,3 = LOWER Δt EXPOSURES
4,5 = HIGHER Δt EXPOSURES

** LINES CONNECT THOSE GROUPS FOR WHICH DIFFERENCES WERE NOT SIGNIFICANT ($\rho > .05$)

the observed variation revealed significant differences among all durations. In addition, PA8 differed significantly between control and treatment groups in the 10-min duration test and between the two high and two low thermal exposures in the 10 and 30-min tests. The 20-min test revealed no differences between thermal exposure groups.

Batch 3 survivorship differences were not significant among exposure temperatures, but differences between the 20 and 30 min durations were significant for PA8, PA24, and PA48 (Table 13). Analysis of Batch 6 egg data revealed significant variation among duration and exposure temperatures for all dependent variables (Table 13). Orthogonal comparisons indicated that within the 30-min, but not the 20-min exposure, the mortality was significantly lower among controls than treatment groups 8 hr after thermal shock. In addition, survival was significantly greater among groups exposed to lower Δt's than those subjected to higher temperatures. This reinforces the earlier observations on the relationship between Batch 6 egg survival and thermal exposure (Figures 44-45). Those figures also illustrate the observed effects of calculated dose on the surviving proportion of Batch 6 eggs. In each case, exposure greater than 1024°ΔF-min above ambient or to temperatures above 94°F caused increased mortality. This survival rate change at high dosages, and the significant exposure temperature-duration interaction (Appendix Table D7) indicate a synergistic relationship between the two factors as they relate to egg survival.

Batch 8 egg analysis (20, 30 min duration) showed no significant duration differences, but did indicate significance among exposure temperatures for PA48 (Appendix Table D7). Orthogonal comparisons revealed that PA48 was significantly greater for the lower ($\Delta t \leq$ 10°F) than the higher ($\Delta t \geq$ 14°F) temperature exposure groups (Table 13).

(b) Larval Bioassays

Two-way ANOVA across exposure temperatures and durations (10, 20 min) for Batch 3 larvae are presented in Appendix Table D7. For all dependent variables except PA1 in Experiment 6 there were no significant differences among treatments. Orthogonal contrasts (Table 13) showed that Experiment 6 PA1 was greater in the 20-min exposure group than for those exposed for only 10 min. It has been shown previously, however, (Figures 42-44) that mortality in the 10-min groups occurred rapidly, with larvae surviving beyond 8 hr in only two baskets. In both the 10 and 20 min duration tests, the PA1 in the low and high dosage treatment groups differed significantly (Table 13).

PA1, PA8 and TD50 were significantly different among exposure temperatures for Batch 5 larvae. In each case, survival was higher in the groups exposed to lower Δt's (Table 13). There were also no significant differences among thermal exposure levels in the proportion of live Batch 6 larvae up to 8 hr after exposure to $\Delta t \leq 24°C$ for 20 min. TD50, however, was significantly higher for control than treatment groups (Table 13).

Batch 7 and 8 larvae were all tested for 20 min; ANOVA was used to compare differences among experiments and exposure temperatures. Differences among experiments were generally significant (Table 13), likely the result of increasing larval age, which has been discussed previously. In addition, orthogonal comparisons revealed that in the Batch 7 test series, Experiment 10 and 11 results were not different, although both differed significantly from Experiment 12. This was largely due to the unusually high mortality rate observed among Experiment 12 larvae (Figure 49). Within Experiments 10 and 11, PA4 and PA8 were significantly different between control and the treatment groups (Table 13). Batch 8 larvae ANOVA showed that PA1 and PA4 were significantly different between Experiment 11 and Experiments 13 and 14 (Table 13). As discussed previously, mortality occurred rapidly among treatment groups in Experiments 13 and 14, with few survivors beyond 8 hr

(Figures 50-51). Orthogonal comparisons also indicated that PA4 was greater among controls than among treatment groups in all Batch 8 larvae experiments (Table 13). In addition, within Experiment 11 the groups subjected to the lower dosages showed a lower mortality after 4 hr than did the high exposure groups.

In Experiment 14, Batch 9 larvae controls survived significantly better than the treatment groups 8 hr after thermal shock, although no survival differences were observed at one and four hours. Additionally, TD50 was not significantly different among the treatment groups or the controls.

3) Summary

a) 1975

Laboratory bioassays in 1975 indicated a direct relationship between larval mortality and exposure temperature, such that higher exposures resulted in greater mortality. Cumulative survival was fairly constant when exposure temperature $\leq$ 96° and $\Delta t \leq$ 20°F, but at higher exposure temperatures, survival decreased sharply. Larvae older than 230 hr did not survive as well under test conditions as the younger organisms. In most test series, survival was higher among the controls than the treatment groups.

b) 1976

In 1976, both eggs and larvae were tested. Egg bioassay results were variable. Survival was not related to exposure temperature in four of the seven egg batches tested. Only the PA48 differed among exposures in the Batch 8 test. In the remaining two batches (2 and 6), survival differed significantly ($p < .05$) among both exposure temperatures and durations, giving evidence for a synergistic relationship

between temperature and duration. Those groups with survival differences among exposure levels were not subjected to more rigorous conditions than the other groups. There was no generally apparent survival change with increasing egg age.

Survival was generally much lower among larvae than among eggs. Total larval mortality, including controls, usually occurred within 80 hr of testing, and most test groups died within 20 hr. The survival data varied considerably, particularly among experiments. Although mortality was often rapid following a test series, the differential mortality among exposure groups was not always significant. In those test series where significant differences in PA1, PA4, PA8 or TD50 occurred, the control survival rate was usually higher than the treatment groups, and the lower exposure groups survived better than those exposed to higher temperatures. As shown by the regression analysis, mortality also varied with larval age such that younger larvae survived better than older larvae under the bioassay conditions.

III. DISCUSSION

A. THERMAL TOLERANCE

1. Eggs

Shad egg survival was not influenced significantly by exposure to temperatures below 93°F or to Δt's less than 25°F. All but one test group subjected to these conditions survived as well as the controls. Batch 2 eggs (Experiment 3) were the exception, but in this case the treatment groups survived better than the controls. Batch 6 eggs were the only ones exposed to temperatures above 93°F or to Δt's greater than 25°F. Under these test conditions, (1) mortality differed significantly between control and treatment groups the 30-min duration test, but not in the 20-min test; and (2) mortality was greatest in the groups exposed to highest temperatures and lowest in control groups. This mortality increase at the highest dosages combined with the similarity to control survivorship under less-rigorous conditions, indicate that exposure to 96°F for more than 20 min is the minimum thermal dosage required to increase shad egg mortality. Similarly, Merrimack Station field bioassays conducted with Δt's and maximum exposure temperature of up to 16 and 90°F, respectively, indicated no clear-cut temperature-related mortality.

These results corroborate the apparent insensitivity of shad eggs reported by Schubel (1974) and Schubel and Koo (1975), who essentially found no measurable effect on shad egg hatching success after exposure to temperatures < 30°C for up to 60 min. Additionally, the apparent higher response to maximum exposure temperature than Δt observed by these authors was also corroborated. However, the age relationship observed for some field bioassay dependent variables was not evident for eggs tested under laboratory conditions.

The Maryland studies (Schubel, 1974; Schubel and Koo, 1975) used different endpoints than were used in Merrimack investigations. Schubel and co-workers used only hatching success whereas survivorship over time was studied at Merrimack Station. In addition, observed mortality was lower and resulting precision greater in the Maryland studies. The most likely explanation of the higher precision is the egg procurement method employed. Eggs used in the Merrimack studies represent a composite sample from many females, thereby incorporating an unknown and uncontrolled source of genetic and environmental variability. The Maryland investigators were able to separate their egg lots by female and employ a randomized block analysis to partition this source of variability. This results in a smaller "error" component and increased precision.

2. Larvae

1976 bioassays revealed that exposure of shad larvae to temperatures below 92°F and Δt's less than 23°F for up to 30 min caused no statistically significant mortality differences between control and treatment groups. Only Batch 8 larvae (Experiment 11) were exposed to temperatures above 92°F and $\Delta t > 23°$, and in this test series only PA4 differed significanlty between controls and treatment groups. These findings appear to contradict 1975 results, which indicated a significant larval mortality after exposure to $\Delta t > 20°F$ or temperatures above 94°F for 20 min. This apparent discrepancy can be related to larval age at test time; 1976 Batch 8 larvae were considerably younger than the larvae tested in 1975 (87 vs. 200 hr since fertilization). Regression analysis based on 1976 experiments showed that mortality was directly related to larval age. Thus, the younger (Batch 8) larvae showed a higher thermal resistance than the older groups tested in 1975. Overall, exposure to temperatures above 94°F or Δt's greater than 20°F for 10 min were required to significantly influence mortality in shad larvae older than 200 hr; more extreme conditions (temperature > 95° and $\Delta t >$ 27°) were necessary to effect the same results in younger larvae.

As was the case for eggs, both the Merrimack and Maryland (Schubel *et al.*, 1975) investigations indicate a maximum temperature effect which is more evident than the Δt response. Schubel *et al.* (1975), for example, found that exposure to Δt = 10°C (18°F) increased mortality significantly at base temperature = 27°C (80.6°F) and maximum exposure temperature = 37°C (98.6°F). At base temperature = 17°C (62.6°F), exposure to Δt = 14.5°C (26.1°F; maximum temperature = 88.7°F) produced no significant mortality, but the same experiment run at base temperature = 18°C (64.4°F; maximum temperature = 90.5°F) produced significant mortality at the highest exposure temperatures and longest durations (Schubel *et al.*, 1975). The same trends are evident for the Merrimack larvae bioassays.

In general, shad larvae appear more easily affected by the rapid temperature increases typical of powerplants than do the eggs. An important consideration in evaluating both Merrimack Station and Maryland laboratory results, however, is that in all cases the larvae were stressed to some degree by handling before encountering any thermal stress. Although designed to minimize handling and related stresses, the success of these efforts was not monitored as part of the experiment's design. The high control mortality in many experiments attests the stress imposed by the experimental procedures. Older, post-yolk sac larvae reared in the laboratory were further stressed; all indications are that laboratory feeding attempts to date have been unsuccessful. Therefore, post-yolk sac larvae reared entirely in the laboratory were at some stage of starvation prior to thermal exposure. Larvae from the hatching boxes (1975 Merrimack studies only), by virtue of their age, had probably been feeding prior to testing.

In conclusion, the prior stress condition of the larvae, from handling, starvation, or both, infers that temperature tolerances resulting from laboratory investigations to date may represent worst-case conditions.

B. ENTRAINMENT

Based on physical and biological data generated by this investigation and ongoing study at other power plants located on shad spawning rivers, American shad eggs and larvae will undoubtedly be entrained in Merrimack Station cooling water. Entrained eggs and larvae will be subjected to a variety of mechanical and thermal stresses depending on (1) whether they are entrained directly in the cooling water or indirectly in the thermal discharge; (2) plant output and resultant heat rejection; and (3) pre-entrainment ambient thermal conditions. The following section discusses the likely magnitude of entrainment and probability of death for entrained organisms in relation to these variables.

1. Pump Entrainment

The number of eggs entrained directly in the cooling waters will be related to the physical responses of the eggs to various flow-related parameters. For larvae, behavioral responses will also be important.

a. Eggs

Potential pump entrainment of the semi-buoyant eggs can be discussed under two sets of conditions. The first case is for spawning having occurred far enough above the cooling water intakes for the eggs to have reached the substrate. Under these conditions eggs will be transported as a function of current speed, as investigated and discussed in Section II.C.1. The second possibility is for shad to have spawned close enough to Merrimack Station that the eggs will still be in the water column upon reaching the intakes. In this case egg movement will be related to both current speed and fall velocity.

For the latter case of spawning near the intakes, wherein the probability of entrainment is, intuitively, greater than in the former case, consider the following series of computations: Examination of Columns 7-9 in Table 3 reveals that mean velocities for transects north of the intakes (Figure 1) range from 0.8 kts (4.1 cm sec^{-1}) at Transect IO, Station D at 1000 cfs, to 1.62 kts (83.3 cm sec^{-1}) at Transect SOUS, Station A at 8000 cfs. The maximum depth recorded at any station north of the intake is about 12 ft (3.66 m). Considering that viable, water hardened eggs fall at about 1.25 cm sec^{-1} (p. 60), the maximum travel time from surface to bottom north of the intake is approximately

$$366 \text{ cm} \div 1.25 \text{ cm sec}^{-1} = 292.7 \text{ sec}$$

Non-water hardened, freshly spawned eggs are generally denser and sink faster; at a sinking rate of 1.9 cm sec^{-1} (fall velocity of Stira's non-water hardened artificial eggs, p. 65), fall time for 12 ft is approximately

$$366 \text{ cm} \div 1.9 \text{ cm sec}^{-1} = 192.5 \text{ sec}$$

The values of 1.25 cm sec^{-1} and 292.7 sec are therefore, conservative. Using minimum and maximum mean velocities from Table 3 for further simple multiplication, the following range of distances traveled downstream during the fall from surface to bottom (12 ft) can be generated:

	FALL VELOCITY (cm sec^{-1})	TIME OF TRAVEL (sec)	RANGE OF MEAN VELOCITIES (cm sec^{-1})	RANGE OF DISTANCES TRAVELED (m)
Water hardened eggs	1.9	192.5	4.1-83.3	12-243
Non-water hardened eggs	1.25	292.7	4.1-83.3	8-160

Thus, using the most conservative estimate (highest mean velocity, deepest water, slowest fall velocity) the zone in which freshly-spawned eggs will be vulnerable to the intakes extends less than 250 m upstream. A point approximately 250 m upstream of the intakes at Merrimack Station corresponds approximately to Transect N-7 on Figure 1 and represents approximately 6% of the distance between the plant and Garvins Falls Dam. At discharge levels < 8,000 cfs and mean velocities more typical of the area around the intakes (Table 3), this distance is correspondingly smaller.

Consider next the streamlines in Figure 21. As these illustrate, the lateral (cross-stream) extent of the intakes' zone of influence decreases with increased flow. The magnitude of this change is roughly proportional to the volumetric relationship between cooling water volume and flow. The ratio of cooling water to river volume decreases exponentially over the range approximately 0.5 at 1000 cfs to approximately 0.05 at 8000 cfs. At the same time, the upstream extent of vulnerability decreases from an absolute maximum of 250 m, as previously discussed, to a minimum of somewhere on the order of 10 m at approximately 1000 cfs in direct proportion to vertical average velocity, which also varies with flow. Because of the velocity "plateau" beginning at about 4000 cfs (p. 47, Figure 22), the area of influence is most likely at its maximum at approximately 4000 cfs; above this the volumetric relationship decreases the cross-stream component with little commensurate increase in the upstream, velocity-related component.

The Merrimack is approximately 750 ft (229 m) wide at the intakes. Assuming it to be rectangular in cross-section and using the volumetric approximation, the cross-stream extent of the zone of influence for newly-spawned eggs is

$$(229\ \text{m}) \cdot {}^{444}/_{4000} \approx 25\ \text{m}.$$

Using the 4000 cfs mean velocity at Transect IN-B of 0.079 kts (40.6 cm sec^{1}; worst case near intake @ 4000 cfs from Table 3), the upstream component can be computed as

$$(292.7 \text{ sec})(40.6 \text{ cm sec}^{1}) \approx 120 \text{ m}.$$

The maximum area of influence, then, is a rectangle of roughly 3000 m^2 extending out about 25 m and upstream about 120 m from the intakes. If only the area of Hooksett Pond north of the plant is considered "suitable" for spawning (conservative assumption), there is potentially about 4022.5 m (2.5 mi) • 185 m (600 ft mean width) = 744162.5 m^2 of potential spawning area within Hooksett Pond. The maximum zone of influence, then, represents $\frac{3000}{744162.5} \approx 0.4\%$ of the available area. In other words, if all the areas north of the intakes are equally suitable for spawning (which they are probably not -- see Introduction, page 7), the chances are about 4 in 1000 that any eggs at all will be entrained before they reach the bottom under the most conservative constraints. And, even if this unlikely event should occur, only a fraction of the eggs produced in the zone would be entrained.

For eggs spawned farther than 250 m north of the intakes, potential pump entrainment must be considered in a different manner. These eggs will be subjected to the conditions of sediment transport discussed in Section II.C.1. That is, movement over a bed of sediment will begin at approximately 5 cm sec^{-1} as a downstream rolling motion with considerable sheltering effect. This phase will continue through about 10 cm sec^{-1}, when saltation, or "hopping" along the bottom, begins. At approximately 15 cm sec^{-1} these bed-load phases will begin to be supplemented by suspended load transport wherein some eggs will be carried in the moving water mass itself rather than in association with the substrate. At 20 cm sec^{-1} there will be significant suspended load transport, and sediment in the coarse sand category typical of much of Hooksett Pond will begin to be unstable. Sheltering will remain significant in depressions on the order of 10 to 100 times the egg diameter at velocities up through 20 cm sec^{-1}, however.

In relation to Hooksett Pond, the critical velocities 5, 10 and 20 cm sec^{-1}, determined in the laboratory, represent different stages of potential egg movement. When velocity in the lower 1-2 cm of the water column reaches 5 cm sec^{-1} eggs will just begin moving in areas where no sheltering can be effected, such as on a relatively smooth sand bottom; it is doubtful that a current of 5 cm sec^{-1} will dislodge sheltered eggs from a gravel or cobble substrate area, such as Transect SOUS, or an area where aquatic plants or debris are present. At 10 cm sec^{-1} some eggs may be dislodged from all substrate types through shelter exchange, and this velocity probably represents a valid threshold for egg movement under natural conditions. When velocities in the lower 1-2 cm of the water column approach 20 cm sec^{-1}, egg movement in both suspended and bed-load nodes will occur and sheltering will only take place among pronounced substrate irregularities.

The depths at which the critical velocities of 5, 10 and 20 cm sec^{-1} occur at each transect north of the intake are plotted against flow in Figure 51. These data are from columns 7-9 of Table 3 and illustrate computations discussed on pages 48 to 52. The lines in Figure 51, then, represent lines of equal velocity for each station. From this figure it is obvious that highest velocities occur near Transect SOUS-A and that velocities are typically lower in the area near the intakes, as discussed earlier. For this reason, the velocity 5 cm sec^{-1} in the lower 1-2 cm of water is reached at approximately 2200 cfs for Transect SOUS but not until almost 3000 cfs for the other transects. Similarly, the velocity 10 cm sec^{-1} in the lower 1-2 cm of water, which represents the egg movement threshold, occurs around 3000 cfs at Transect SOUS but not until almost 4000 cfs at the others. Twenty cm sec^{-1}, which represents the velocity at which eggs can become resuspended and, therefore, potentially entrained in significant numbers by Merrimack Station, does not occur until 4-6000 cfs at Transect SOUS. More importantly, as Figure 51 illustrates, this velocity is never attained at Transects IN and IO, near the intake, at flow rates of 8000 cfs or less. And, because the eggs will never be suspended at these typical spawning season flow rates, their entrainment as a direct function of volume will

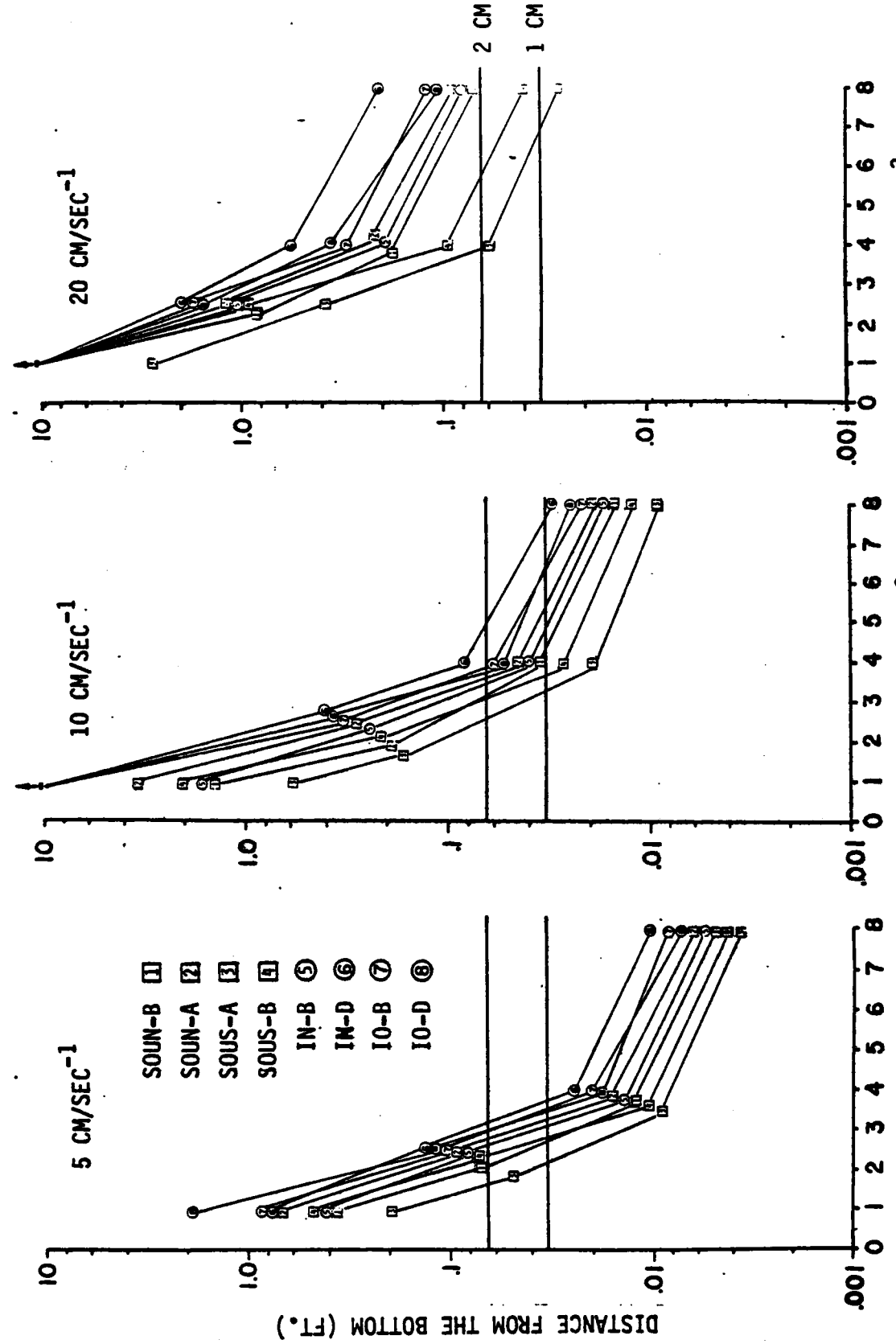


Figure 51. Depths at which the critical egg transport velocities 5, 10, and 20 cm sec-1 occur as a function of Garvin's Falls discharge. Horizontal lines represent depths of 1 and 2 cm from bottom. Merrimack River Anadromous Fisheries Investigations, 1976

never occur. Should flows substantially higher than 8000 cfs occur and, potentially, cause significant egg movement, the volume of the cooling water and resulting entrainment magnitude would be proportionally very small (444 cfs/10000 cfs = 0.044 if eggs mixed uniformly).

Because of this, the only pump entrainment to be experienced by eggs spawned more than 250 m north of the intakes will occur at discharge levels greater than approximately 4000 cfs, when eggs are moving as bed-load associated with the substrate. The probability of entraining bed-load eggs is extremely low because the cross-stream component of the near-bottom current decreases rapidly with distance from the intake.

In conclusion, the laboratory and field data indicate that the probability of directly entraining shad eggs in the Merrimack Station cooling water flow is extremely low. The transport characterisics of the eggs make it unlikely that any eggs will be in suspension near the intakes at discharge levels typical of the spawning season (< 8000 cfs), and the cross-stream component of the near-bottom currents make it further unlikely that any bed-load eggs will be entrained. Some direct egg entrainment is possible if shad spawn in an area extending roughly 25 m offshore and 120 m upstream of the intake. This requires that the fish select a particular 3000 m^2 area adjacent to a bank, which represents approximately 0.4% of the potential habitat between the plant and Garvins Falls, in which to spawn. Direct egg entrainment, even under these most conservative assumptions, is a remote possibility at the worst and, more realistically, highly unlikely.

b. Larvae

The potential entrainability of shad larvae at Merrimack Station is considerably more difficult to assess than that of eggs. This is largely because many aspects of larval ecology, especially be-

havioral ecology, are at best poorly understood. Experiments conducted during 1976 and Connecticut River field observations together have produced some additional insight into previously unknown distributional and feeding aspects. However, the laboratory studies conducted to date were, admittedly, somewhat crude and the resolving power of present field studies, in terms of their ability to quantitatively elucidate behavioral responses to environmental variables, appears limited. Nevertheless, recent findings have helped and the following represents a brief summarization of current thought concerning larval ecology with inferences regarding potential entrainment.

All indications suggest that 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 laboratory displayed this behavior pattern almost 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. Laboratory observations, then, indicate that for the first day or so after hatching the larvae are in a periodically active, swimming state characterized by a net upward movement. At the end of this initial period, sac-fry in the laboratory were observed swimming continuously and actively at the surface, oriented towards any current. However, current speeds as low as 3 cm sec^{-1} were capable of displacing these young individuals. As a result, larvae can be classified as "actively passive" for at least the first day after hatching.

After the first day or two, laboratory larvae became progressively more adept at maintaining position in the test flume. Observations indicated that they were able to detect and orient to currents of

less than 3 cm sec^{-1}. During this stage they tended to seek areas of minimal current, a trait which remained consistent throughout the approximately 3 weeks of laboratory observations. These observations are consistent with Connecticut River field study; during the summer of 1976, larvae were seined successfully from eddies and backwaters, as depicted in Plate 3a.

From the results presented in Section II.B.1. and the earlier work of Massman (1963) and Maxfield (1952), it appears shad larvae begin feeding at a size of about 8-10 mm total length. According to Maxfield, this corresponds to an age of about 3-5 days after hatching. The immature zooplankters and benthic insects present in the larval guts examined indicate at least some active, sight-oriented feeding, rather than filter feeding, and may imply that the larvae occasionally venture outside of their quiescent zones. Whether this is accidental or intentional has not yet been determined, but it is consistent with flume observations (see page 68). Further, their demonstrated ability to swim rapidly for short periods suggests that they may be able to return to low-velocity river areas after only slight downstream displacement.

Some of the 1976 laboratory and field observations offer plausible explanations for the apparent invulnerability of shad larvae to conventional ichthyoplankton sampling equipment and power plant cooling water intakes as discussed in the introduction for Connecticut Yankee (page 8). 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 period appears to then be followed by a general shoreward movement. Both activities tend to move the larvae into the relatively low velocity regions of a typical free-stream flow; surface tension and boundary friction cause velocities to be lower in the extreme surface layers and, in places, at or near zero along the lateral boundaries. Further, the perimeter refugia are always available, even under high-flow conditions. While velocity may increase more rapidly with distance from the banks under high than low flow conditions, it always approaches zero along one or both banks.

Conventional ichthyoplankton sampling equipment is typically either towed or moored in the free-stream region or towed at or near bottom attached to some type of sled or trawl. River ichthyoplankton sampling is seldom or never conducted exclusively at the surface, as is done for marine neuston, and with the exception of the 500 μ seine sampling being conducted on the Connecticut, is never performed in eddies and backwaters along banks. If the larvae behave in the field as they do in the test flume, they are only vulnerable in the free-stream region from immediately after hatching until they reach and can remain at the surface, a period which may last only several hours. The surface-oriented phase is then followed by a general shoreward movement which further reduces their vulnerability*. Power plant intake structures located along the river banks, because they generally draw most of their water from the mid-water layers, are as ineffective as conventional towed plankton nets at capturing the surface-oriented young larvae. And even though located along the banks they, like moored plankton nets, are passive devices requiring downstream movement on the larvae's part to effect capture.

Test flume observations clearly indicate some downstream larval transport, even under low-flow low-velocity conditions. 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 larvae movement, and hence the magnitude of the entrainment problem, is therefore dependent on both physical and behavioral factors.

Intuitively, the rate (number per unit time) at which larvae are transported past Merrimack Station will be related to water velocity which, as described earlier, increases more or less linearly with dis-

*Stira and Ciesluk (1976) recently presented data tending to corroborate the retention ability of larval shad in the Hudson River. Comments after the presentation indicated somewhat of a consensus that the larvae were "someplace not sampled". The inferences were generally in favor of the stream perimeter.

charge up to 4-5000 cfs. At 4-5000 cfs the maximum velocity has been attained, and further flow increases raise the mean velocity slowly (Figure 22 and Appendix Figure C2). The mean is raised because proportionally more of the channel volume is at or near the maximum velocity at higher river height (see discussion on page 47). Even though quiescent areas are present at all flow levels, it is conceivable that the rate of downstream larval transport, in numbers per unit time reaching the intakes, will increase with discharge and mean velocity. However, this rate, which will ultimately determine larval pump entrainment losses at Merrimack Station, is dependent on larval behavioral traits which have not yet been observed or quantified. And until behavioral responses to light, current, food availability and predators have been determined, it will be impossible to predict meaningfully the rate at which larvae at different developmental stages are transported downstream under these varying environmental conditions.

Connecticut River experiences and ecological reasoning suggest that downstream larval transport and potential entrainment might not be significant. On the Connecticut, the 26-mile Holyoke Pool reach has currents comparable to those of Hooksett Pond. In the Montague, MA reach of this pool, for example, currents average 1-1.5 ft sec^{-1} (30-45 cm sec^{-1}; 0.5-0.8 kt) under typical daily discharge conditions, but diurnal fluctuations are much more severe due to Turner's Falls power releases (W. Owen, pers. comm). 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 which, like Merrimack Station, has a shoreline intake, further implies that the larvae are adept at avoiding downstream transport; a major shad spawning area is located at Rocky Hill, only 13 km (8 mi) upstream of the plant.

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 are apt to change

rapidly from day to day (Figures 27, 29 and A2), 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 time-varying environment for its reproductive success could succeed if most of its larvae were not able to retain themselves in suitable nursery areas under normal conditions of late spring floods.

2. Momentum Entrainment

Momentum entrainment in a thermal discharge occurs as a result of turbulent mixing of the warmwater surface lens. As the discharge is cooled by dilution, cooler water from deeper, cooler strata are drawn across the thermocline and into the warmwater lens. Passively distributed planktonic organisms are entrained in this dilution water and exposed to temperature increases which vary in duration and magnitude, depending on where in the thermal discharge they are entrained. For active plankters, such as larval fish, entrainment is also related to their ability to perceive as a negative stimulus, orient to, and avoid the warm water area and, if entrained, to escape. After entrainment, eventual mortality is dependent on the thermal dosage (time and temperature) encountered and previous temperature experience (acclimation). The likelihood of momentum entrainment and resulting death due to thermal shock for Hooksett Pond shad eggs and larvae are discussed in this section.

a. Eggs

The likelihood of egg momentum entrainment is extremely low. As Table 3 illustrates, current velocities at Merrimack Station discharge transects (DO, DS) are generally as low or lower than those near the intake (IN, IO, IS; Figure 1). Further downstream, velocities at Transects SUN-N and SUN-S are more like those of SOU-N and SOU-S. The

likelihood of eggs being resuspended at velocities typical of the discharge stations is extremely low, as discussed previously (p. 152). And although resuspension is more likely to occur at SUN-N and SUN-S than at IN-IO or IS by virtue of higher mean velocities, temperatures at these downstream transects are far below potentially harmful levels for eggs (see Discussion, p. 145). As Appendix Figure A1 illustrates, lethal conditions do not exist within the Merrimack Station thermal plume under typical late-spawning period conditions (ambient water temperature = 77°F; discharge = 1900 cfs; maximum plume temperature at discharge = 90.8°F).

b. Larvae

The momentum entrainment of Hooksett Pond shad larvae is more likely to occur than the entrainment of eggs. The larvae may be vulnerable to the thermal discharge during their "upward swimming" stage immediately following hatching, or later in life should they be displaced downstream along the west bank (see Discussion, p. 154). At the discharge (Station Zero, Appendix Figure A1) temperatures sometimes exceed 90°F and a small area of the plume's surface may at times approach the 93-94°F lethal temperature limit determined for larvae (Section II.B.3.). Although not a normal occurrence, potentially lehtal plume conditions could exist during an unusually warm, dry late June-early July (ambient t = 80°F), when the young shad should be completing their larval phase, if Merrimack Station was operating at or near maximum capacity ($\Delta t > 14°F$). As was the case for estimating pump entrainment rates, the probability of momentum entraining larvae in significant numbers depends on behavioral responses which are presently unknown; no quantitative estimates can be arrived at based on currently available information.

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VII. APPENDICES

APPENDIX A

APPENDIX A

Appendix A contains physical, chemical and biological data describing Hooksett Pond. Figure A1 is a series of isotherm cross-sections on a typical spawning season day, 26 June 1975. On this day air temperature ranged from 50 to 84°F ($\bar{x}$ = 68°F), relative humidity ranged from 40 to 100% ($\bar{x}$ = 65), Garvin's Falls discharge averaged 1902 cfs, and Merrimack Station Units I and II were operating as were 208 psm's. Figure A2 depicts the annual Garvin's Falls discharge cycle from 1969 through 1976, and Figure A3 is a graphic representation of the location and elevation of Merrimack River impoundments and Merrimack Station. Table A1 is a list of fish species captured in Hooksett Pond since 1967 as a result of New Hampshire Fish and Game Department and NAI sampling efforts.

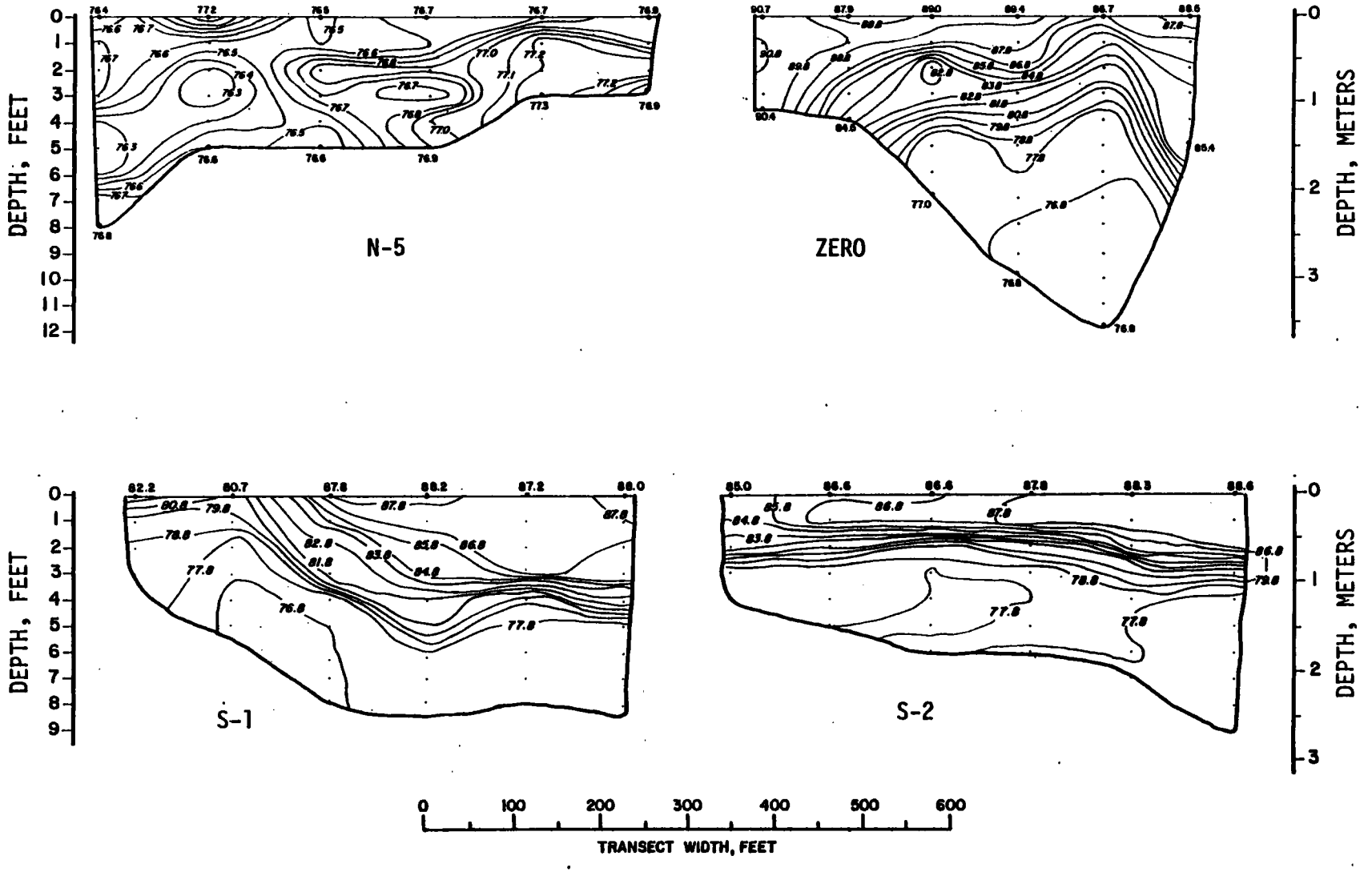

Figure A-1. Isothermal cross-sections of Merrimack River sampling stations, Hooksett Pond, July 1, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

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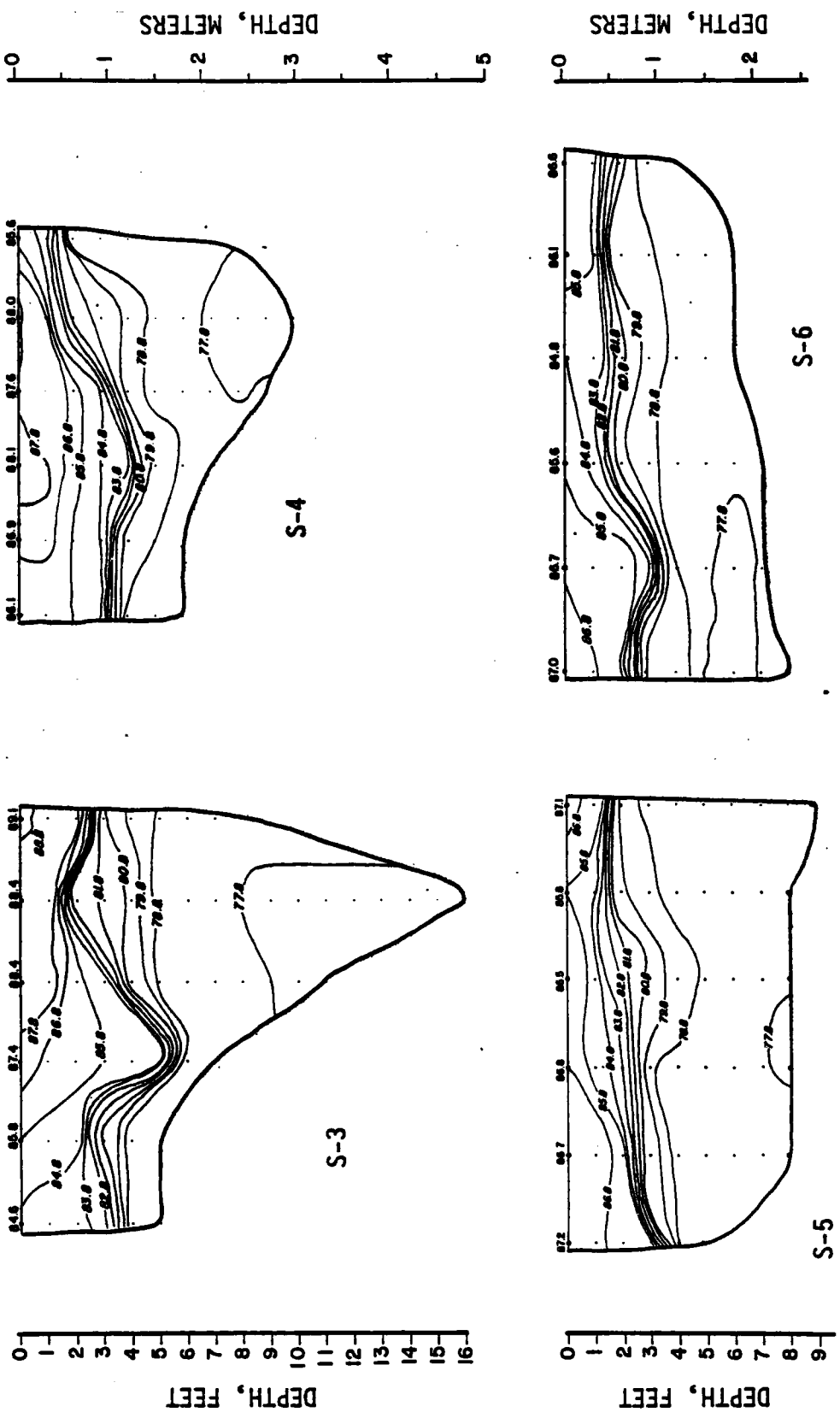


Figure A-1. (Continued)

Continued

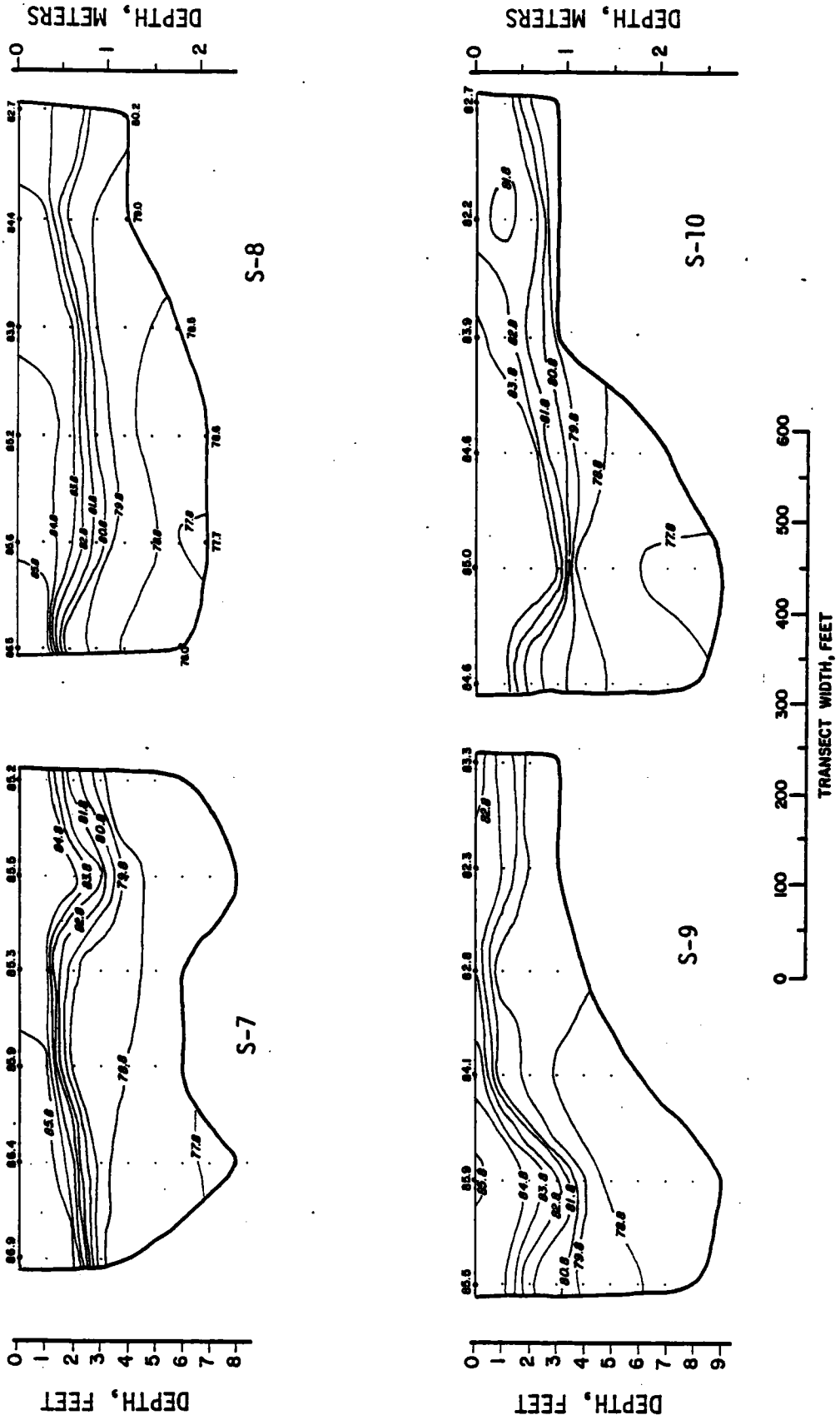


Figure A-1. (Continued)

Continued

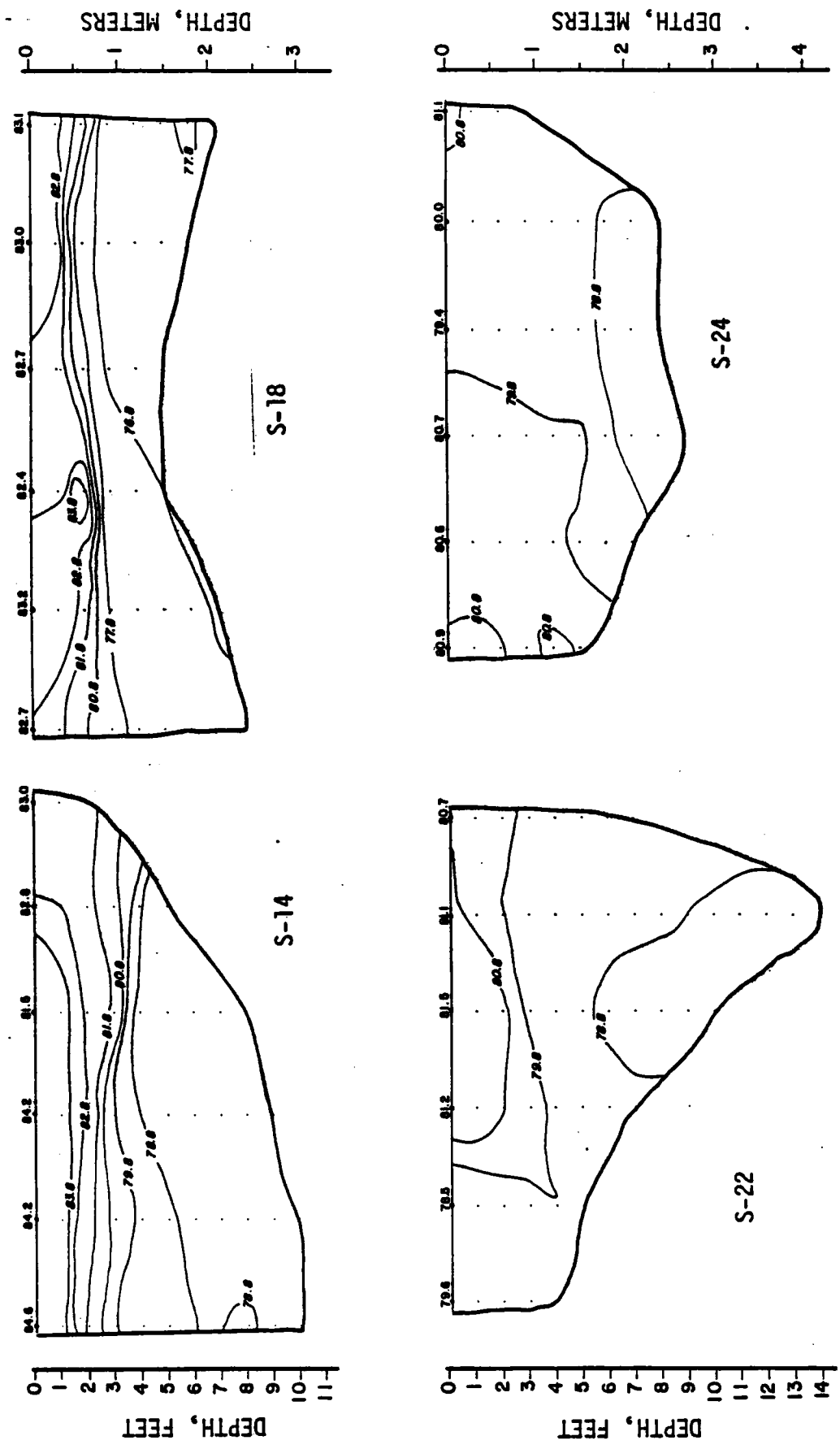


Figure A-1. (Continued)

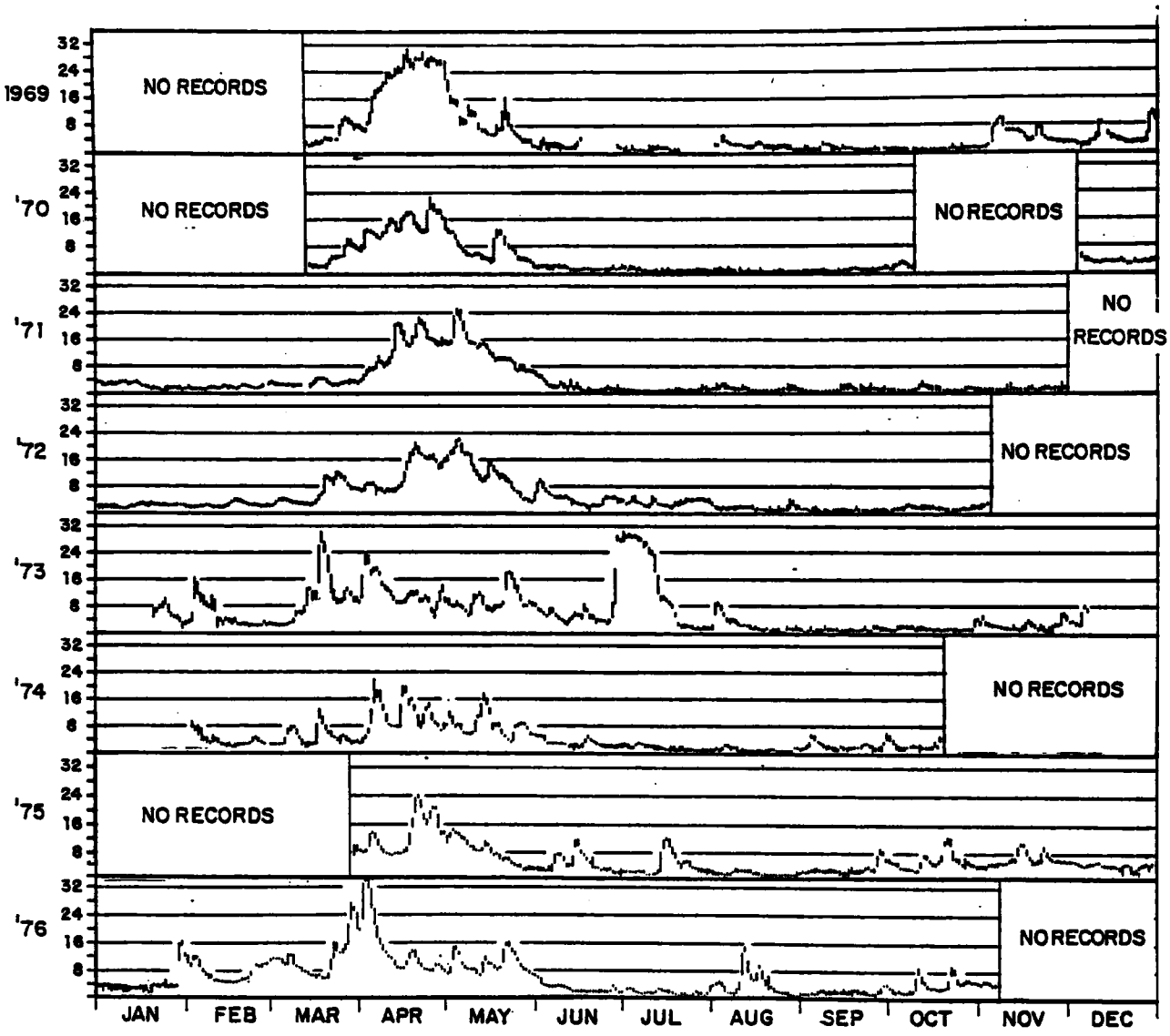


Figure A-2 Range of daily Garvin's Falls discharge, 1969-1976. Merrimack River Anadromous Fisheries Investigations, 1976.

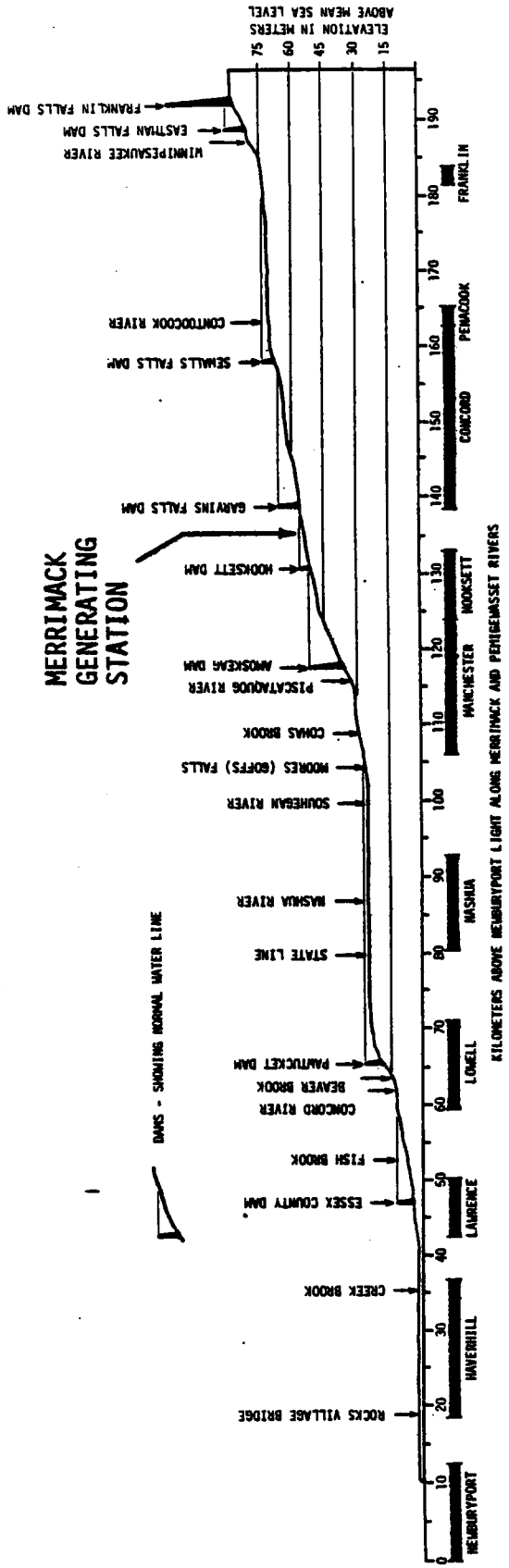


Figure A-3 Merrimack River longitudinal profile locating impoundments, cities, and Merrimack Station. Merrimack River Anadromous Fisheries Investigations, 1976.

TABLE A1. FISH SPECIES ENCOUNTERED IN HOOKSETT POND, 1967-1976. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

FAMILY	GENERIC NAME	COMMON NAME	ABUNDANCE
Salmonidae	*Salvelinus fontinalis*	Brook trout	Rare
	Salmo gairdneri	Rainbow trout	Rare
	S. trutta	Brown trout	Rare
Osmeridae	*Osmerus mordax*	Rainbow smelt	Rare*
Esocidae	*Esox niger*	Chain pickerel	Common
Cyprinidae	*Semotilus corporalis*	Fallfish	Common
	Notemigonus crysoleucas	Golden shiner	Common
	Notropis hudsonius	Spottail shiner	Common
	N. cornutus	Common shiner	Common
Catostomidae	*Catostomus commersoni*	White sucker	Common
Ictaluridae	*I. nebulosus*	Brown bullhead	Common
	Noturus insignis	Brindled madtom	Rare
	Noturus gyrinus	Tadpole madtom	Rare
Anguillidae	*Anguilla rostrata*	American eel	Common
Percichthyidae	*Morone americana*	White perch	Common
Centrarchidae	*Lepomis gibbosus*	Pumpkinseed	Common
	L. auritus	Redbreast sunfish	Common
	Micropterus dolomieui	Smallmouth bass	Common
	M. salmoides	Largemouth bass	Common
Percidae	*Perca flavescens*	Yellow perch	Common
	Stizostedion vitreum	Walleye	Rare
	Etheostoma olmstedi	Johnny darter	Common

*A single dead specimen was captured in a 1976 screenwash sample; no live smelt have been captured.

APPENDIX B

APPENDIX B

Appendix B contains additional data derived from 1975-76 hydrographic investigations. Figure B2 presents data obtained from current meter moorings. The graphs were made by plotting current speed values at 1200 EST each day. The irregular nature of the plots are the result of current meter fouling by river-borne debris. Although the meters were cleaned frequently (as often as once a week), the fouling problem could not be controlled. As a result much of the data are such that natural current fluctuations cannot be distinguished from fluctuations due to fouling. Also, there are several gaps in the data. These resulted from fouling that was severe enough to prevent the current meters from functioning at all.

Some of the data that appeared reliable were obtained during the first three weeks the intake mooring was in operation. These data have been used to provide an indication of short-term current speed variations in Hooksett Pond at three different discharge levels (Figure B3). The dates, time intervals, and discharges represented in Figure B3 are as follows:

DATE	TIME INTERVAL (EDT)	RIVER DISCHARGE (cfs)
6-01-75	1200-1800	2398
6-07-75	0600-1200	5447
6-14-75	0000-0600	9741

Excerpts from the data tape show both speed and direction; each horizontal graduation represents 0.11 hr (6.67 min) and in each case speed is shown in the left channel. The data clearly illustrate fluctuations that are on the same order of a few minutes. The date from June 7 and June 14

appear to be nearly equally variable while the June 1 data shows longer periods of slight variability. The magnitude of the variability appears quite similar in all three illustrations.

Table B1 lists Merrimack Station's operating data for dates corresponding to hydrographic field surveys, and Figure B4 represents actual field current meter plots. Figure B-1 represents the continuous recording current meter mooring system employed during 1975.

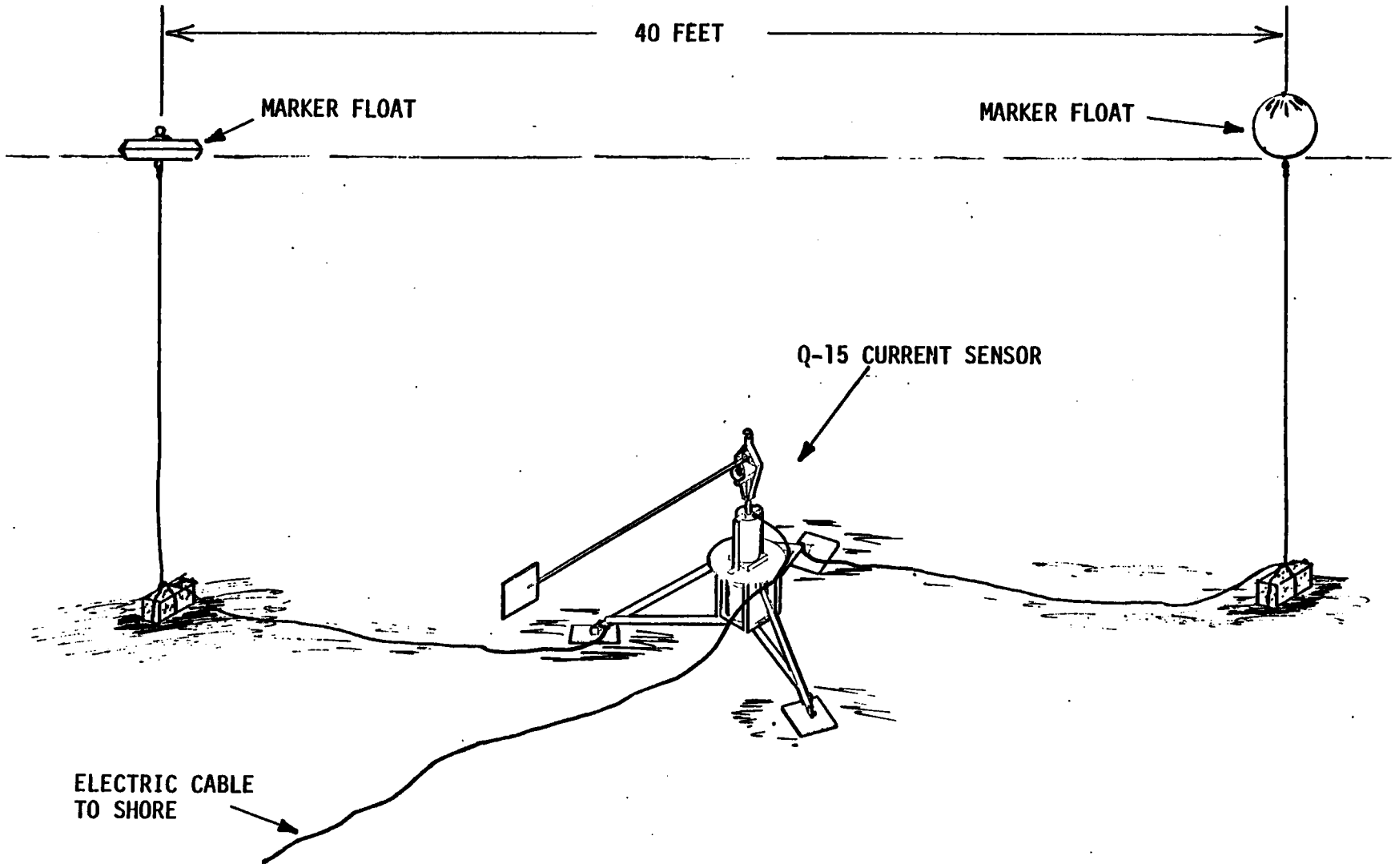


Figure B-1. Mooring system for continuous temperature recorders. Merrimack River Anadromous Fisheries Investigations, 1976.

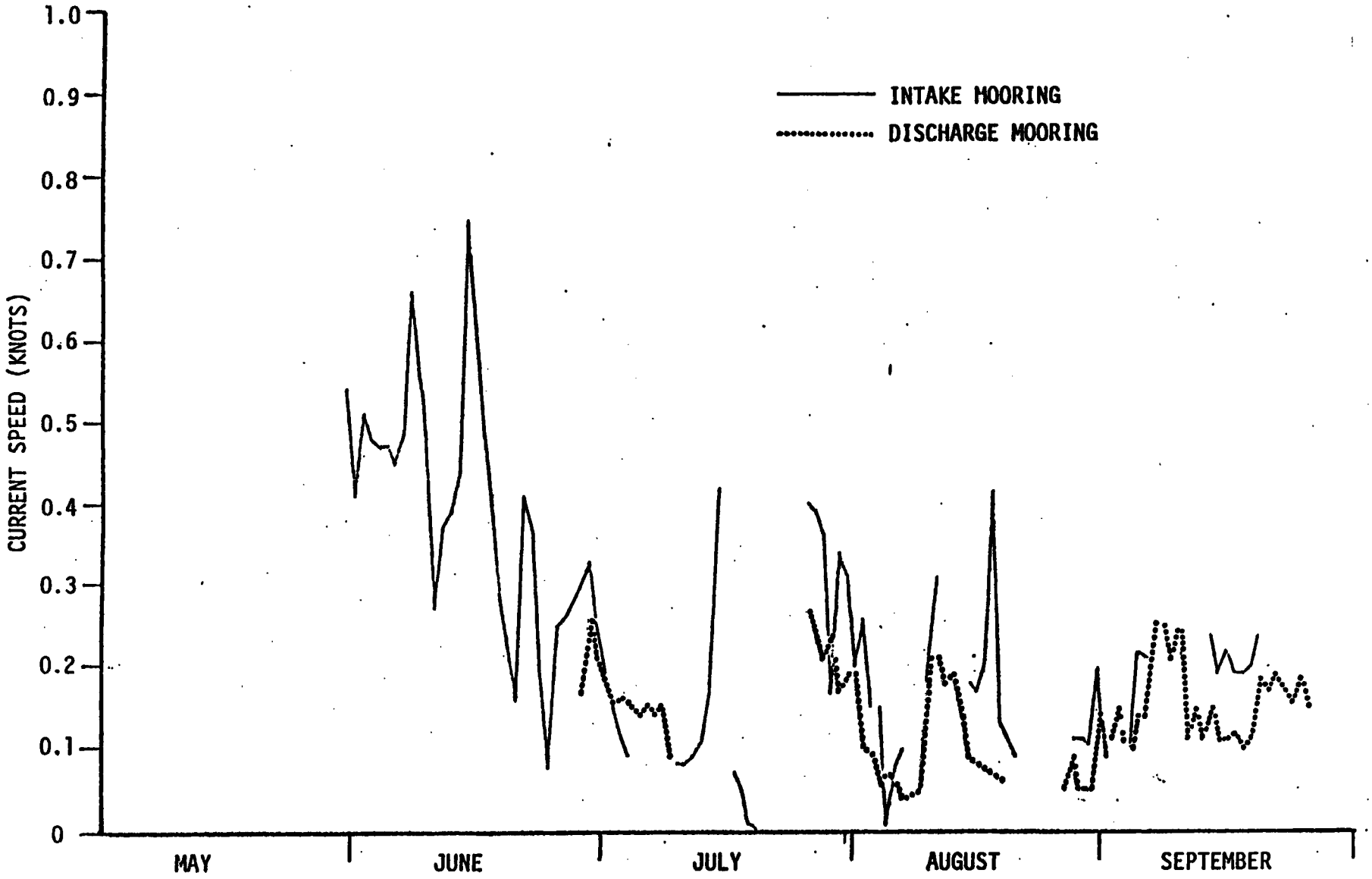


Figure B-2. Plots of current data obtained from the Merrimack River current meter moorings, 1975. Speeds plotted were obtained daily at 1200 EST. Merrimack River Anadromous Fisheries Investigations, 1976.

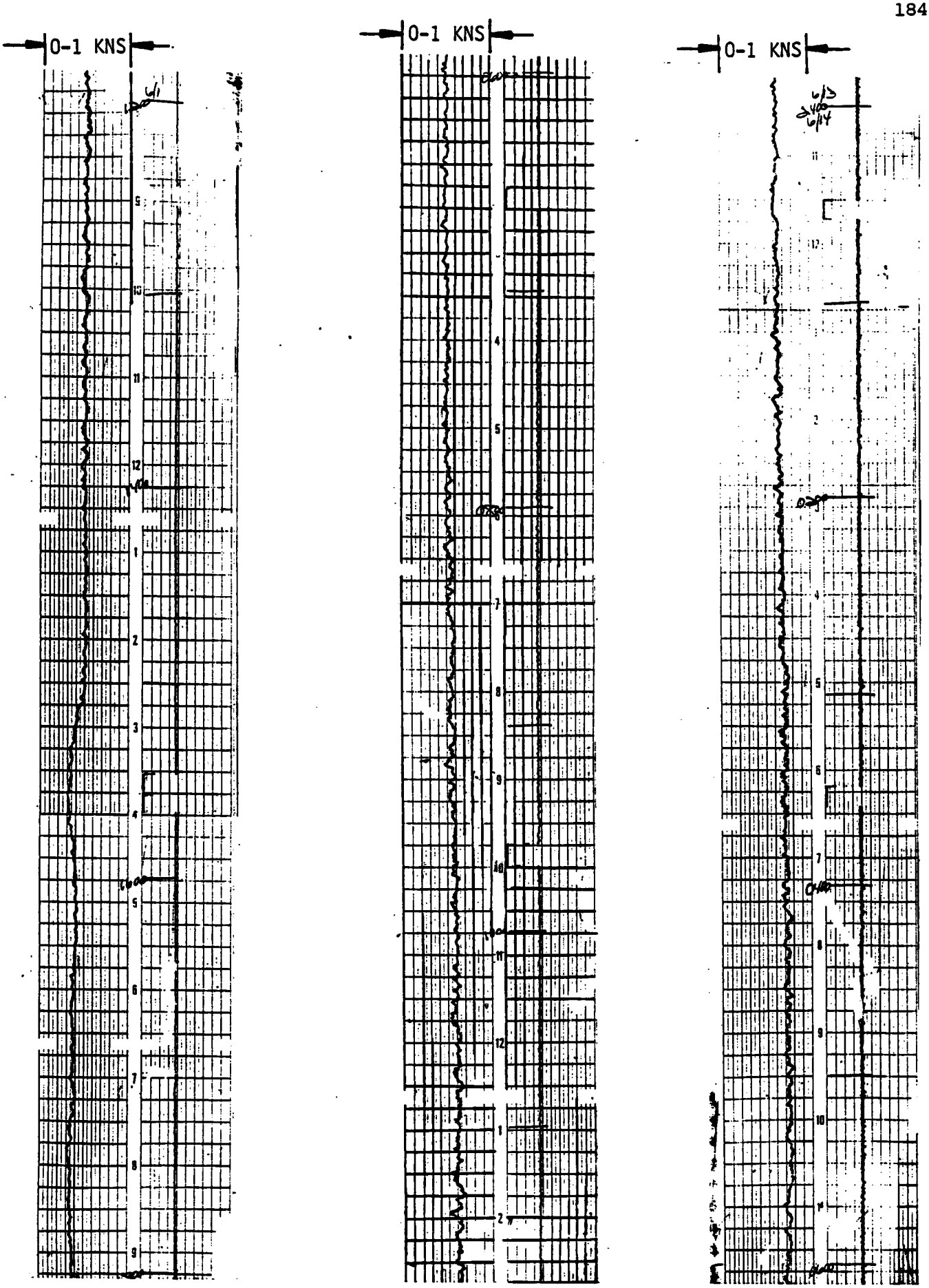
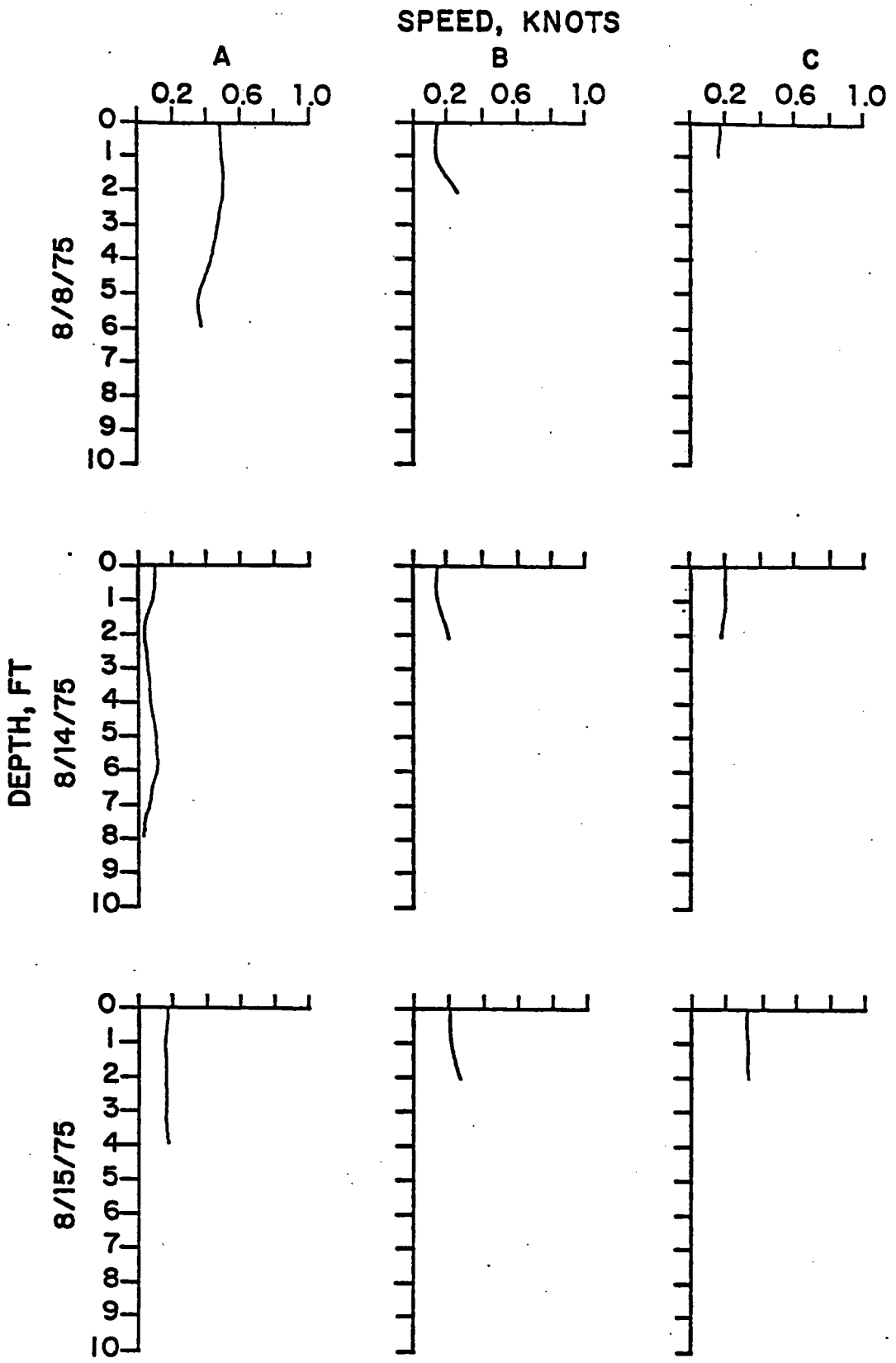


Figure B-3. Plots of current data obtained from the two Merrimack River current meter moorings, 1975. Speeds plotted were obtained daily at 1200 EST. Merrimack River Anadromous Fisheries Investigations, 1976.

Figure B-4a. Vertical current profiles at transect SOUN for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
0.2 0.6 1.0
DEPTH, FT
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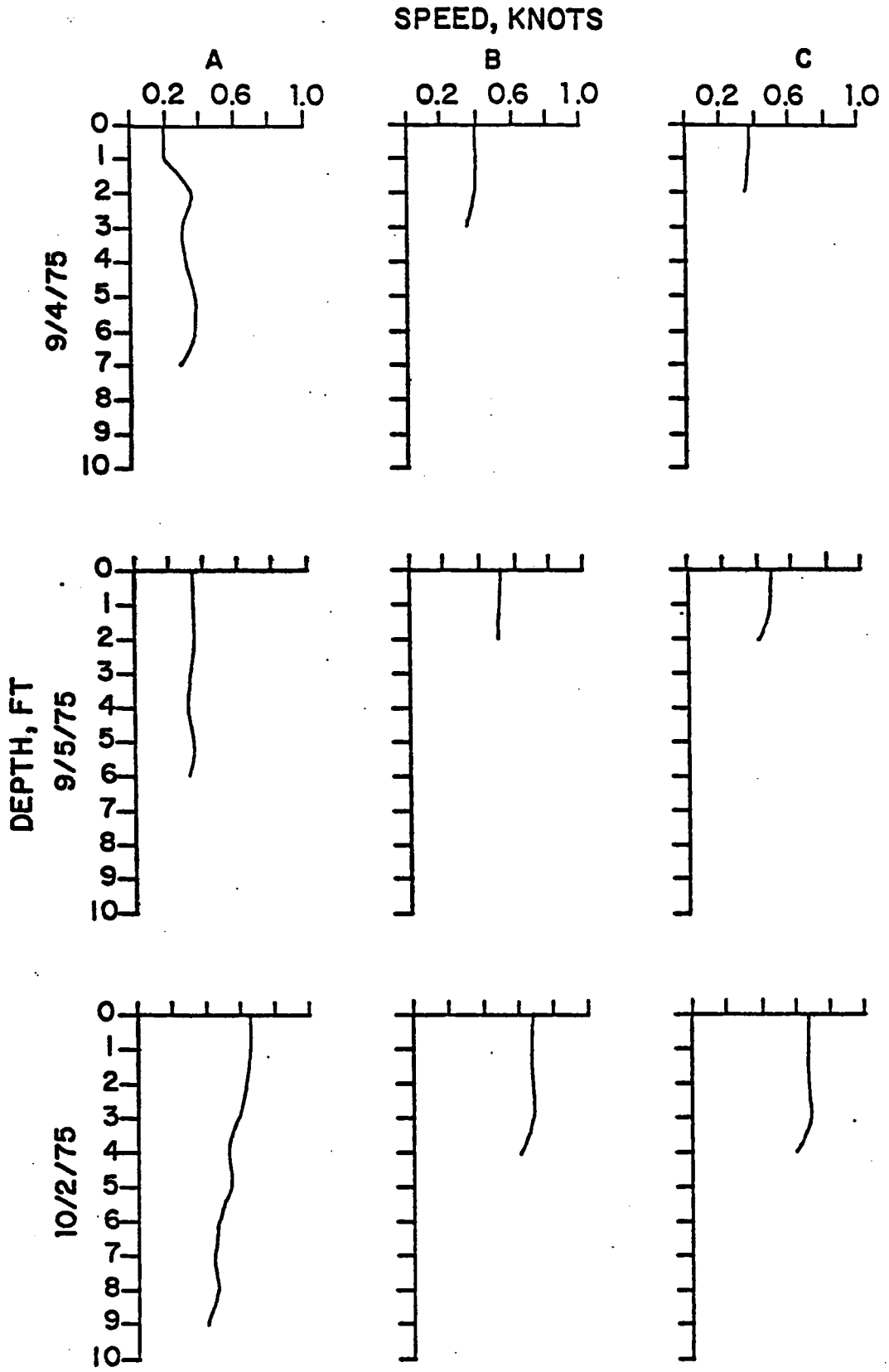
8/14/75
8/15/75
0
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
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9/5/75
10/2/75
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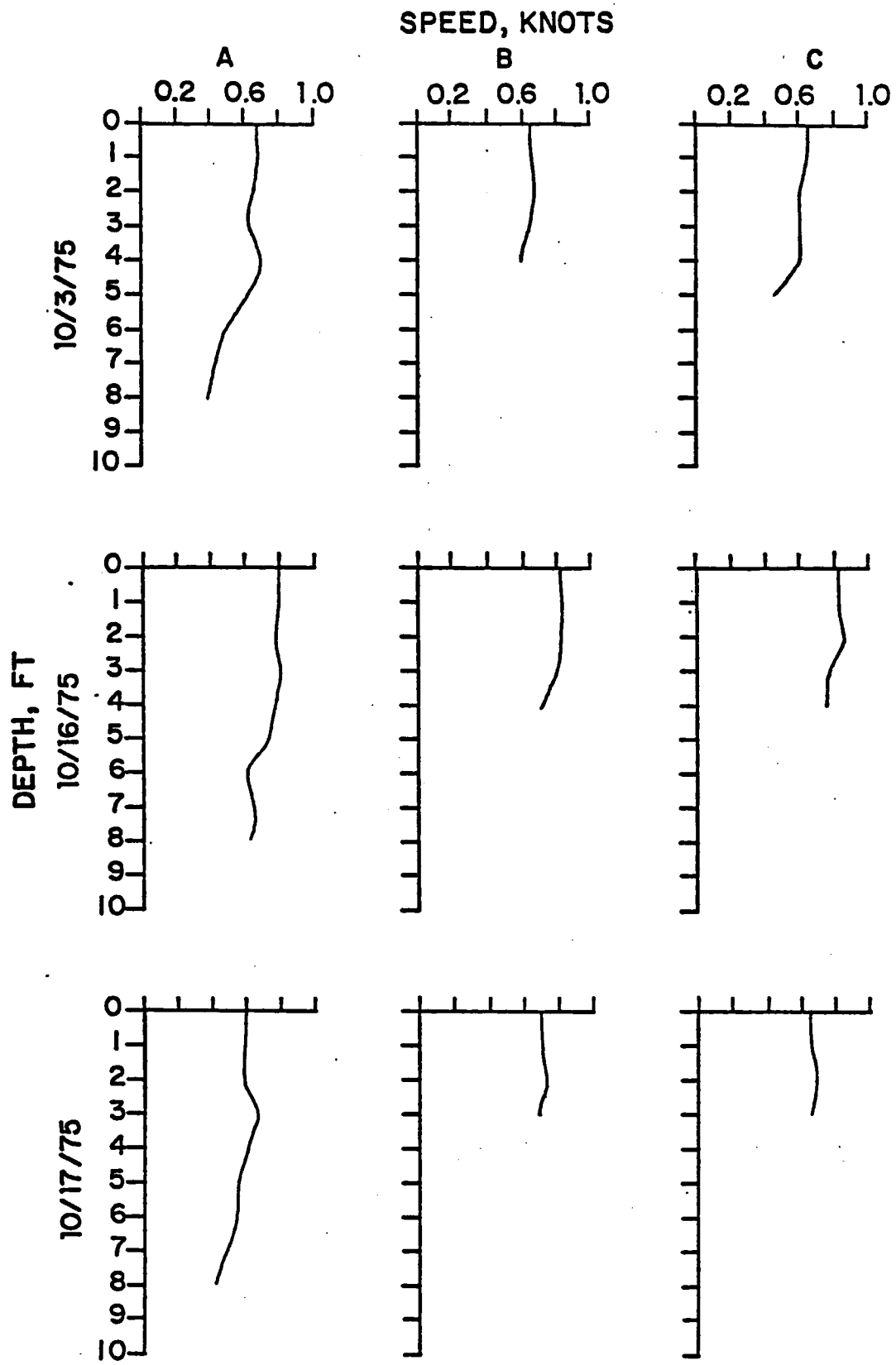
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
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0.6
1.0
DEPTH, FT
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10/16/75
10/17/75
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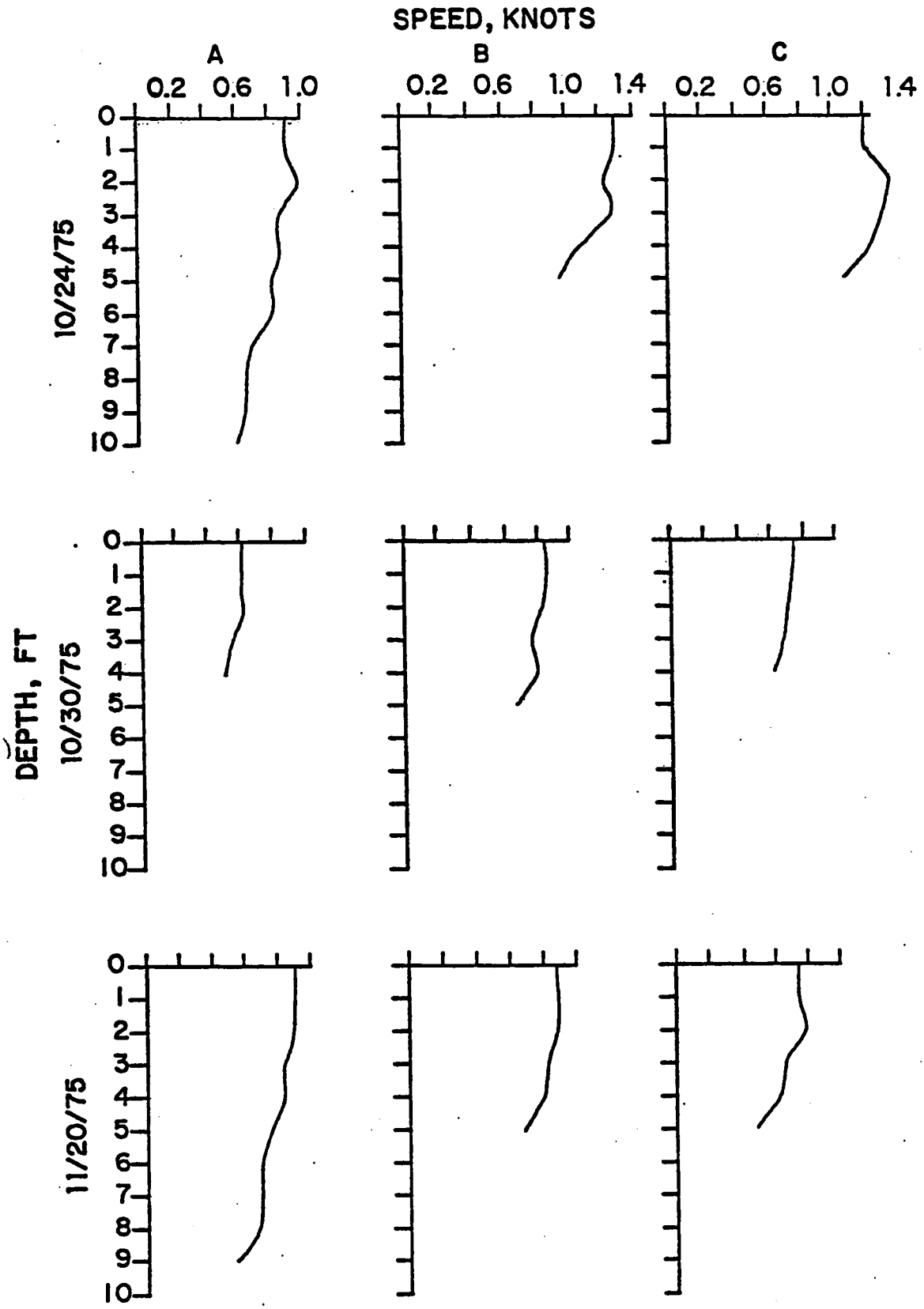
1
2
3
4
5
6
7
8
9
10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B
C
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0.2 0.6 1.0 1.4
DEPTH, FT
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10/30/75
11/20/75
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2
3
4
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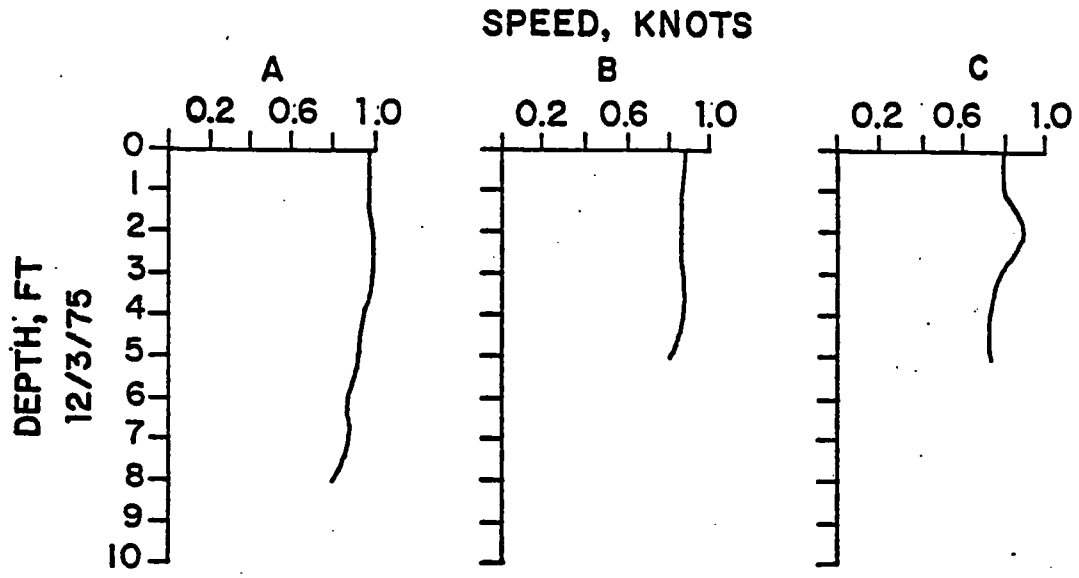
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
12/3/75
0
1
2
3
4
5
6
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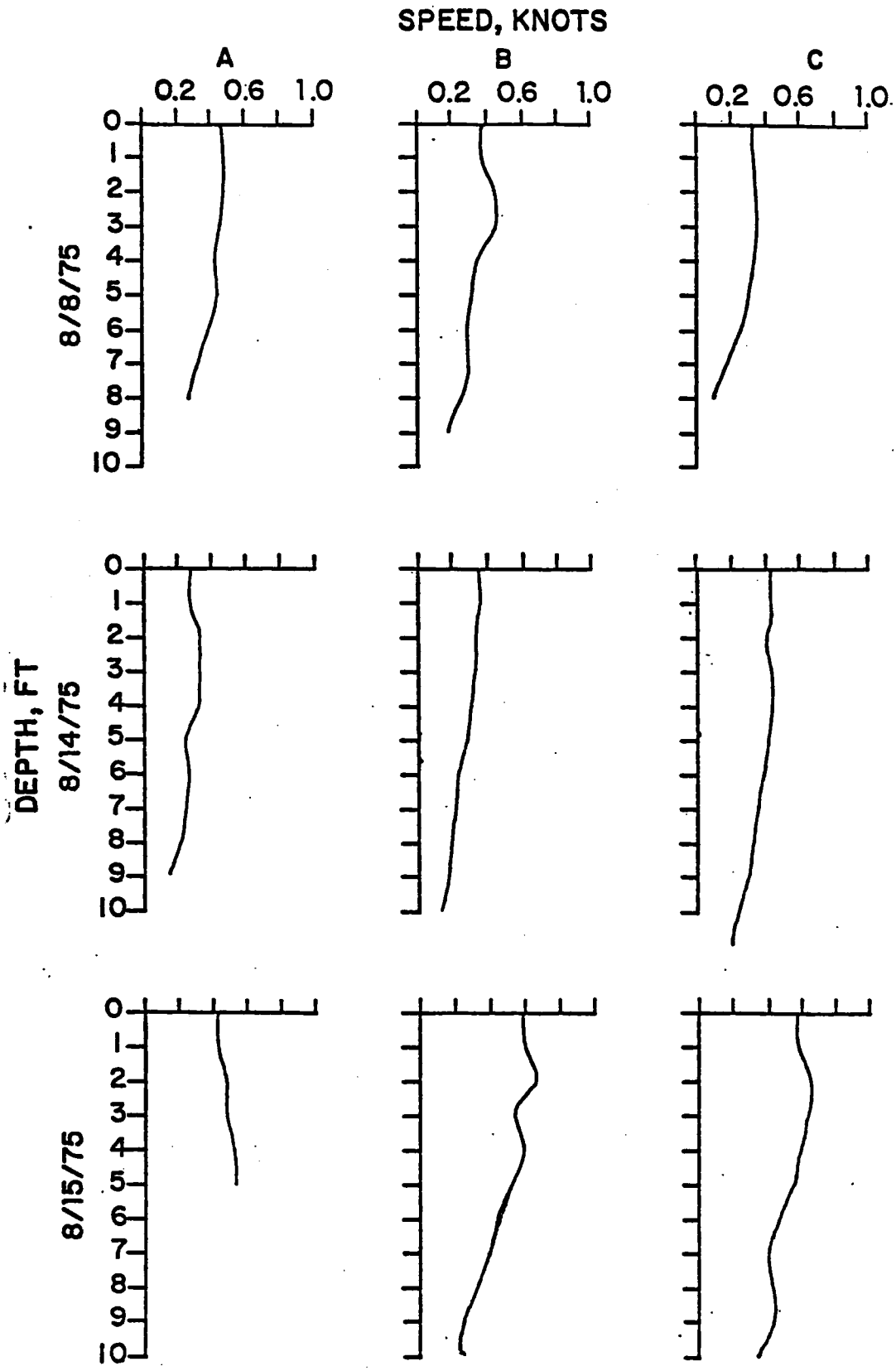
9
10

Figure B-4b. Vertical current profiles at transect SOUS for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
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0.6
1.0
DEPTH, FT
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8/14/75
8/15/75
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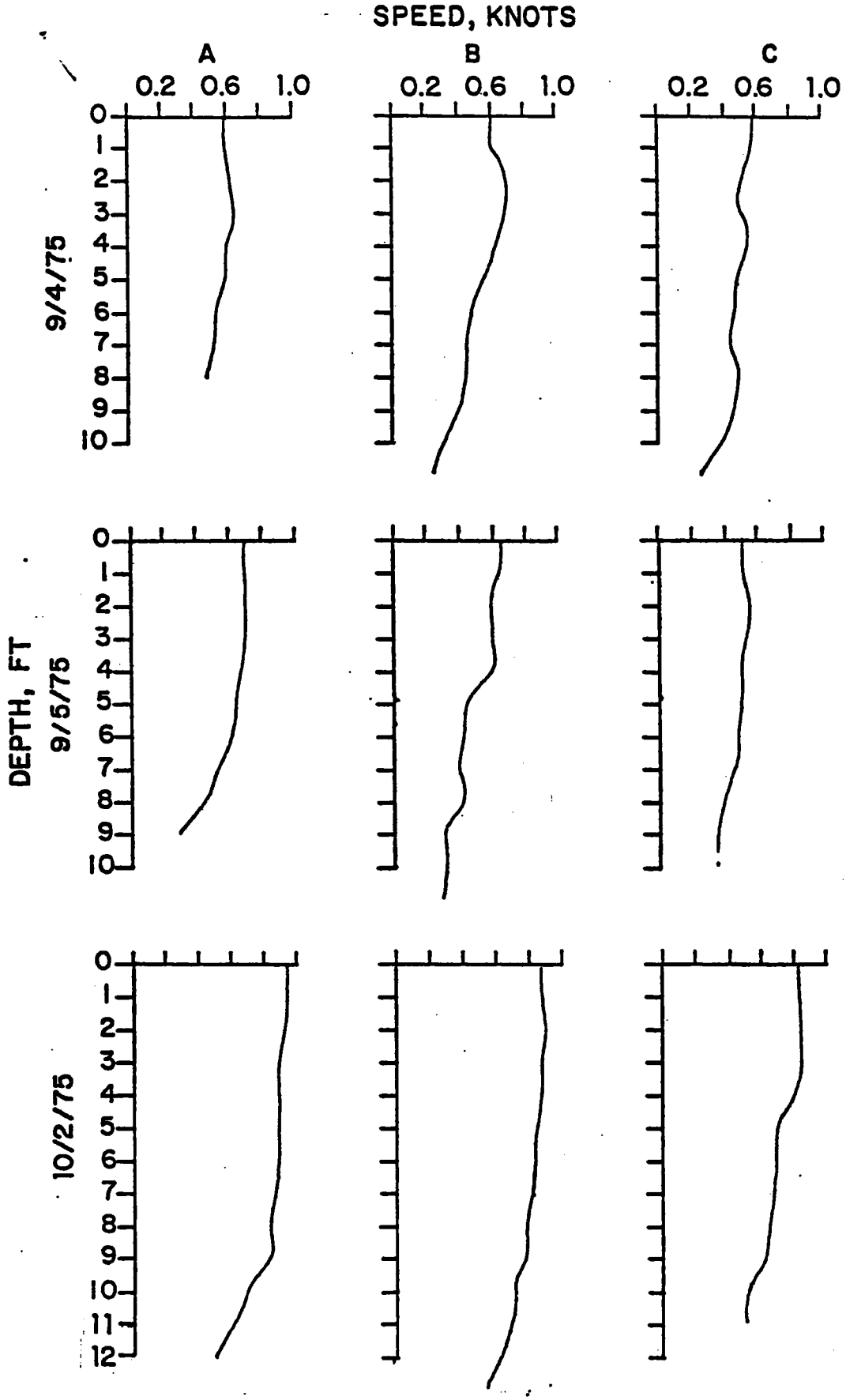
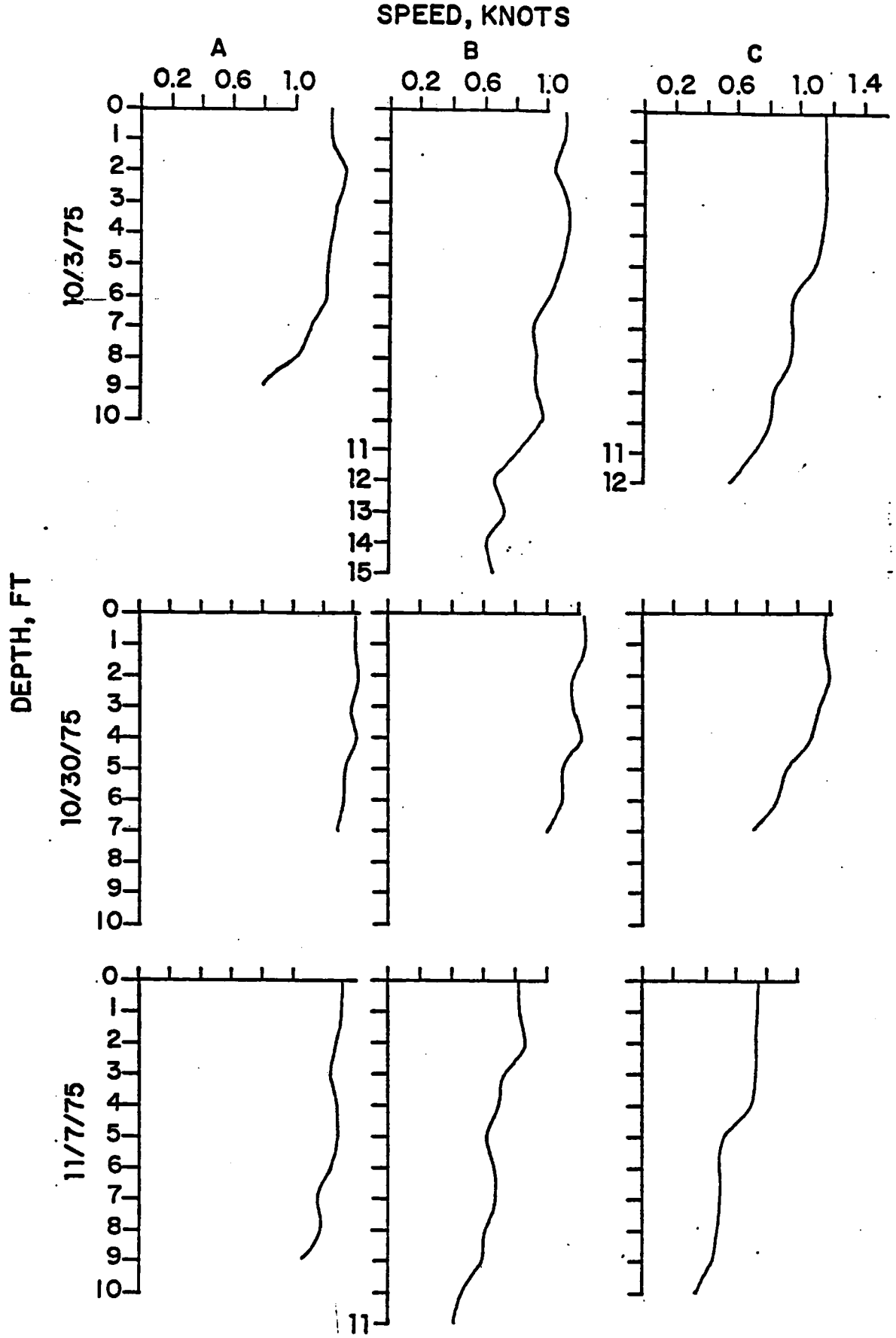

SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
9/4/75
9/5/75
10/2/75
0
1
2
3
4
5
6
7
8
9
10
11
12


SPEED, KNOTS
A
B
C
0.2 0.6 1.0
0.2 0.6 1.0
0.2 0.6 1.0 1.4
DEPTH, FT
10/3/75
10/30/75
11/7/75
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

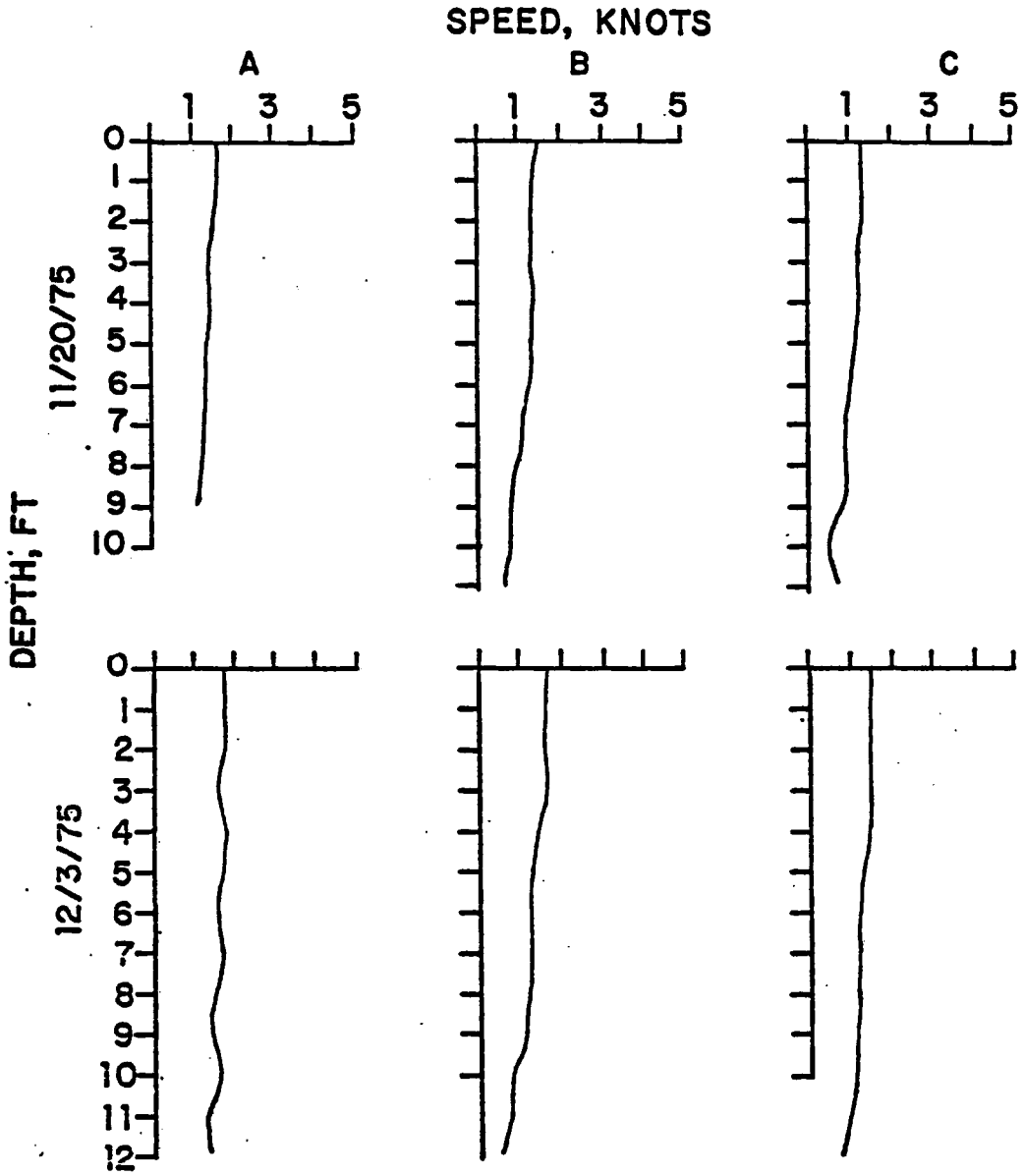
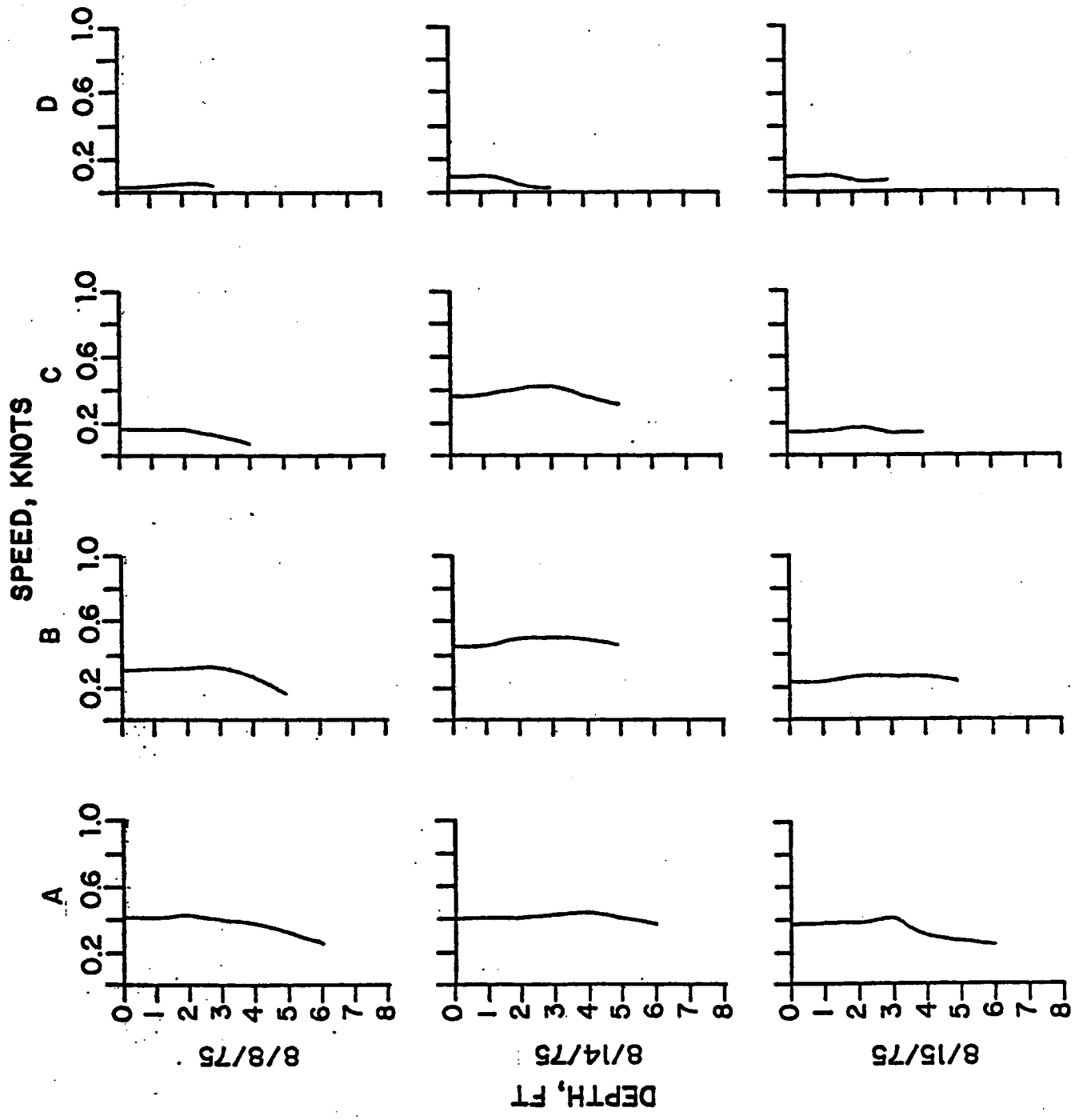
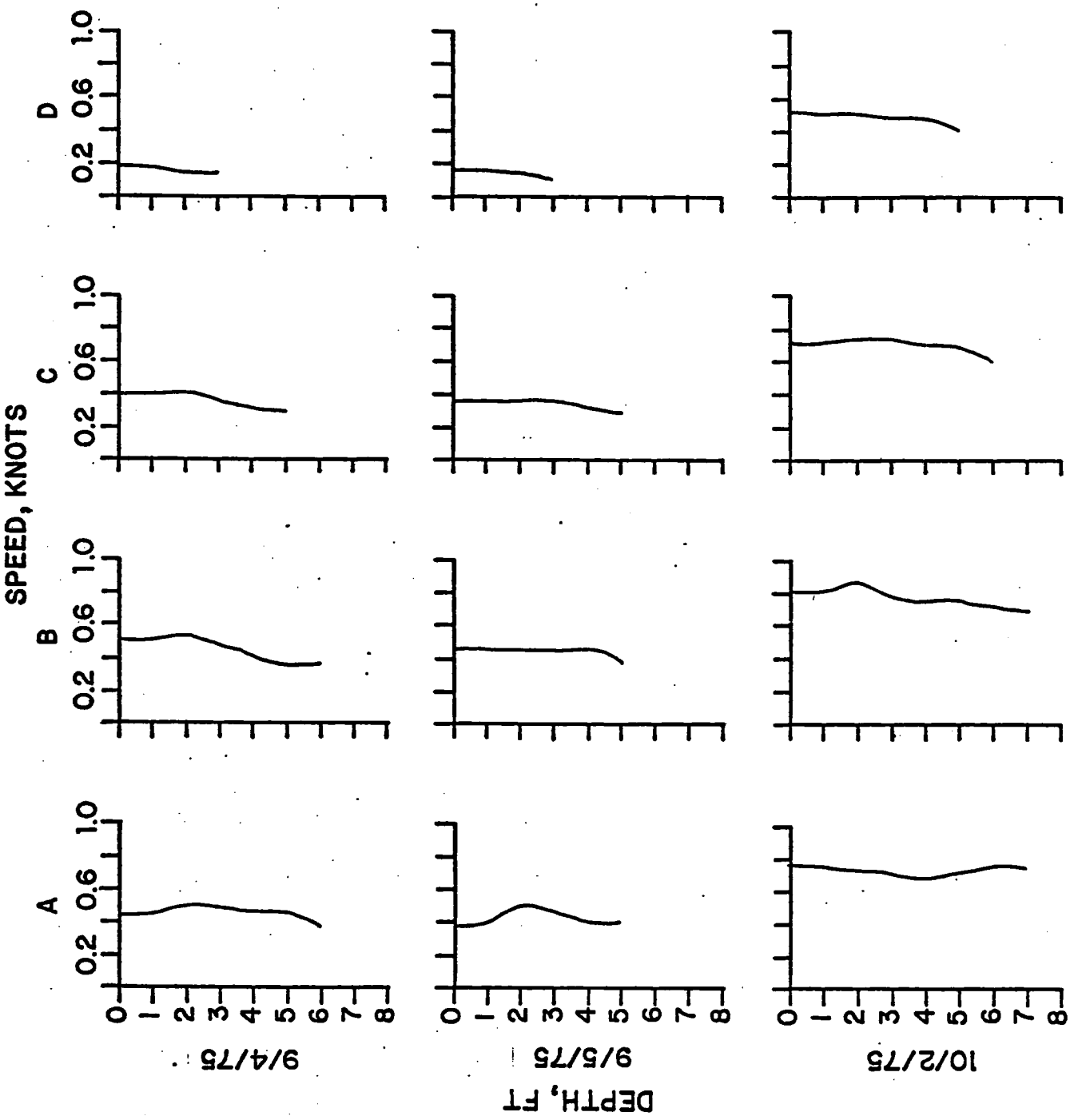
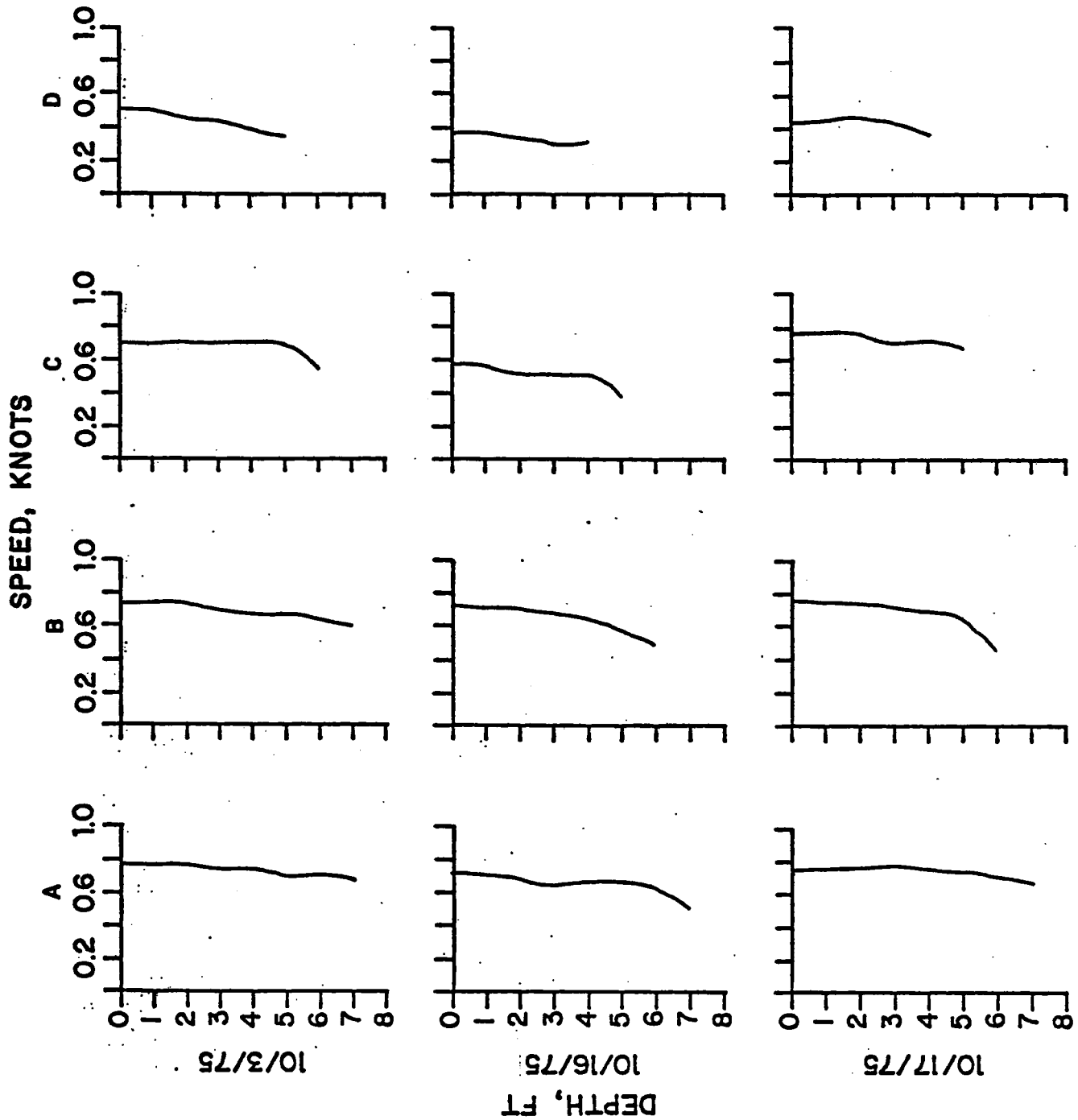
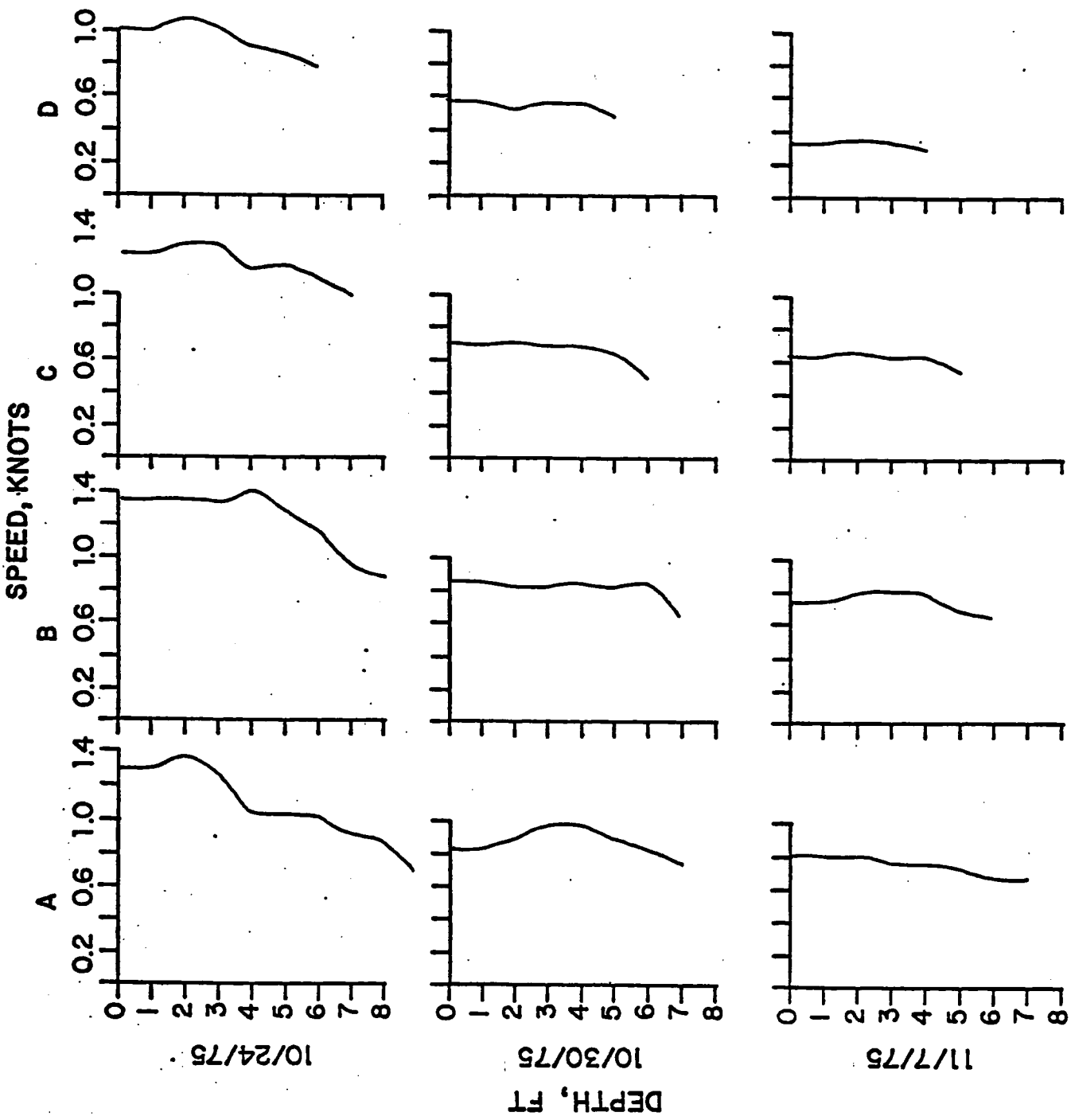

SPEED, KNOTS
A
B
C
1
3
5
DEPTH, FT
11/20/75
12/3/75
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure B-4c. Vertical current profiles at transect IN for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0
1
2
3
4
5
6
7
8
DEPTH, FT
8/8/75
8/14/75
8/15/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0
1
2
3
4
5
6
7
8
DEPTH, FT
9/4/75
9/5/75
10/2/75


SPEED, KNOTS
0.2
0.6
1.0
A
B
C
D
0
1
2
3
4
5
6
7
8
DEPTH, FT
10/3/75
10/16/75
10/17/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
DEPTH, FT
10/24/75
10/30/75
11/7/75

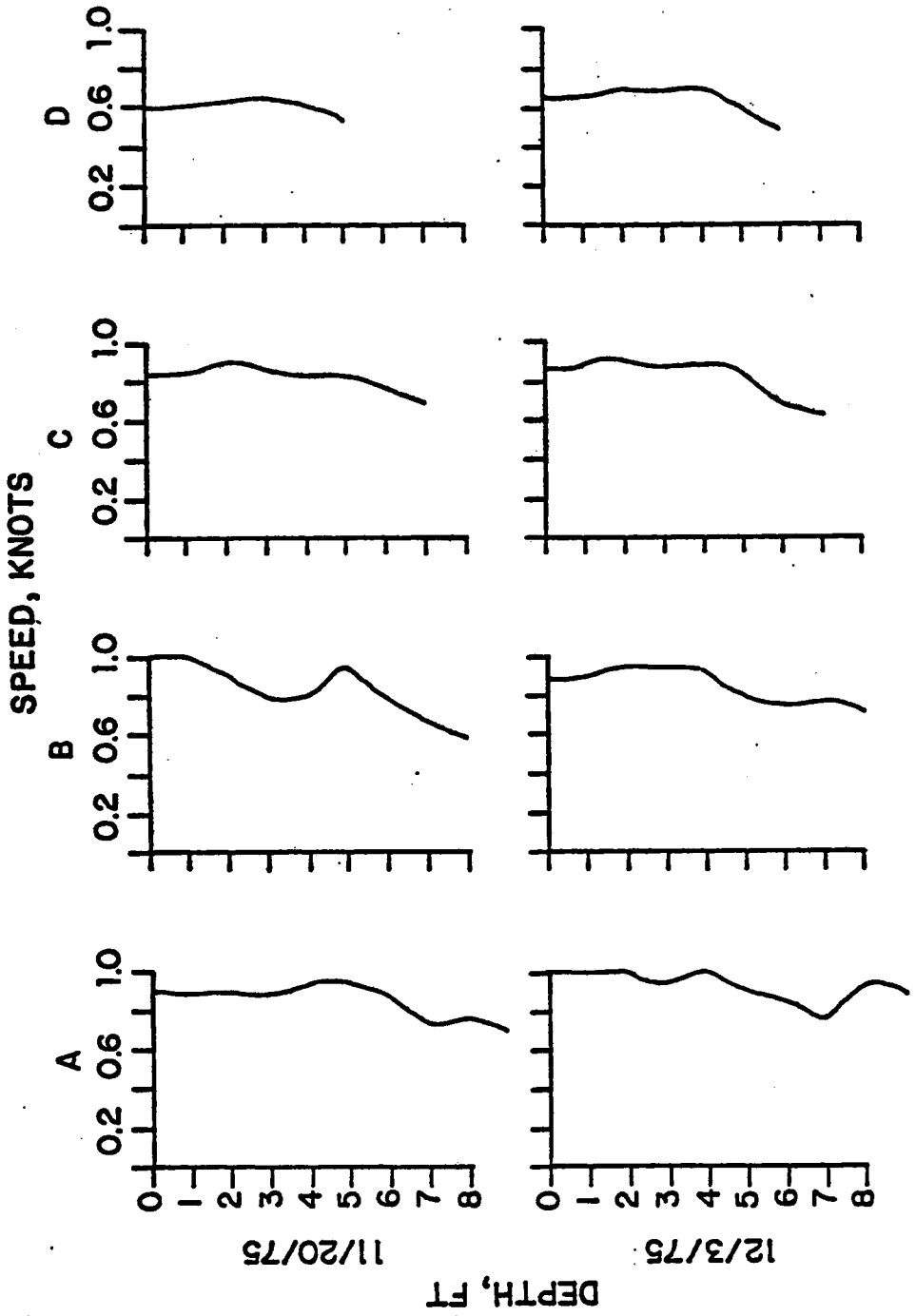
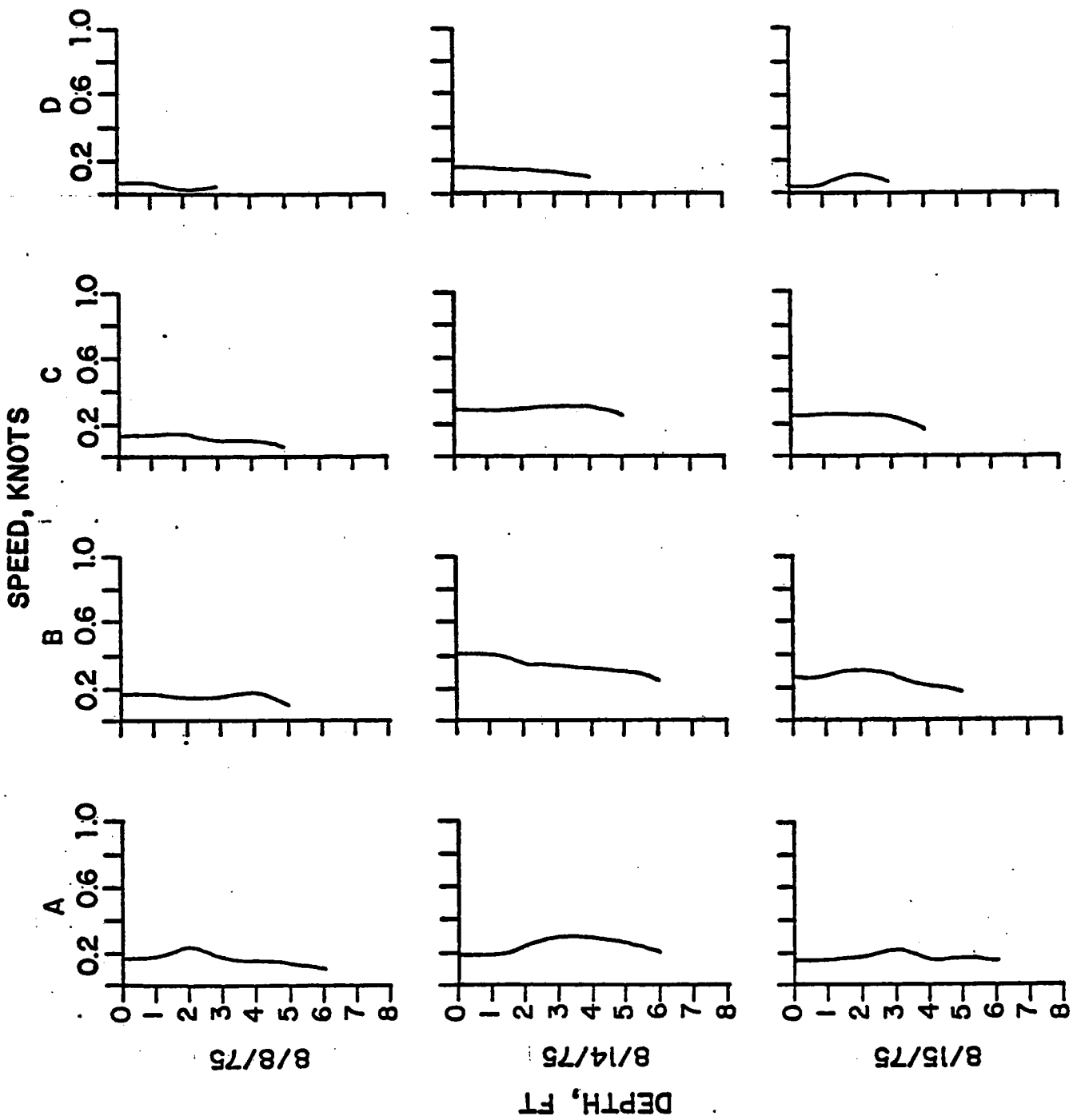
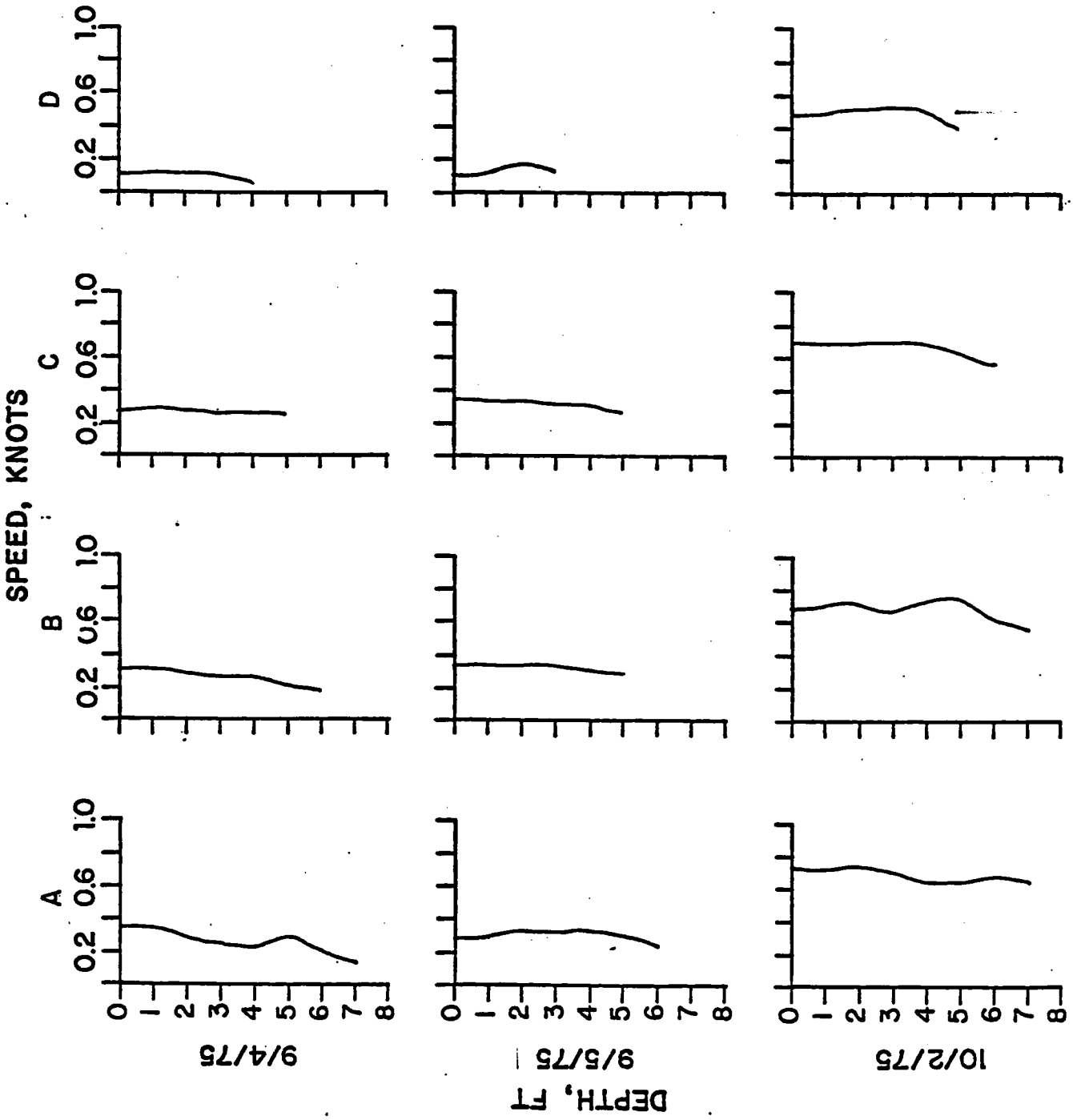
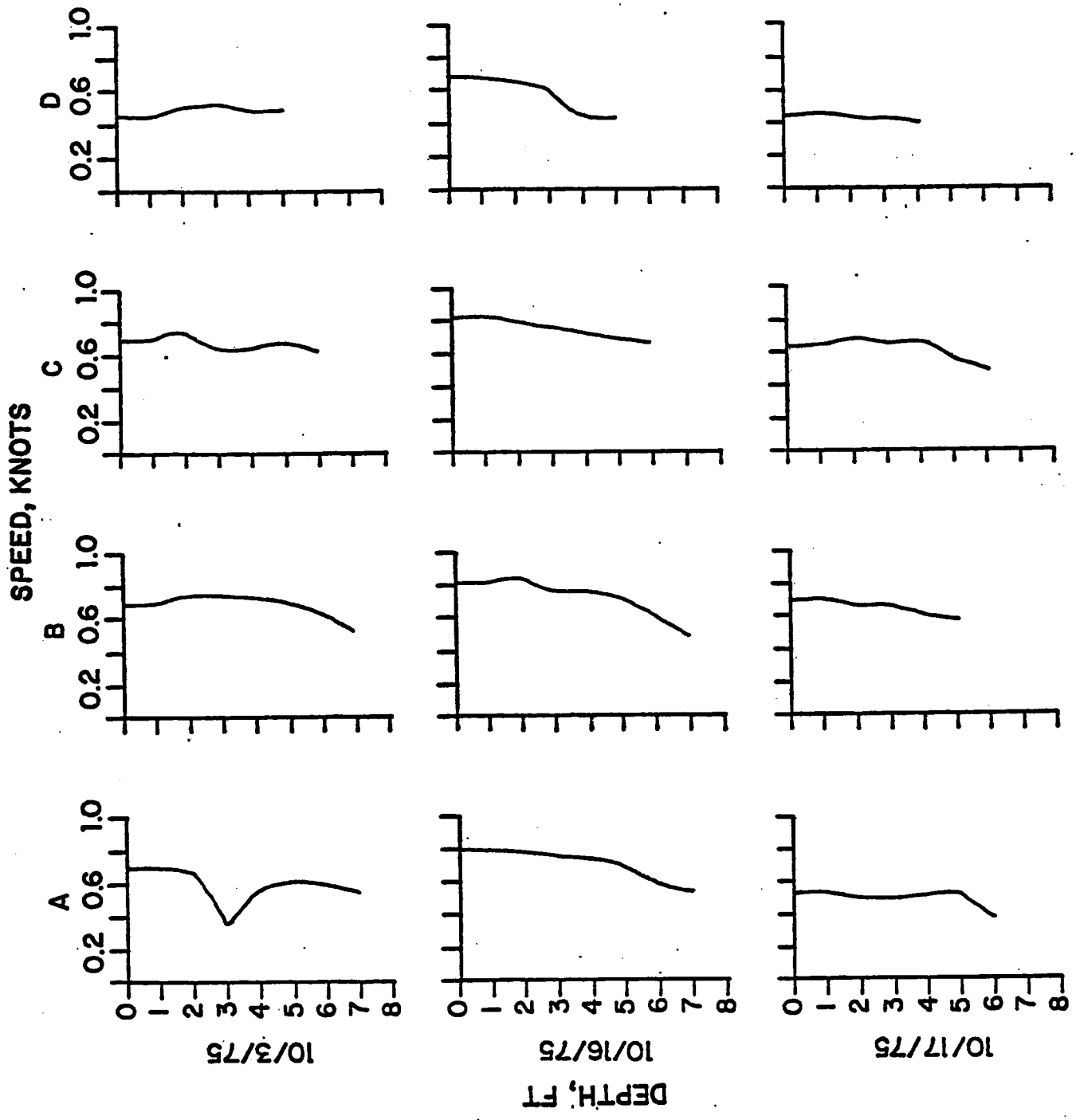
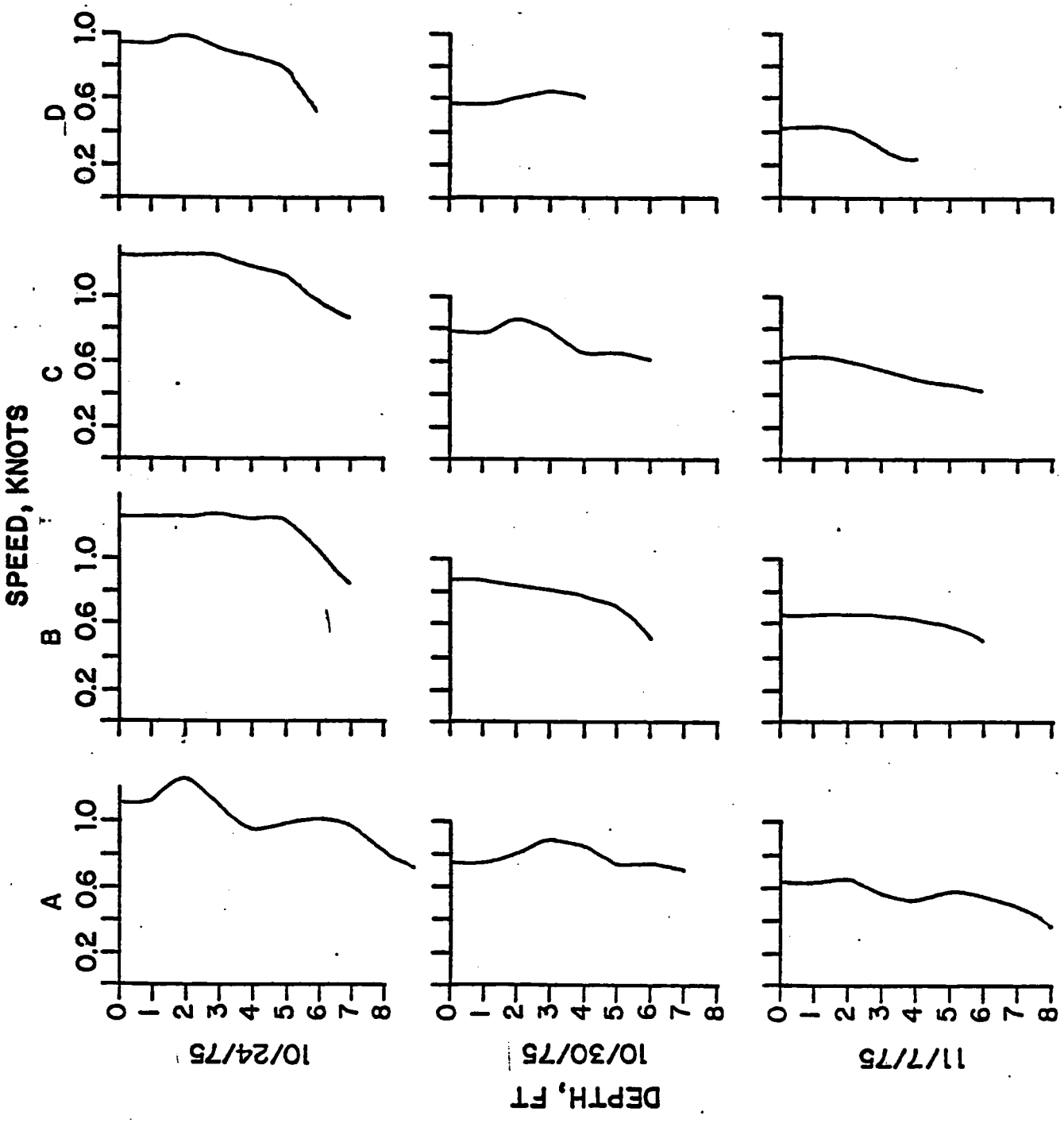

SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0 1 2 3 4 5 6 7 8
DEPTH, FT
11/20/75
12/3/75

Figure B-4d. Vertical current profiles at transect IO for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0 1 2 3 4 5 6 7 8
DEPTH, FT
8/8/75
8/14/75
8/15/75


SPEED, KNOTS
0.2
0.6
1.0
A
B
C
D
0
1
2
3
4
5
6
7
8
DEPTH, FT
9/4/75
9/5/75
10/2/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0 1 2 3 4 5 6 7 8
DEPTH, FT
10/3/75
10/16/75
10/17/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0 1 2 3 4 5 6 7 8
DEPTH, FT
10/24/75
10/30/75
11/7/75

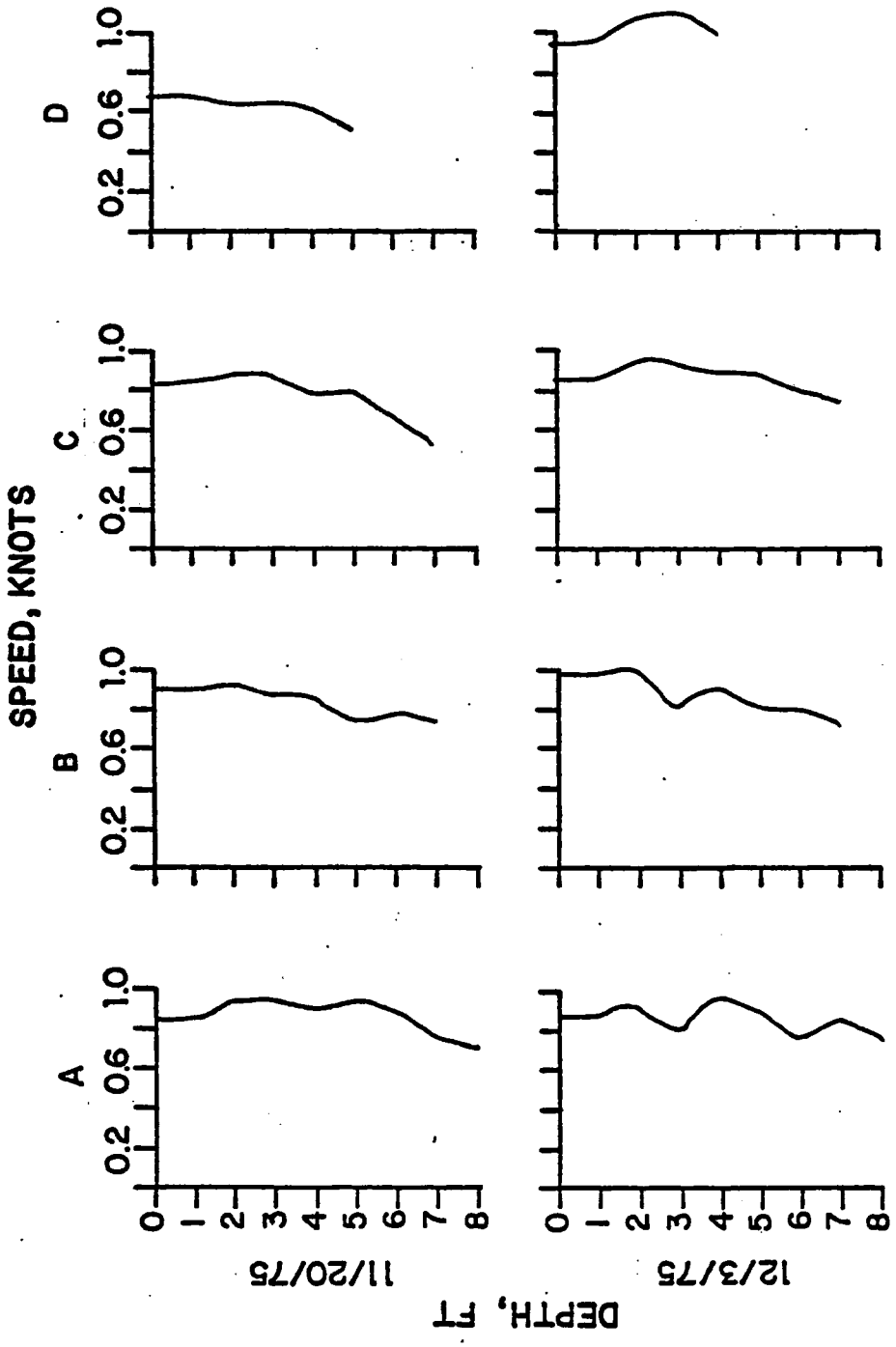
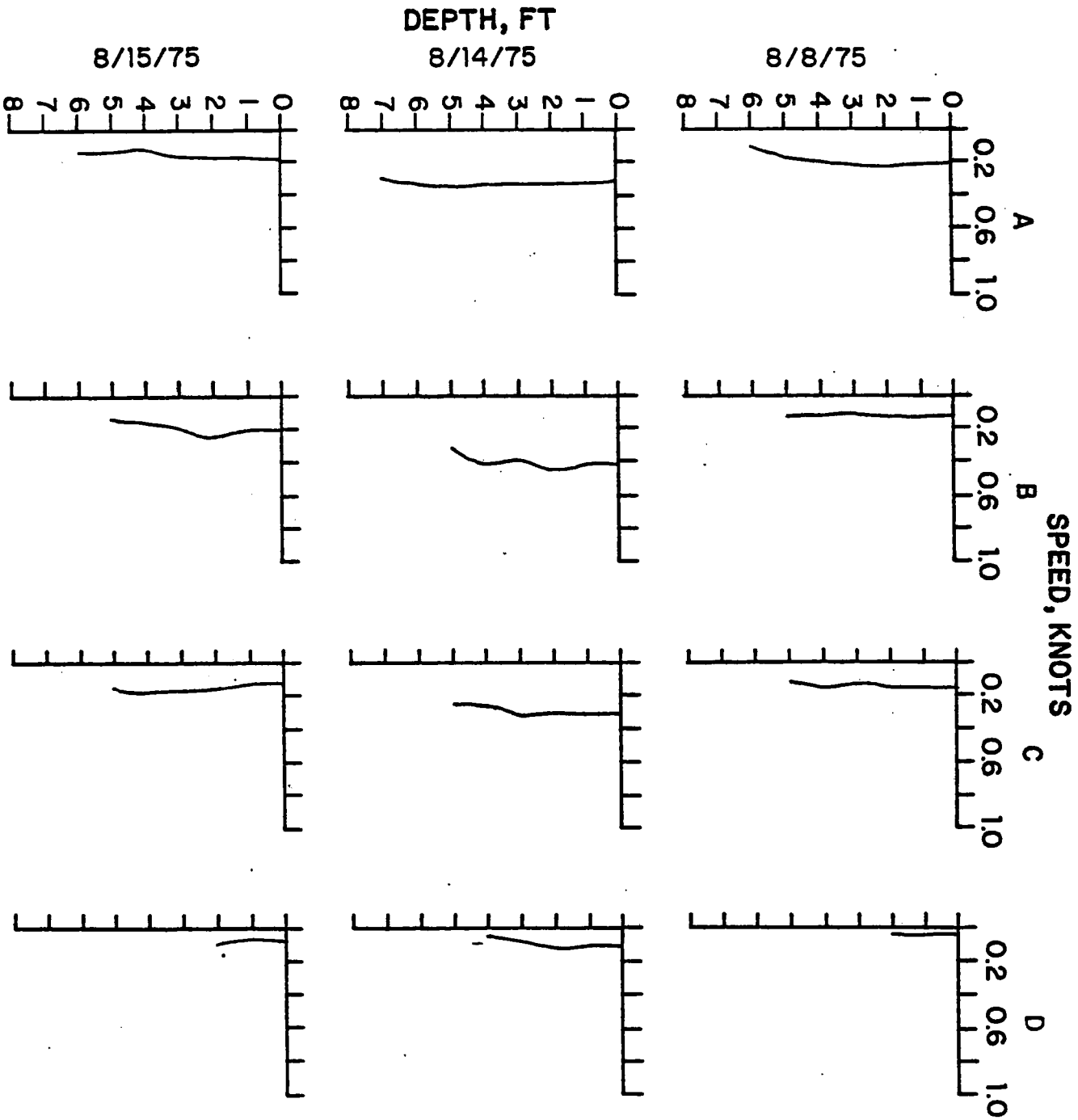
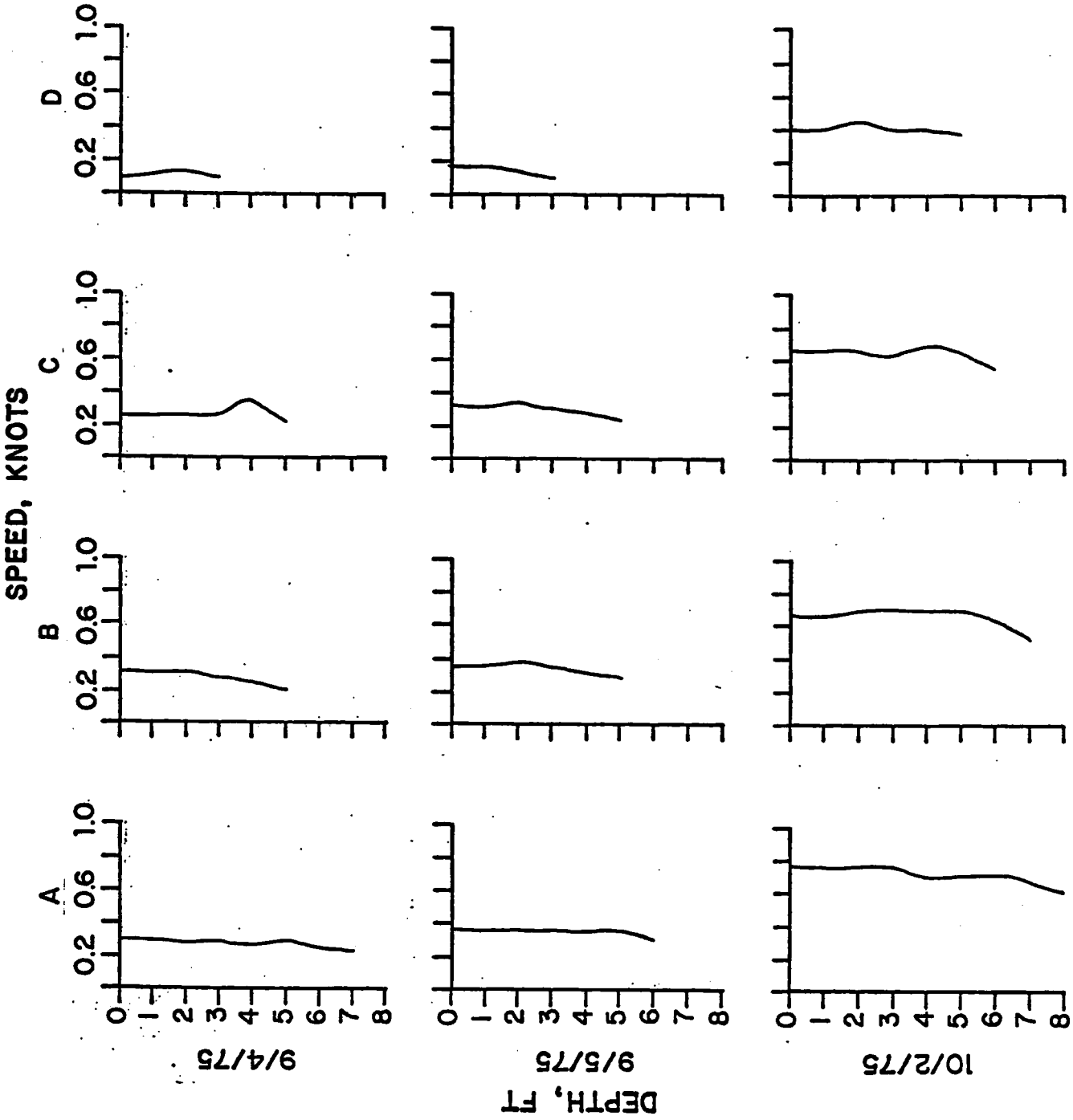
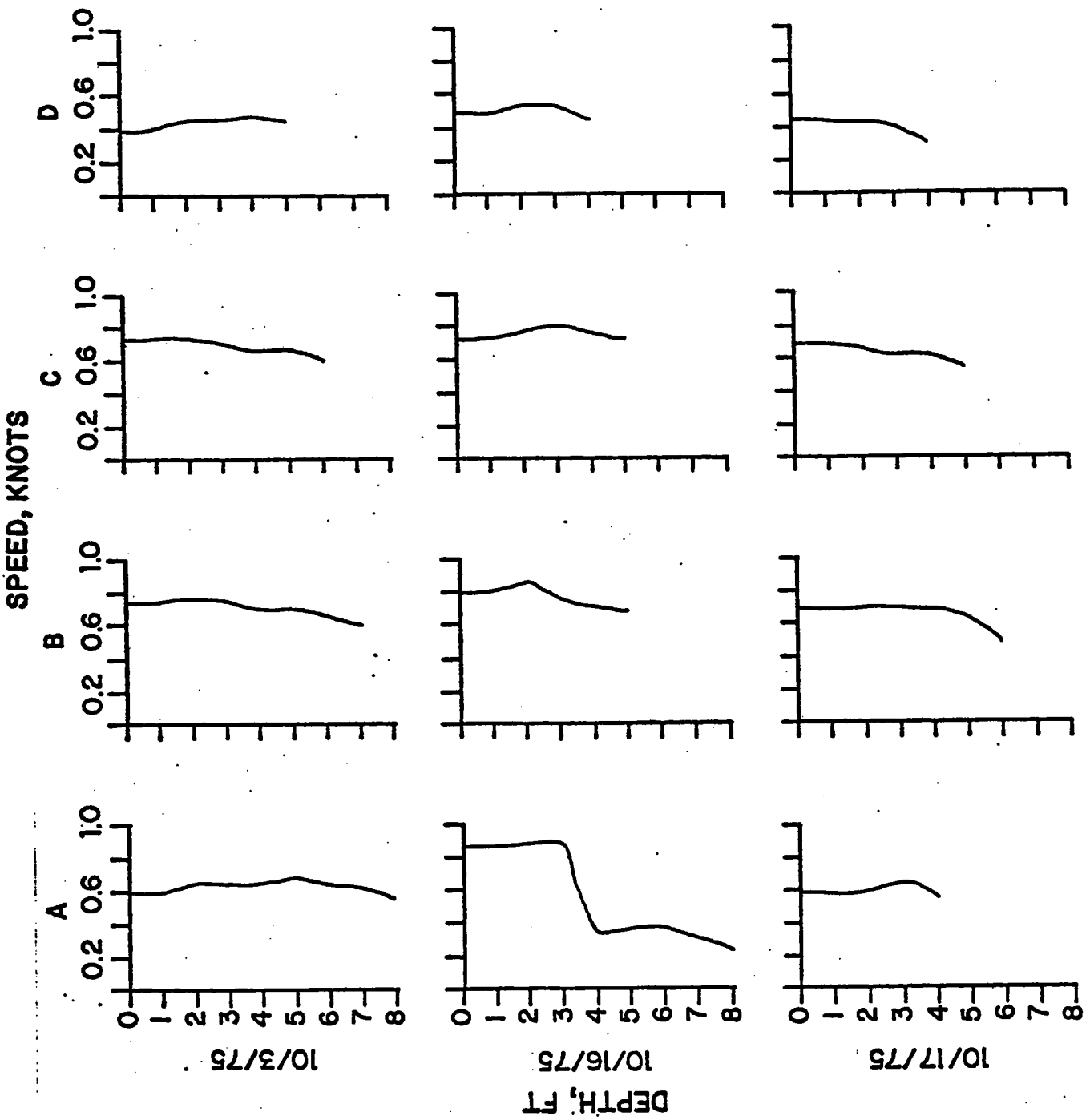
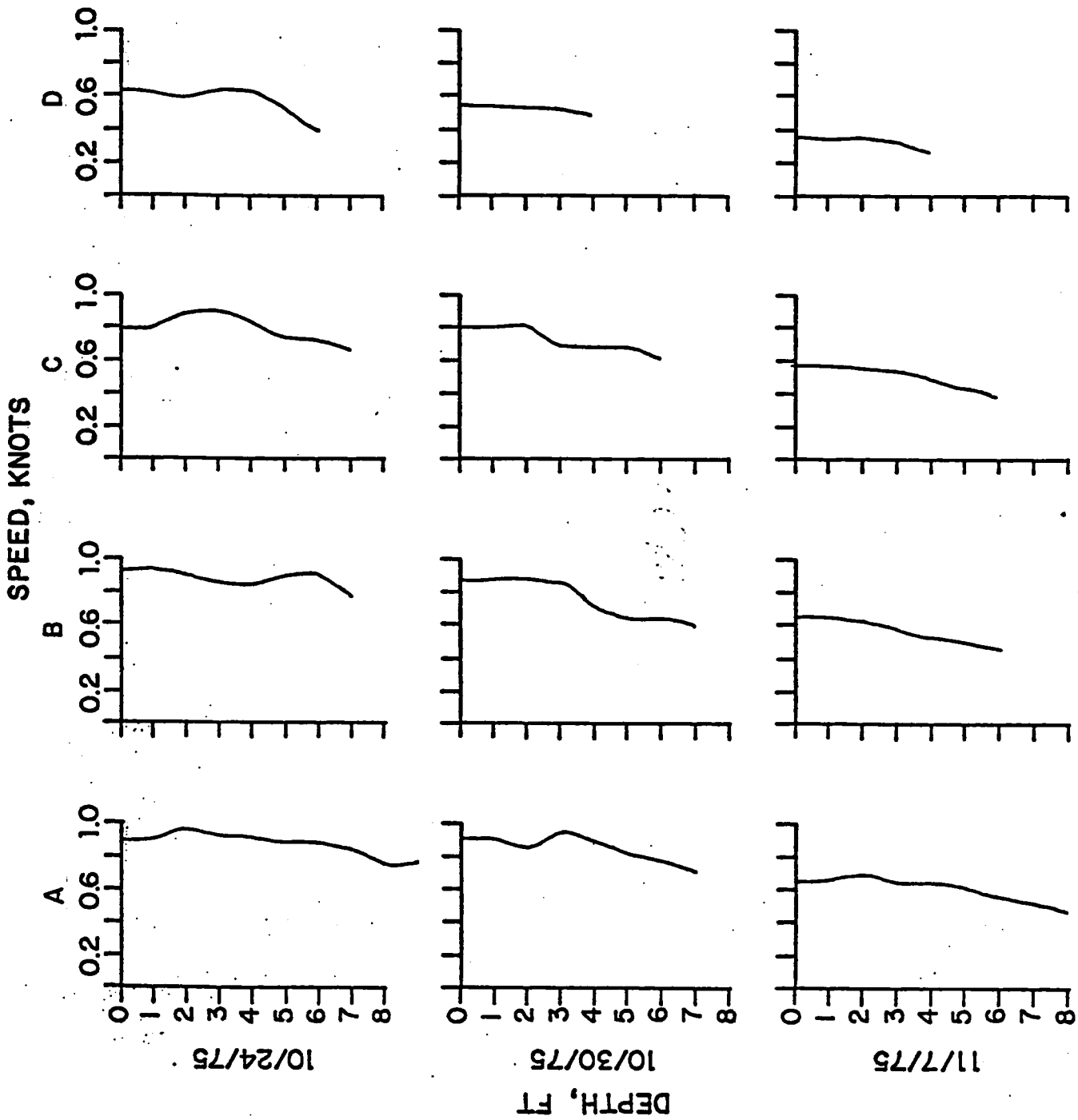

SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0 1 2 3 4 5 6 7 8
DEPTH, FT
11/20/75
12/3/75

Figure B-4e. Vertical current profiles at transect IS for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


DEPTH, FT
8/15/75
8/14/75
8/8/75
0
1
2
3
4
5
6
7
8
A
B
C
D
0.2
0.6
1.0
SPEED, KNOTS


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0
1
2
3
4
5
6
7
8
9/4/75
9/5/75
10/2/75
DEPTH, FT


SPEED, KNOTS
0.2
0.6
1.0
A
B
C
D
0
1
2
3
4
5
6
7
8
DEPTH, FT
10/3/75
10/16/75
10/17/75


SPEED, KNOTS
0.2
0.6
1.0
A
B
C
D
0
1
2
3
4
5
6
7
8
DEPTH, FT
10/24/75
10/30/75
11/7/75

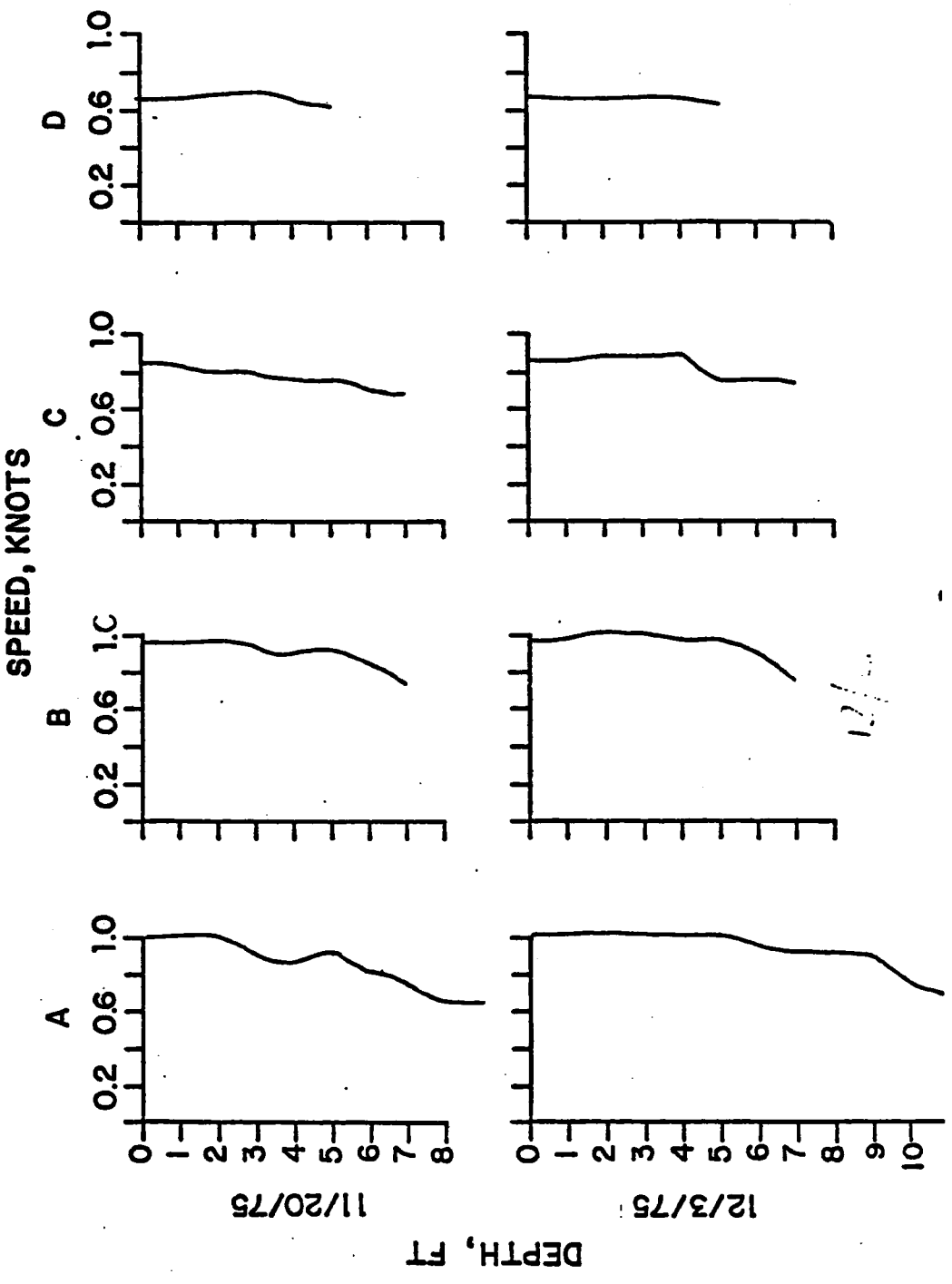
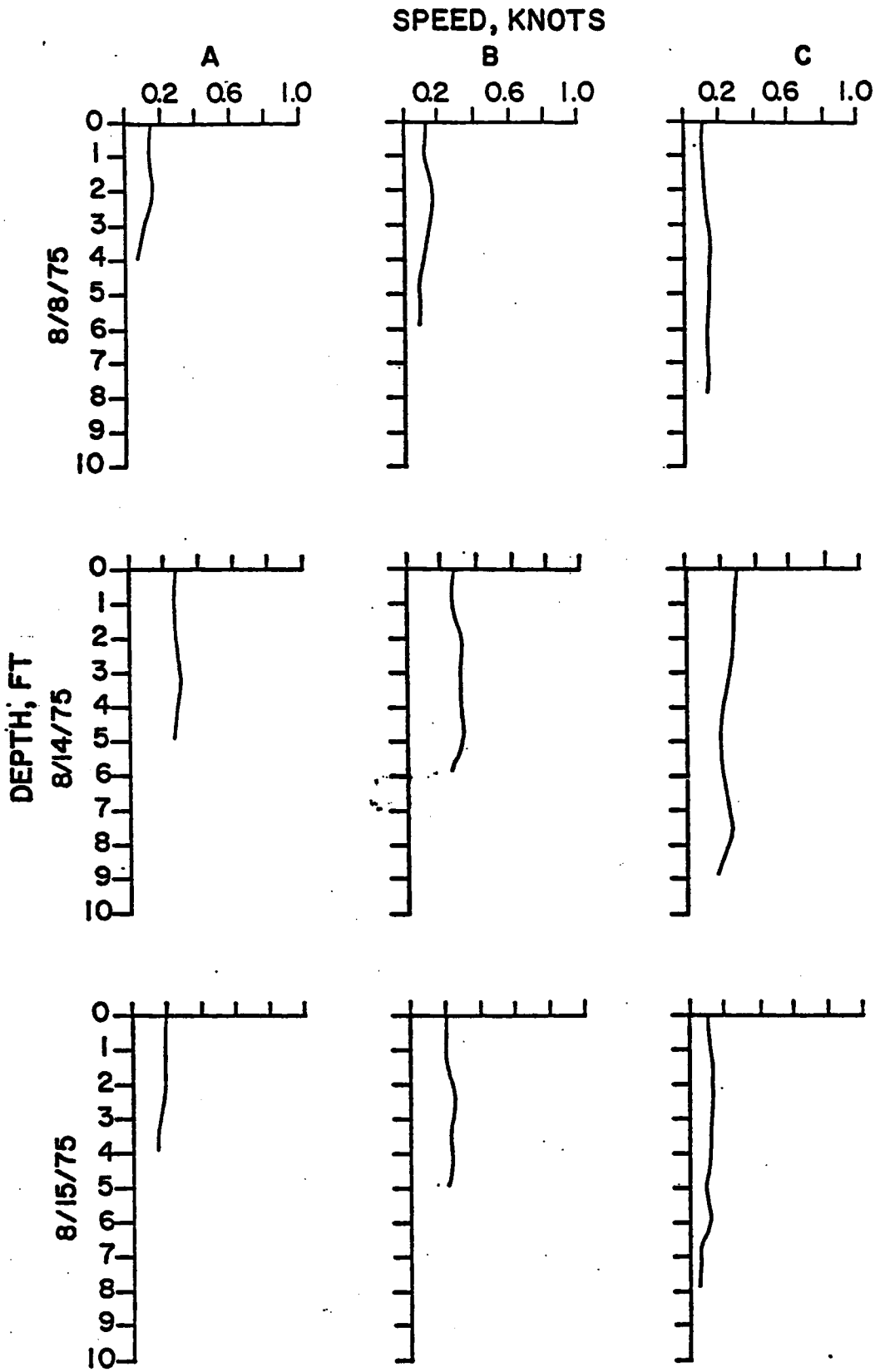
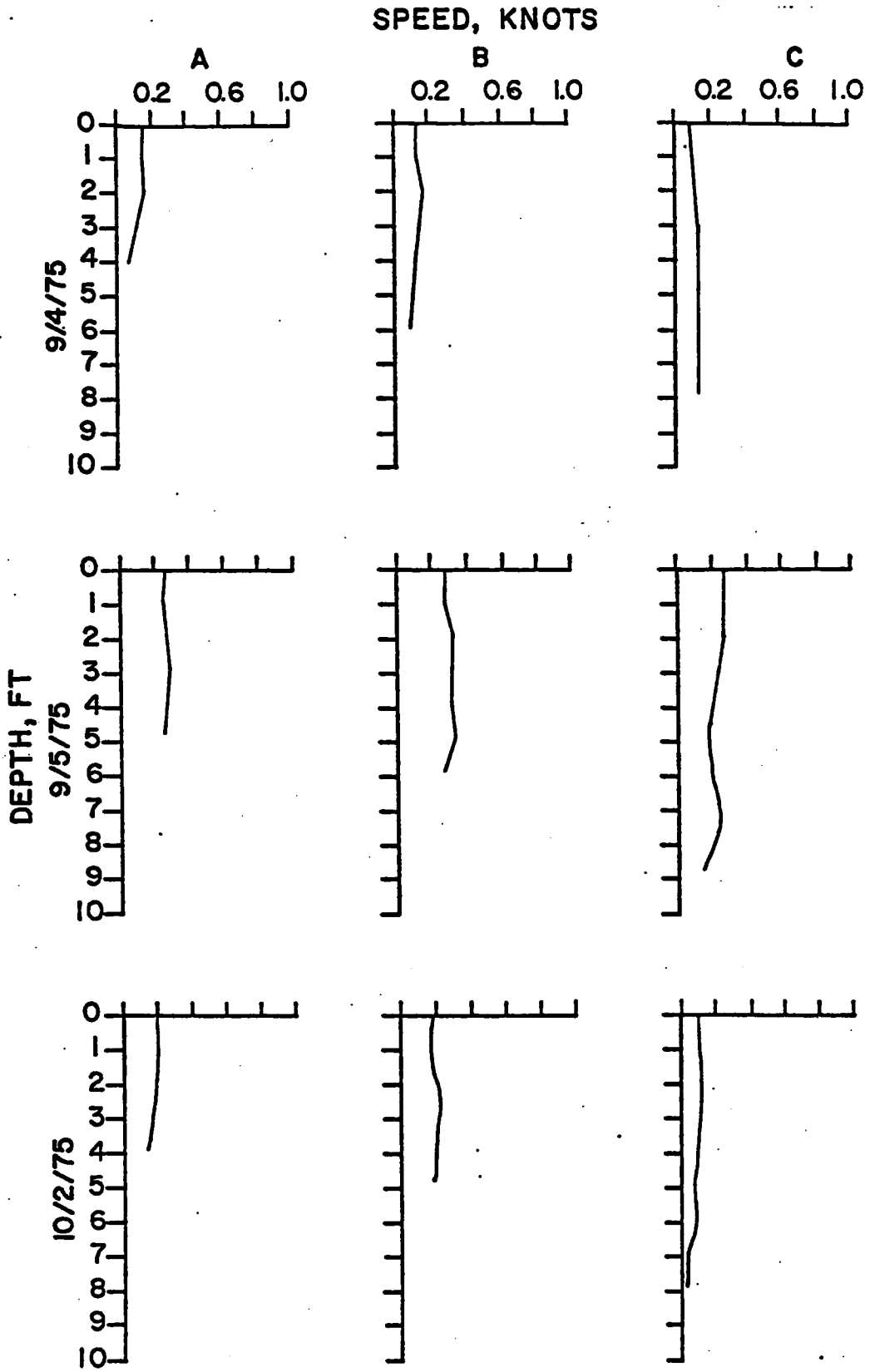
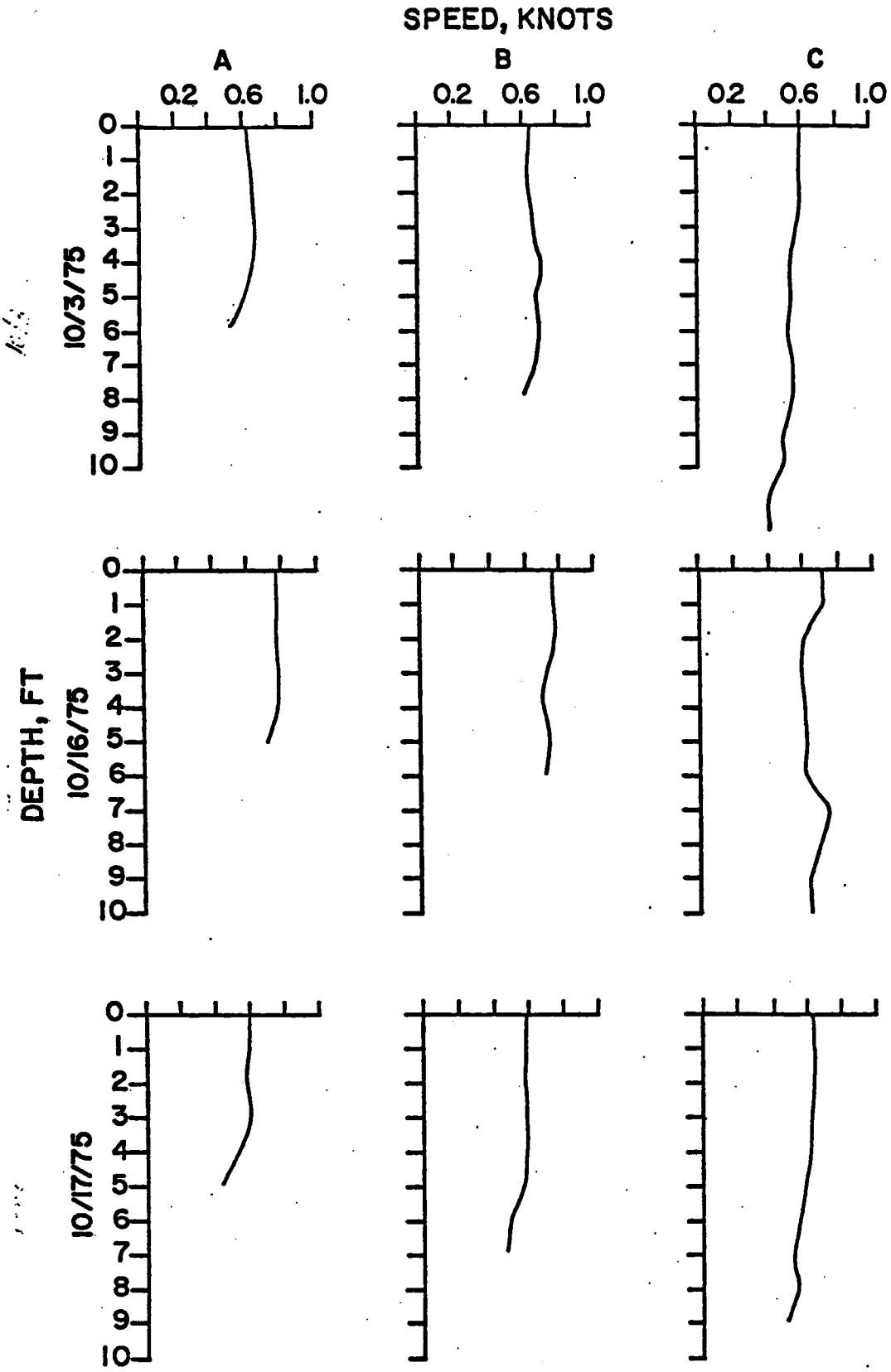
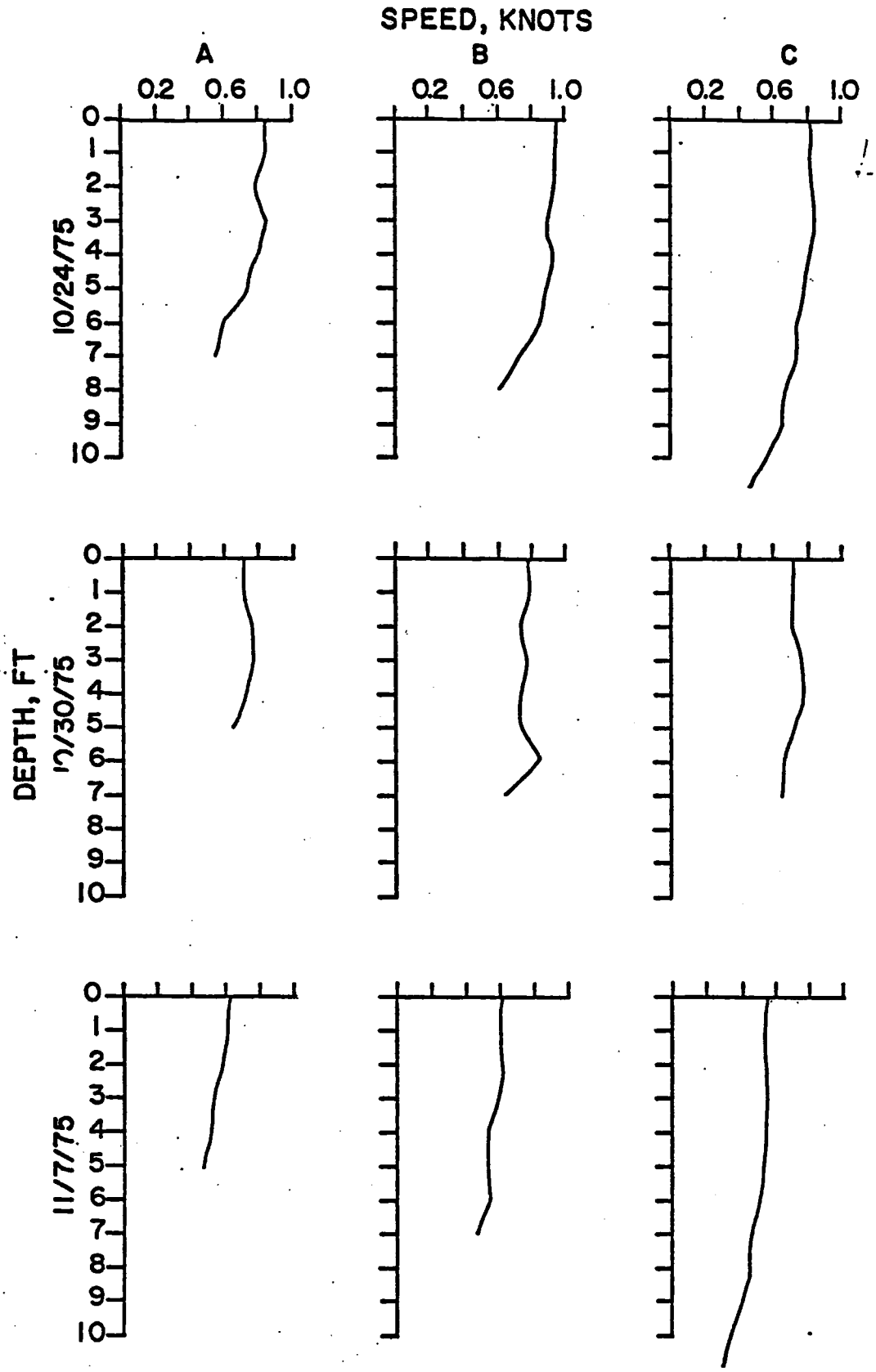

SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
0
1
2
3
4
5
6
7
8
9
10
11/20/75
12/3/75
DEPTH, FT

Figure B-4f. Vertical current profiles at transect DI for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
8/8/75
8/14/75
8/15/75
0
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
9/4/75
9/5/75
10/2/75
0
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/3/75
10/16/75
10/17/75
0
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/24/75
10/30/75
11/7/75
0
1
2
3
4
5
6
7
8
9
10

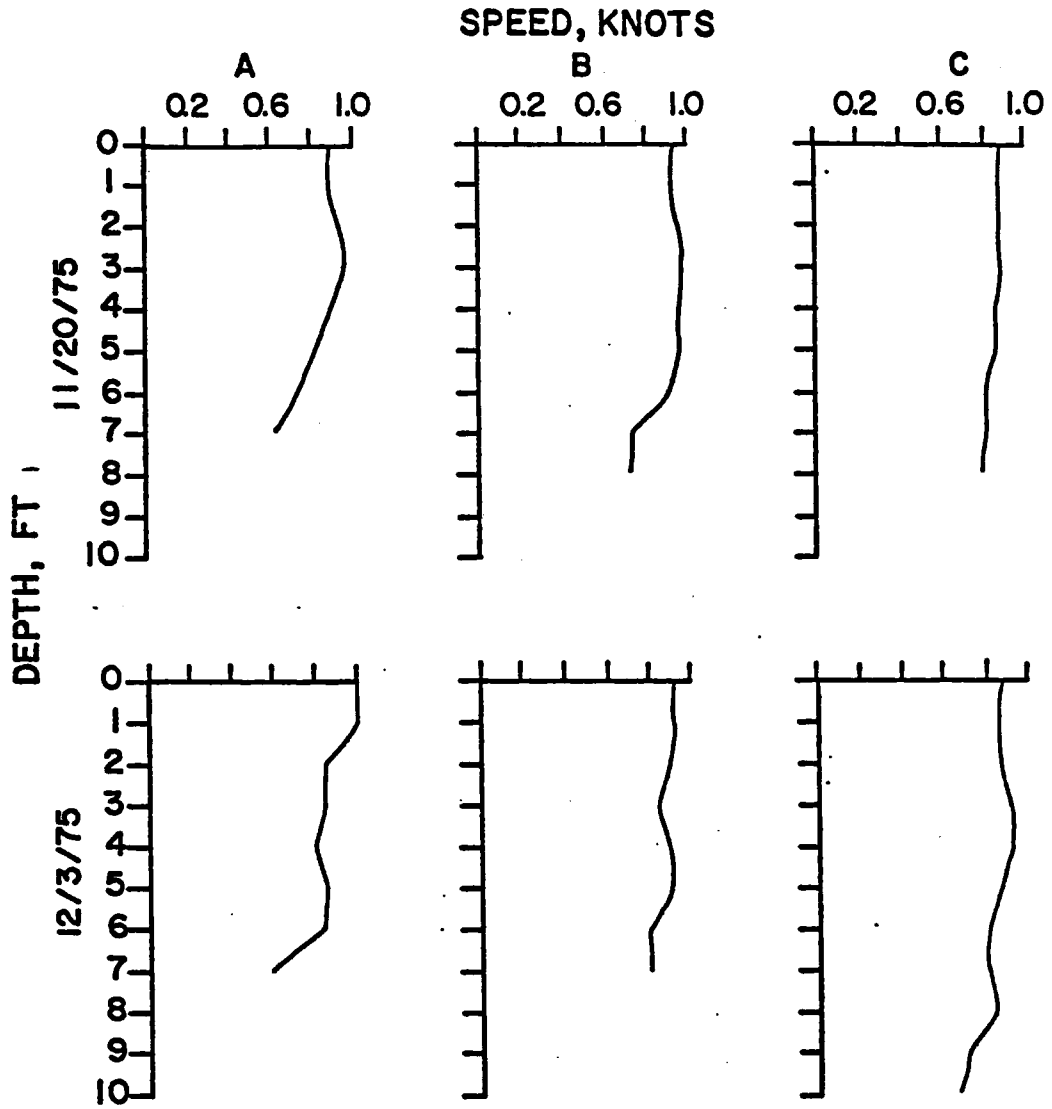
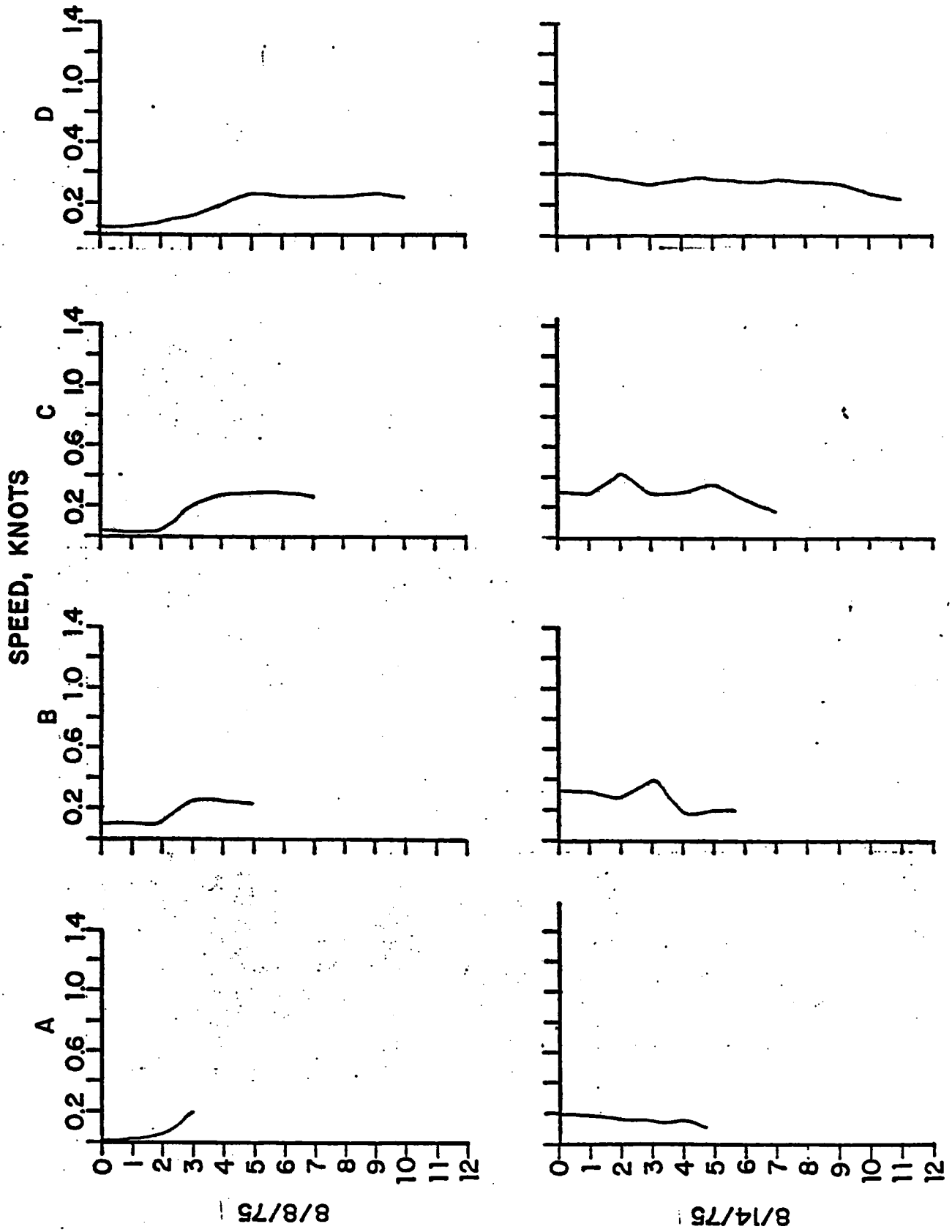
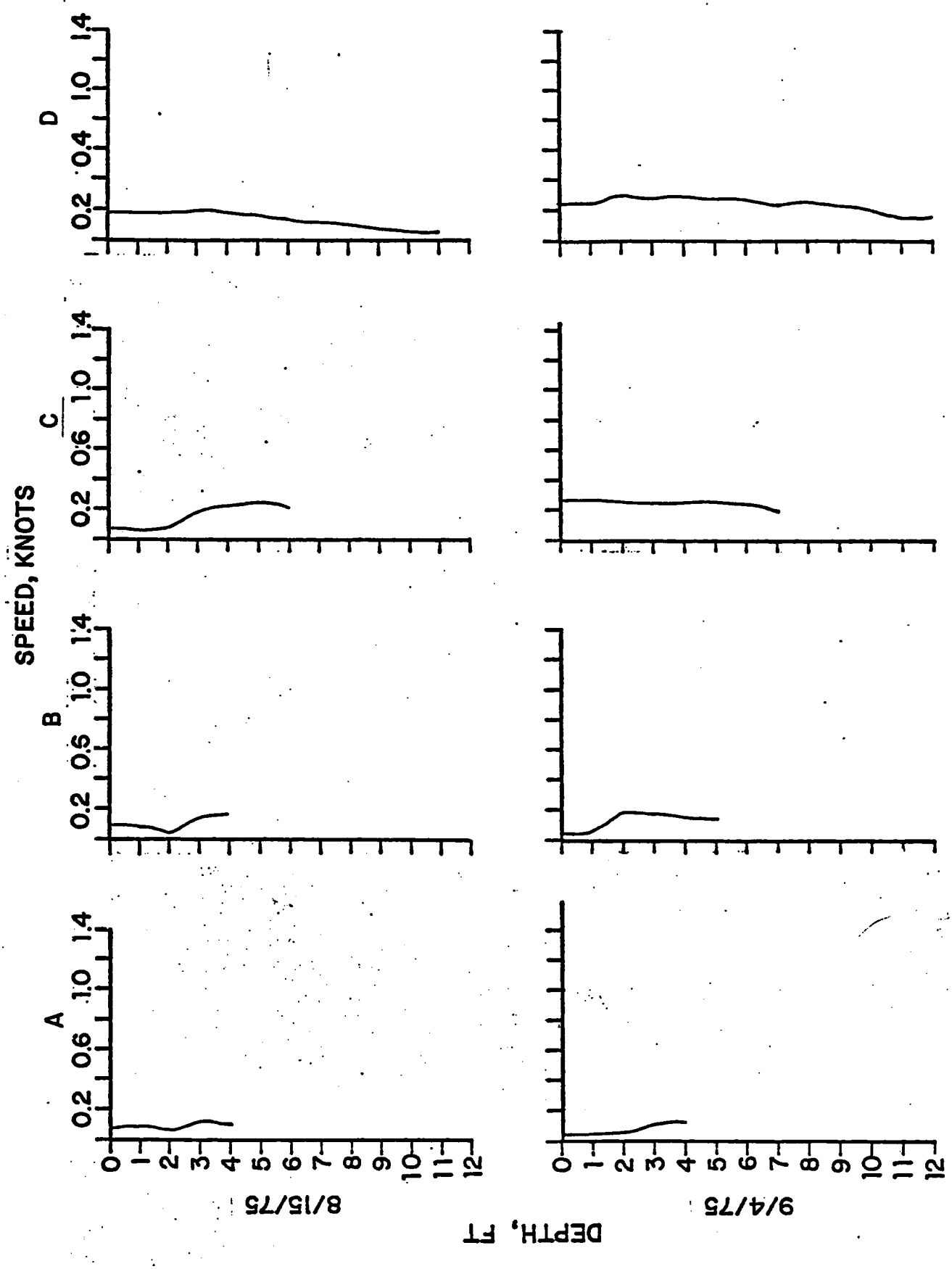
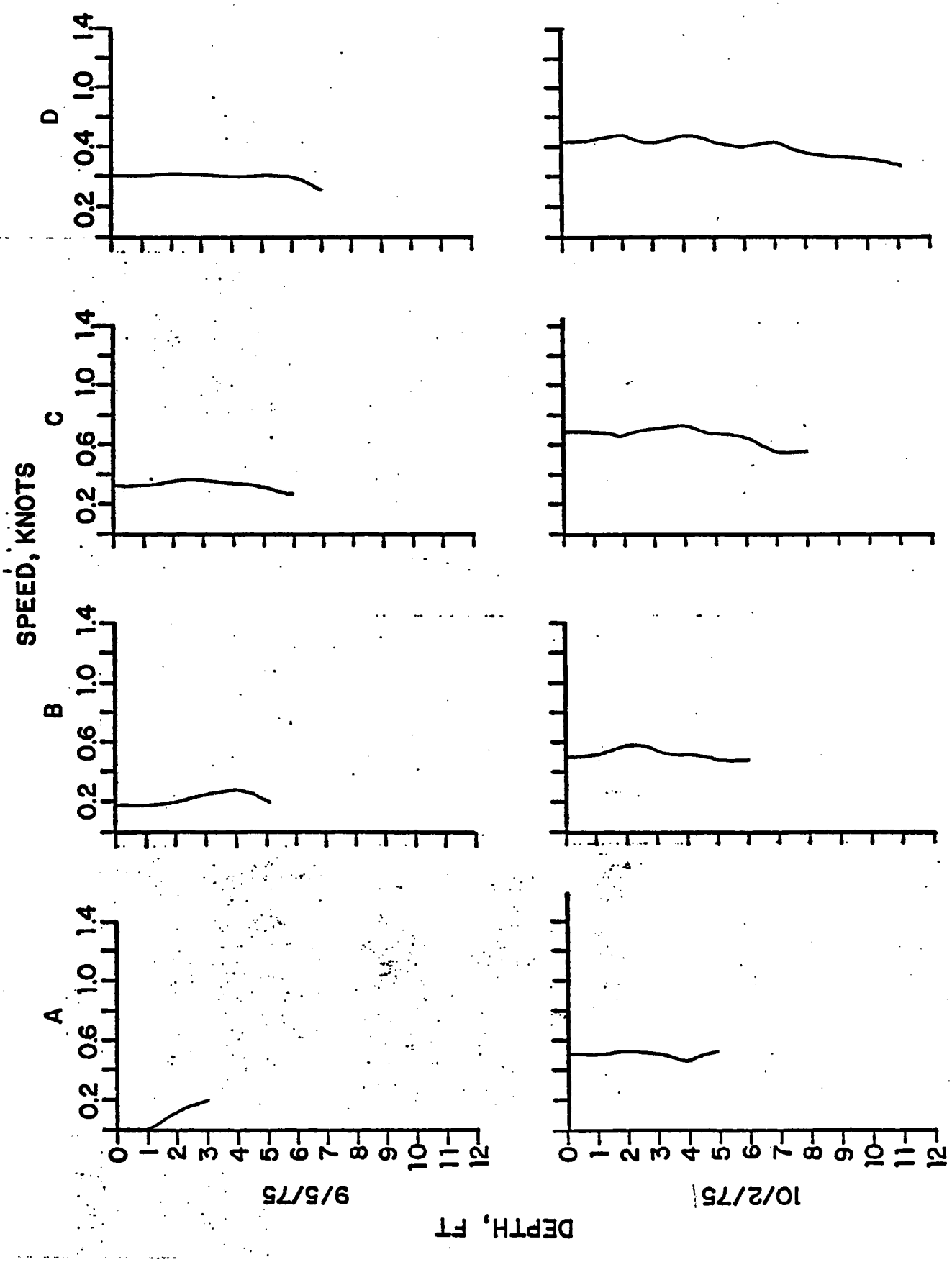
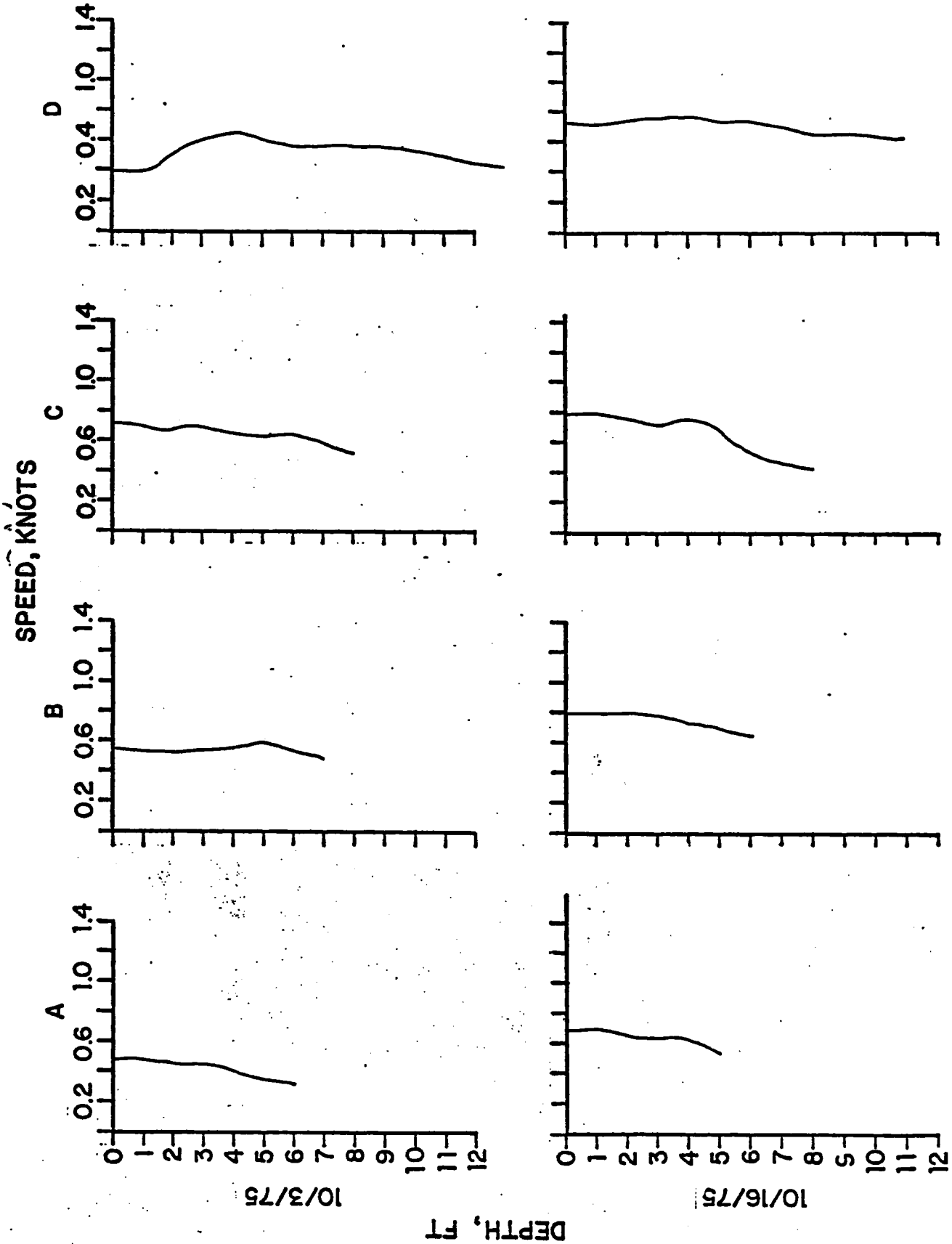

SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
11/20/75
12/3/75
0
1
2
3
4
5
6
7
8
9
10

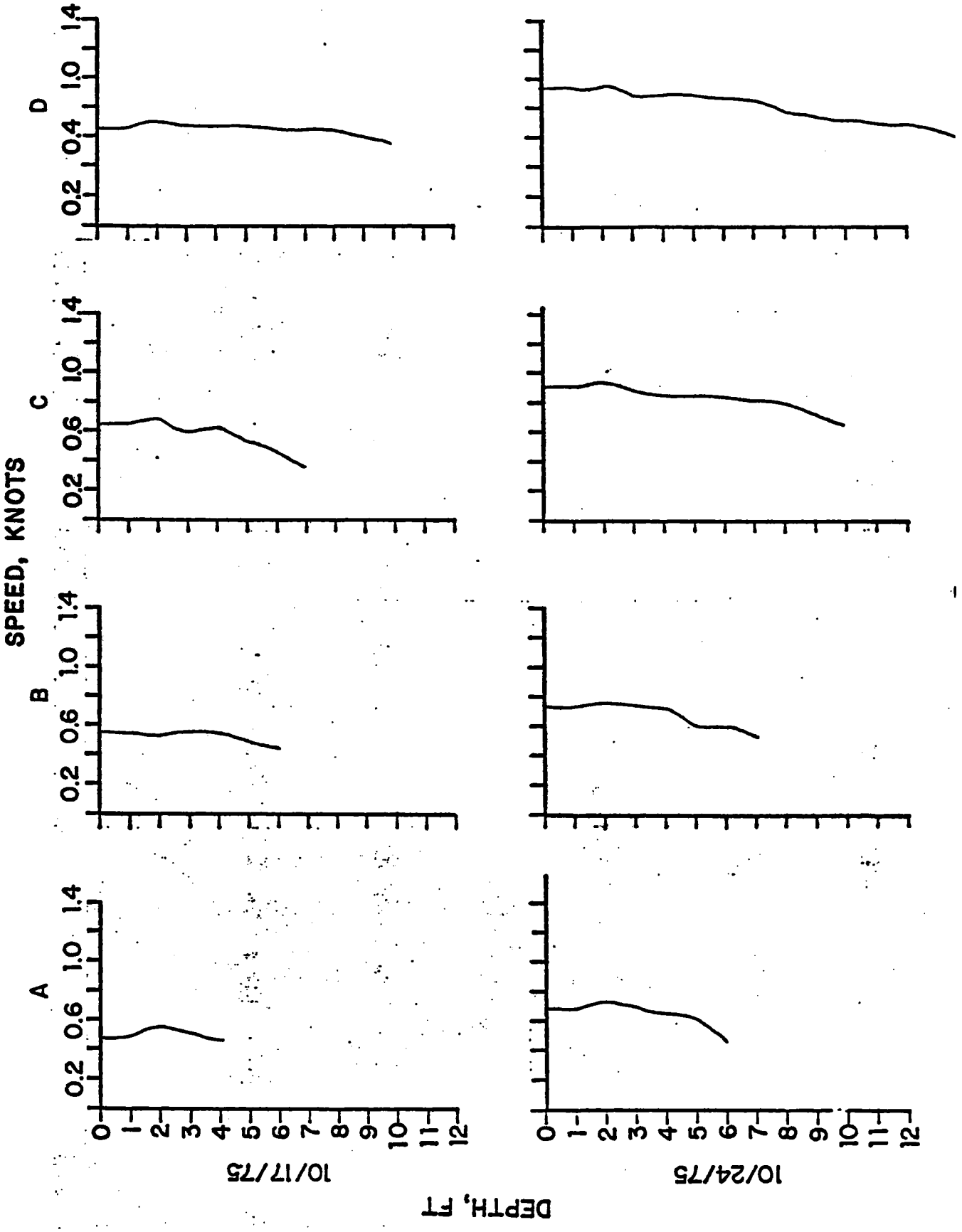
Figure B-4g. Vertical current profiles at transect DN for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

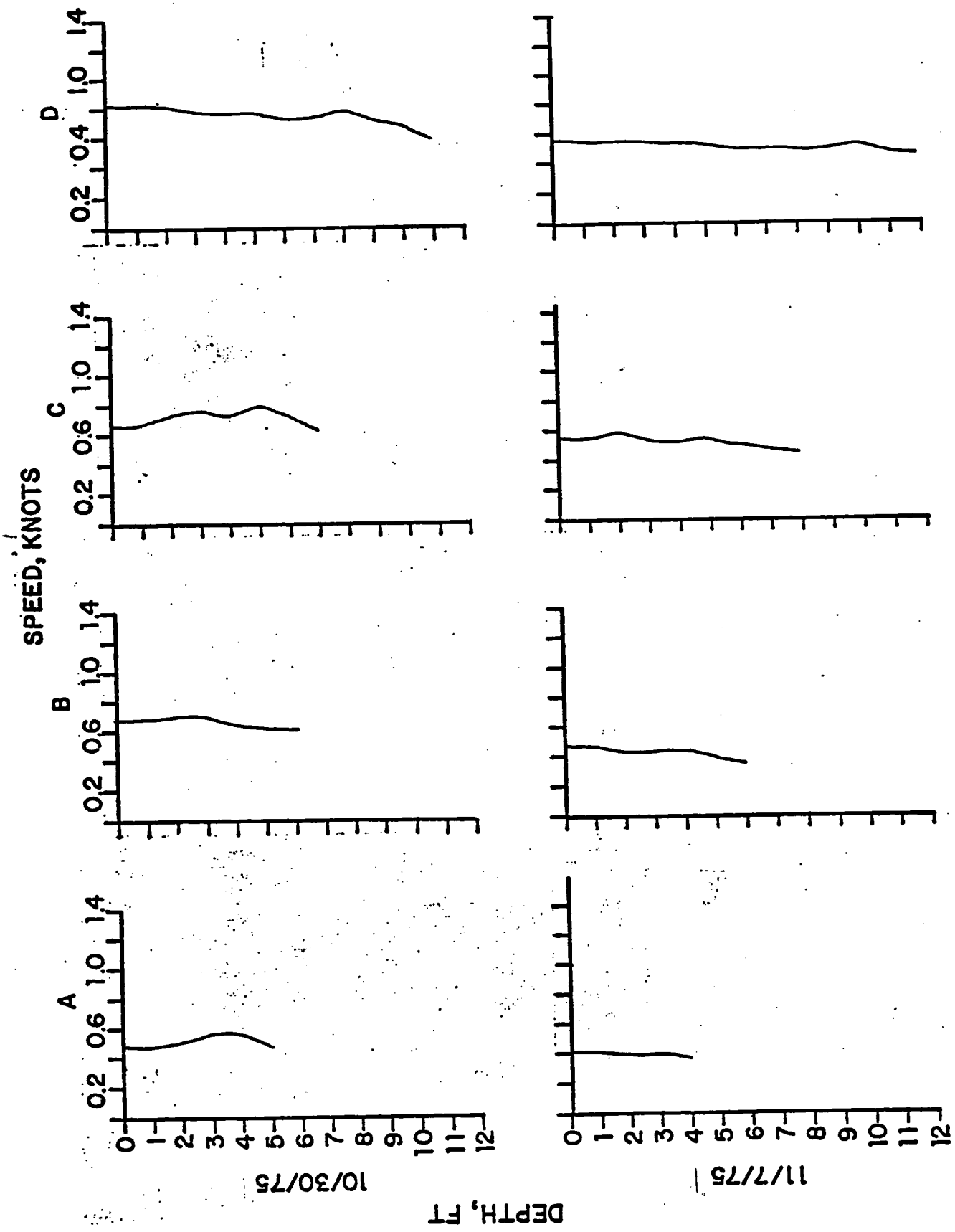

SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0 1 2 3 4 5 6 7 8 9 10 11 12
DEPTH, FT
8/8/75
8/14/75

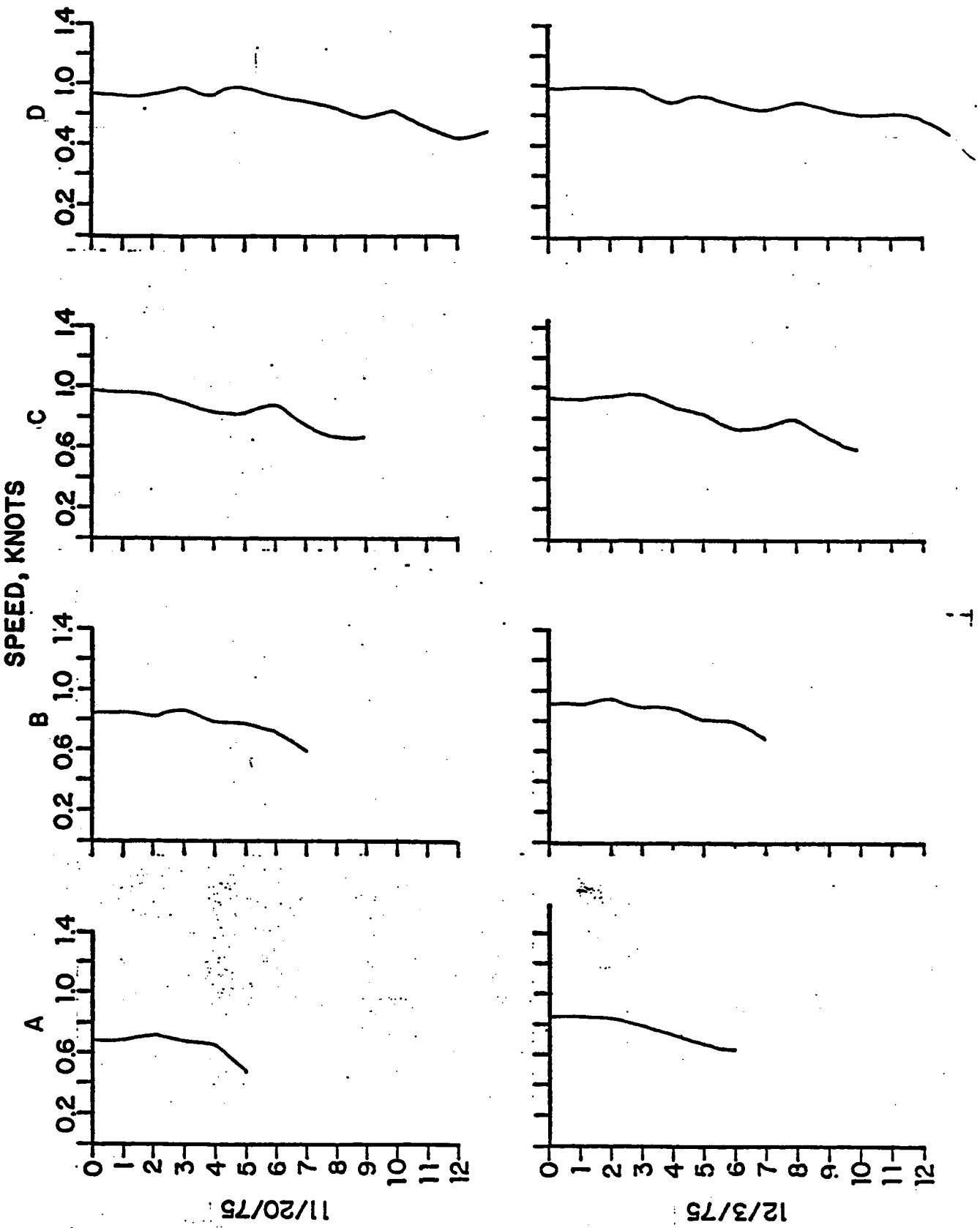

SPEED, KNOTS
A
B
C
D
0.2
0.4
0.6
0.5
1.0
1.4
0 1 2 3 4 5 6 7 8 9 10 11 12
DEPTH, FT
8/15/75
9/4/75


SPEED, KNOTS
A
B
C
D
0.2
0.4
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
9/5/75
10/2/75
DEPTH, FT


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH, FT
10/3/75
10/16/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH, FT
10/17/75
10/24/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH, FT
10/30/75
11/7/75


SPEED, KNOTS
A
B
C
D
0.2
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH, FT
11/20/75
12/3/75

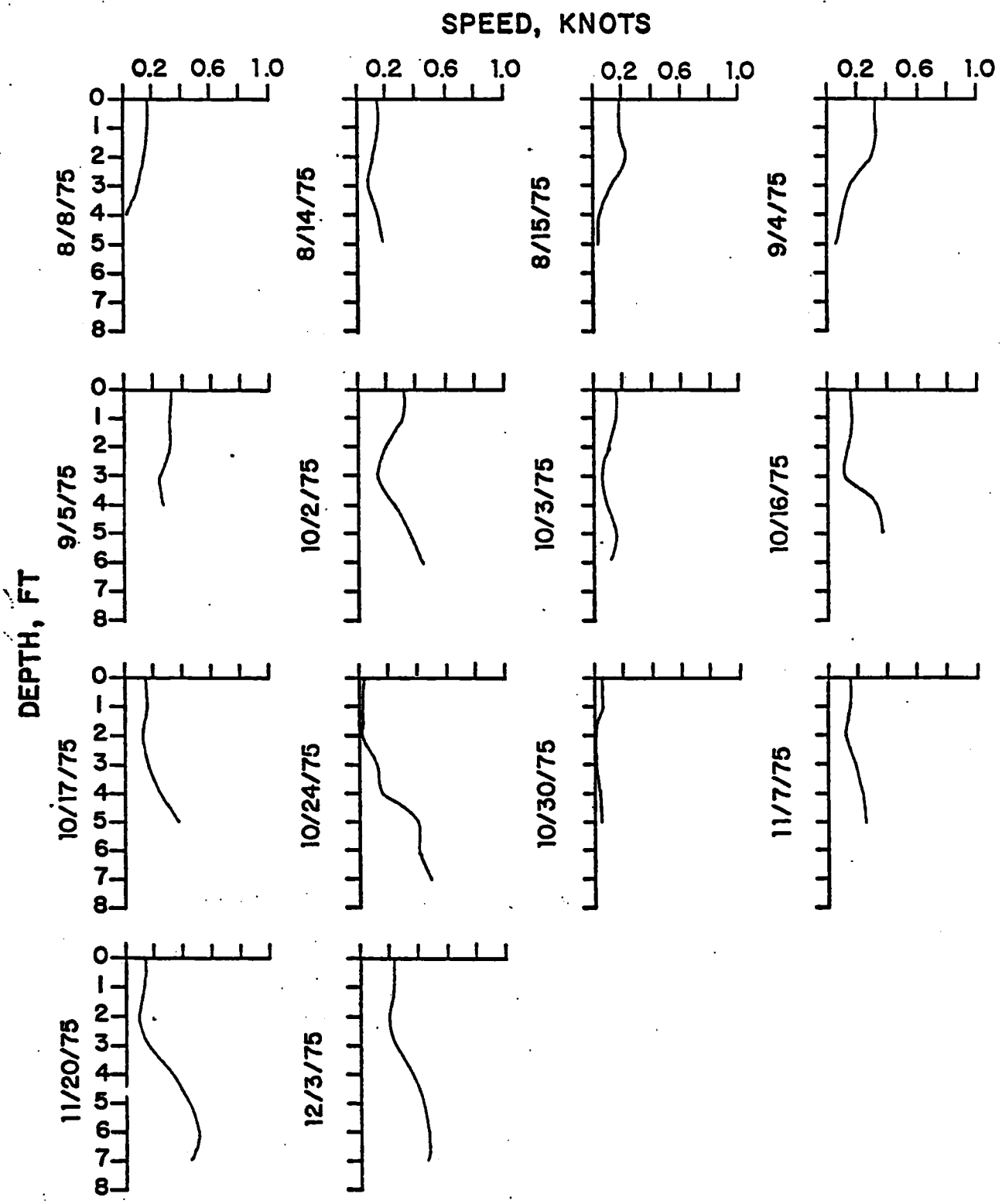
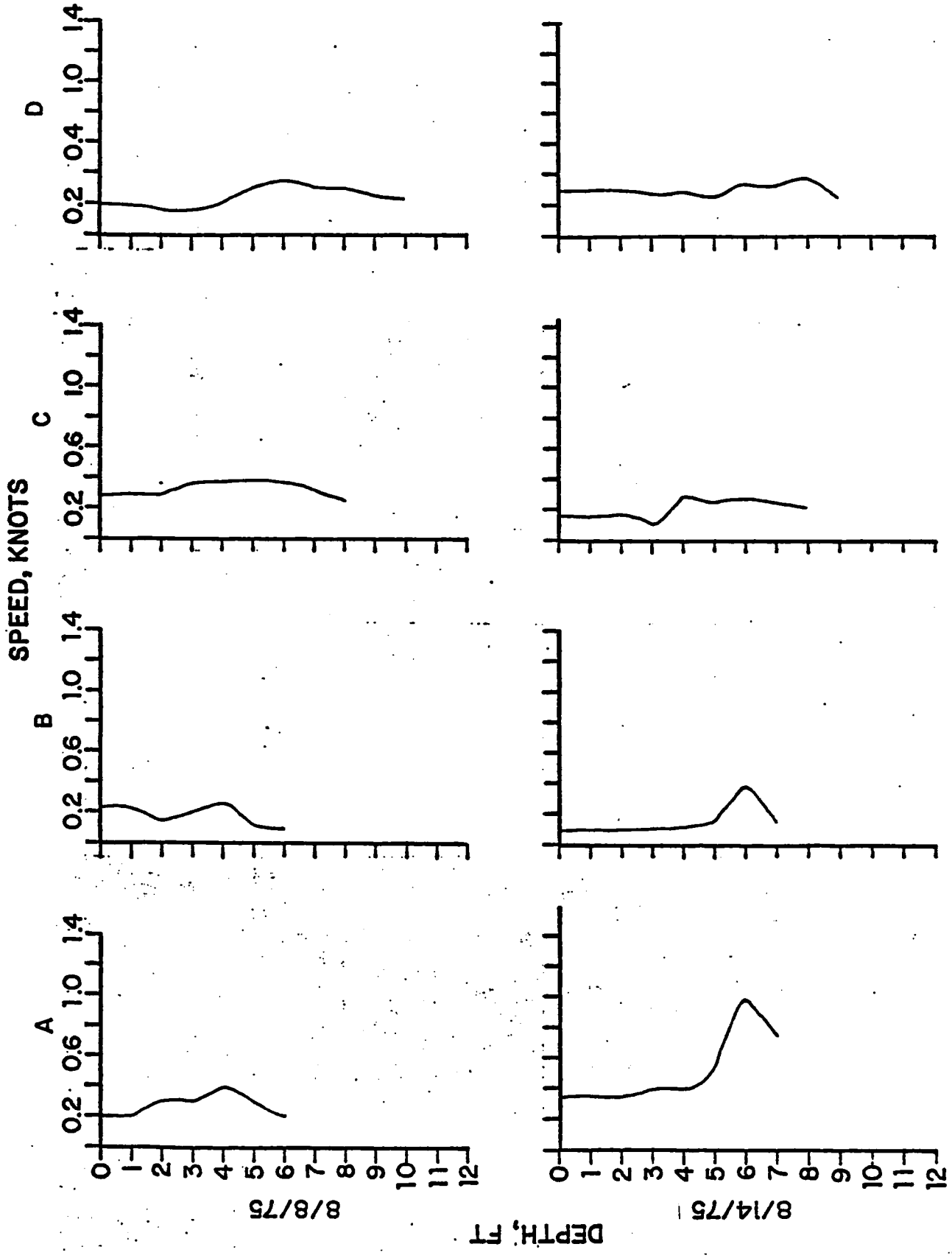
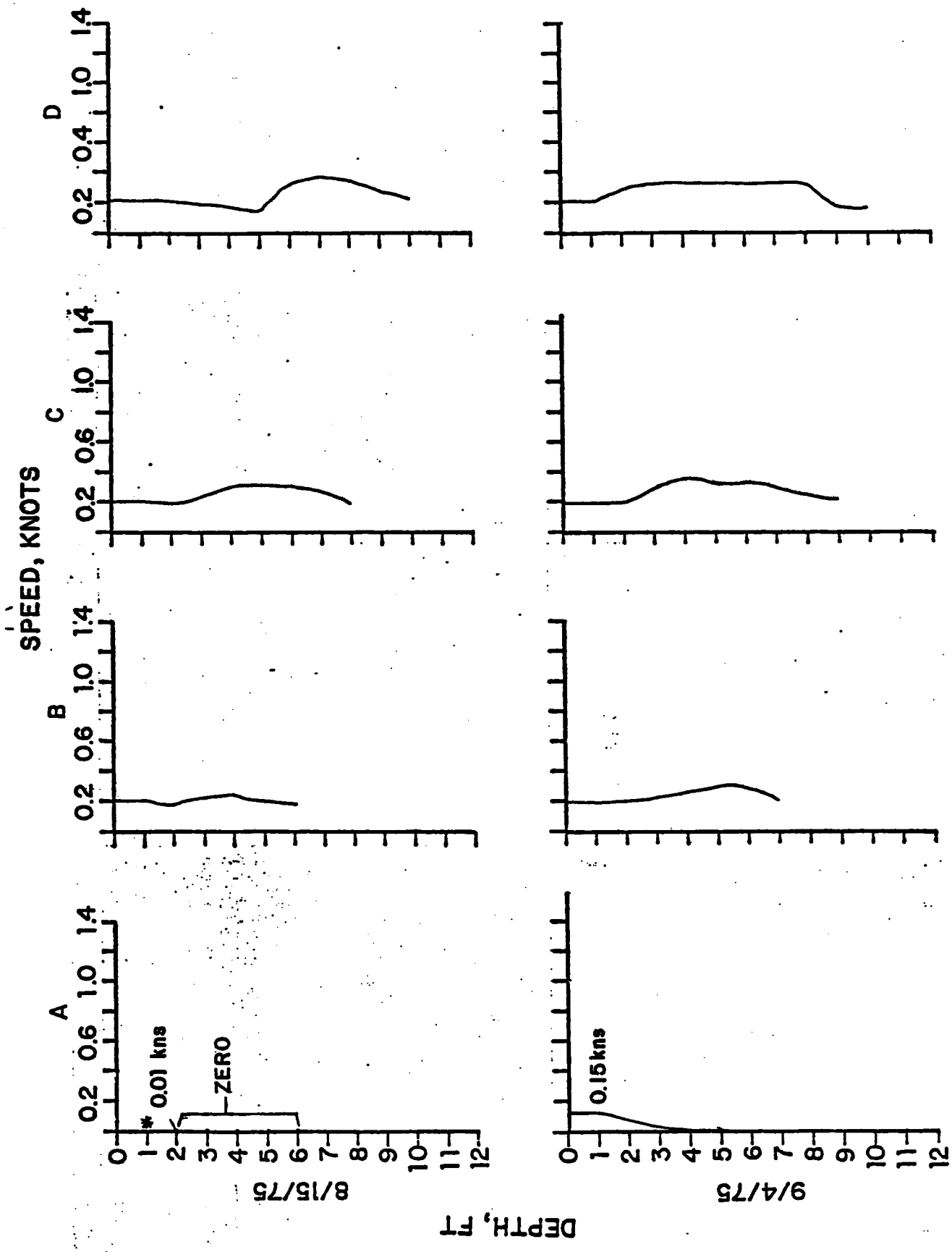


Figure B-4h. Vertical current profiles at station DO for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.

Figure B-4i. Vertical current profiles at transect DS for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
D
0.2
0.4
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
8/8/75
8/14/75
DEPTH, FT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B
C
D
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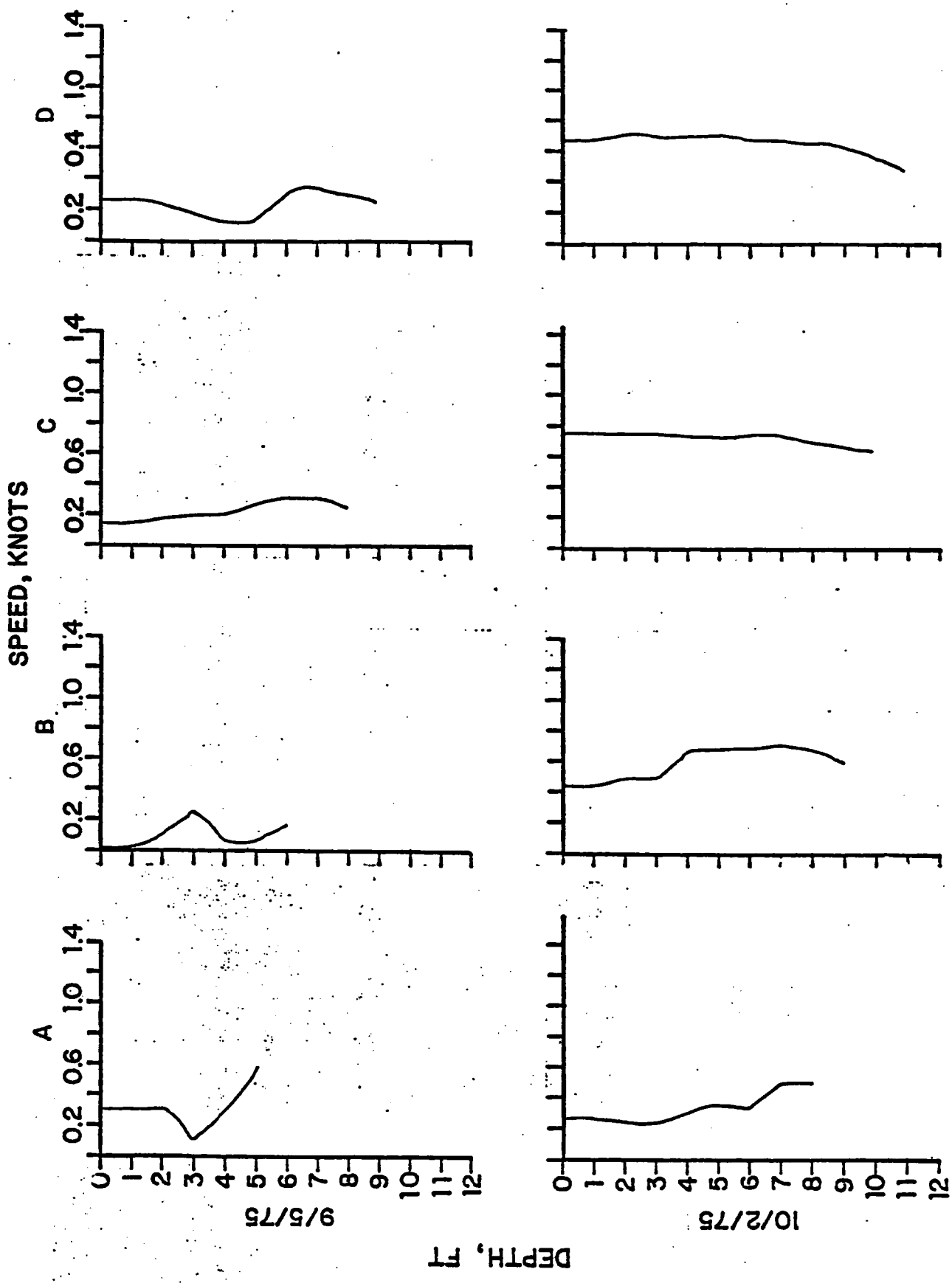
1.0
1.4
* 0.01 kns
ZERO
0.15kns
0 1 2 3 4 5 6 7 8 9 10 11 12
8/15/75
9/4/75
DEPTH, FT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C
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1.4
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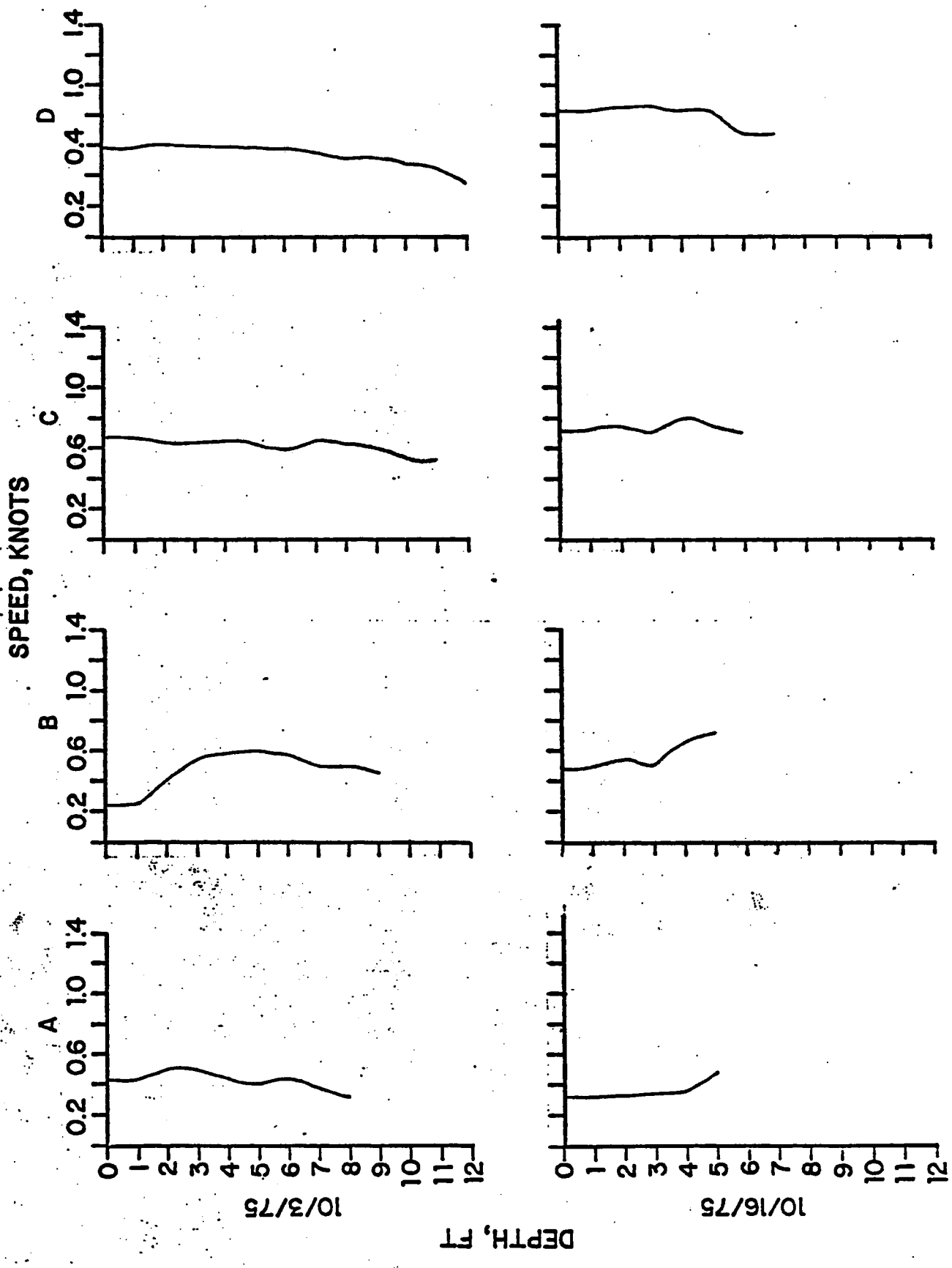
DEPTH, FT
9/5/75
10/2/75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1.4
A
B
C
D
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6
7
8
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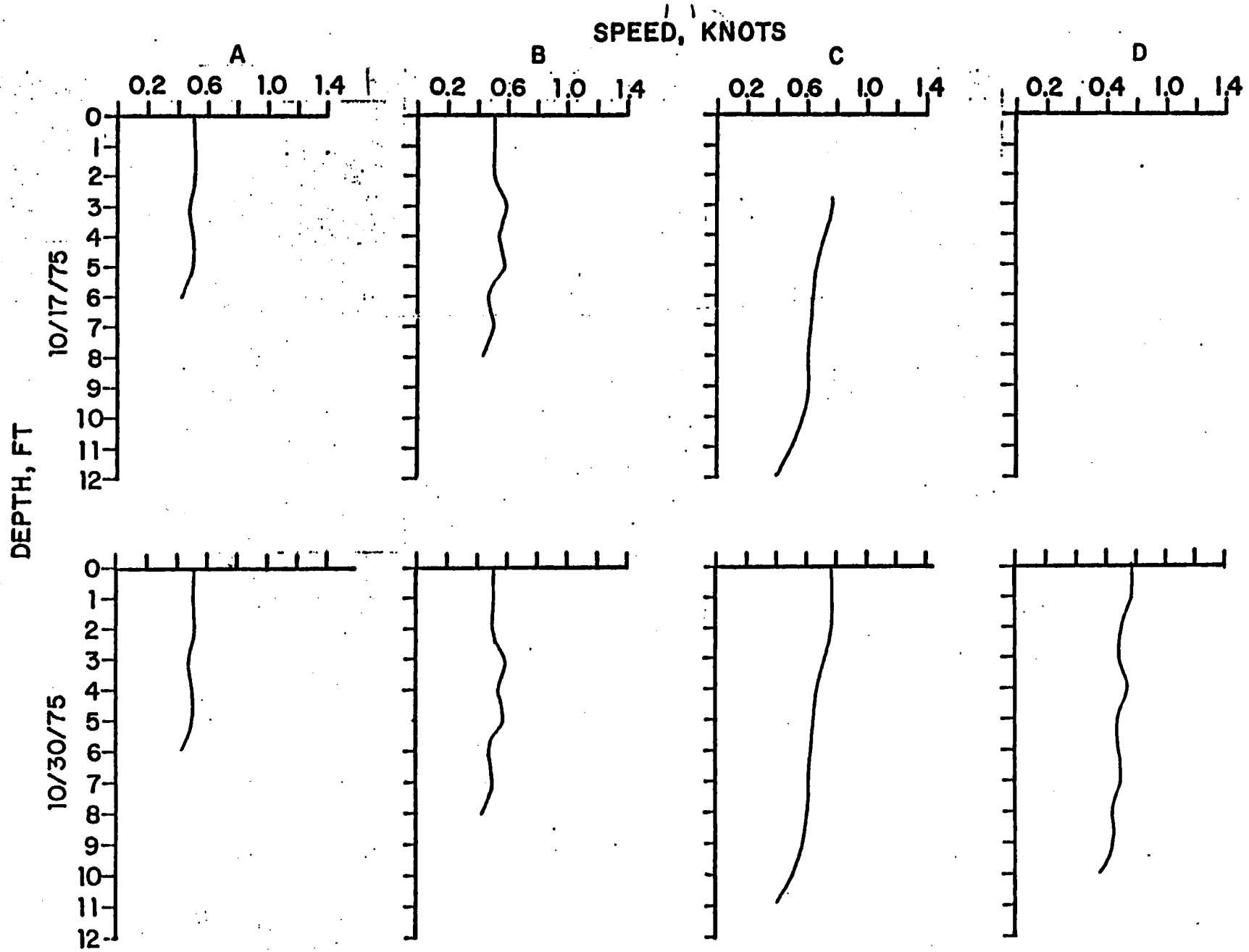
10
11
12
DEPTH, FT
10/3/75
10/16/75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B
C
D
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1.0
1.4
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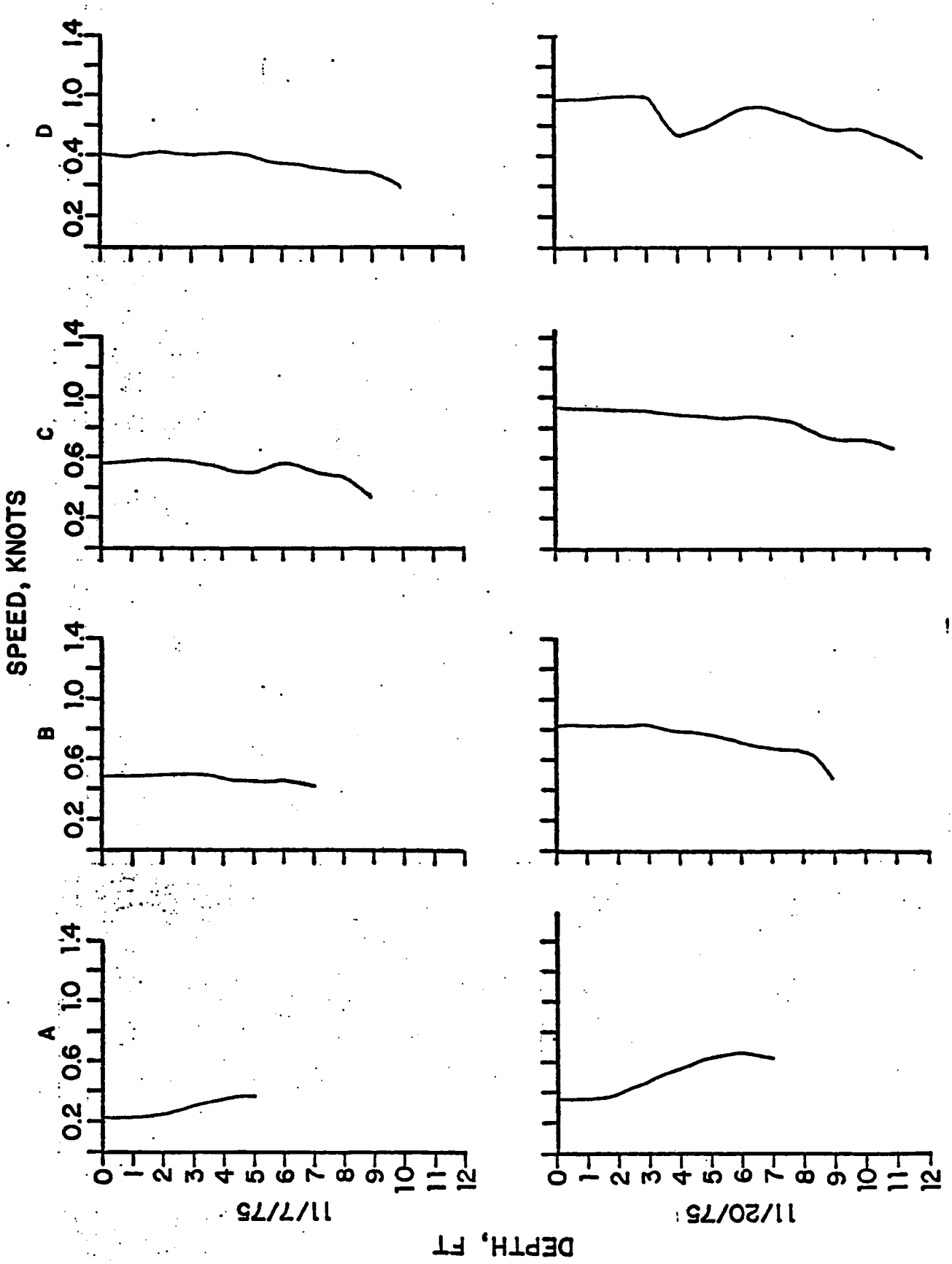
8
9
10
11
12
10/17/75
10/30/75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B
C
D
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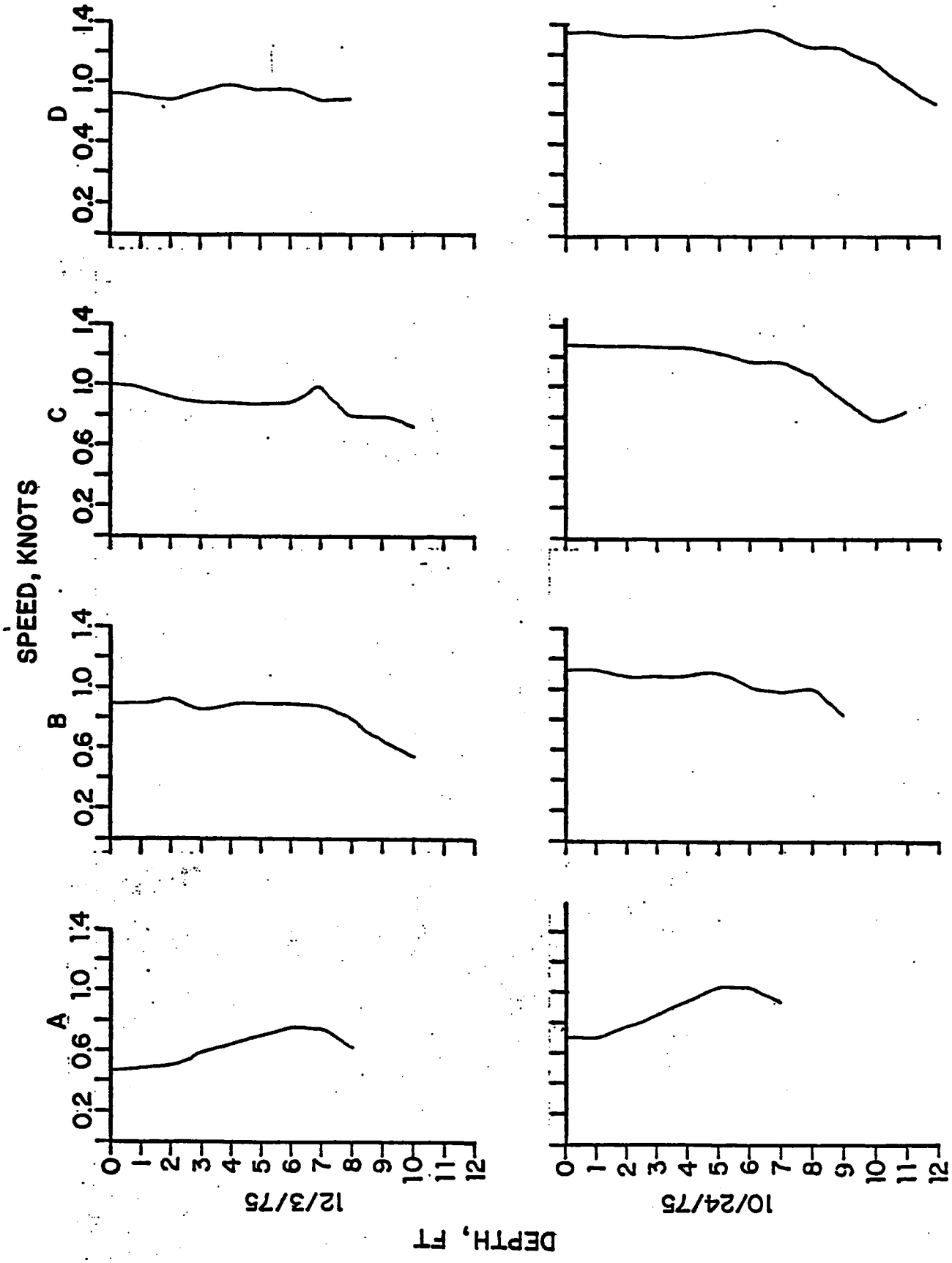
10
11
12
11/7/75
11/20/75
DEPTH, FT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B
C
D
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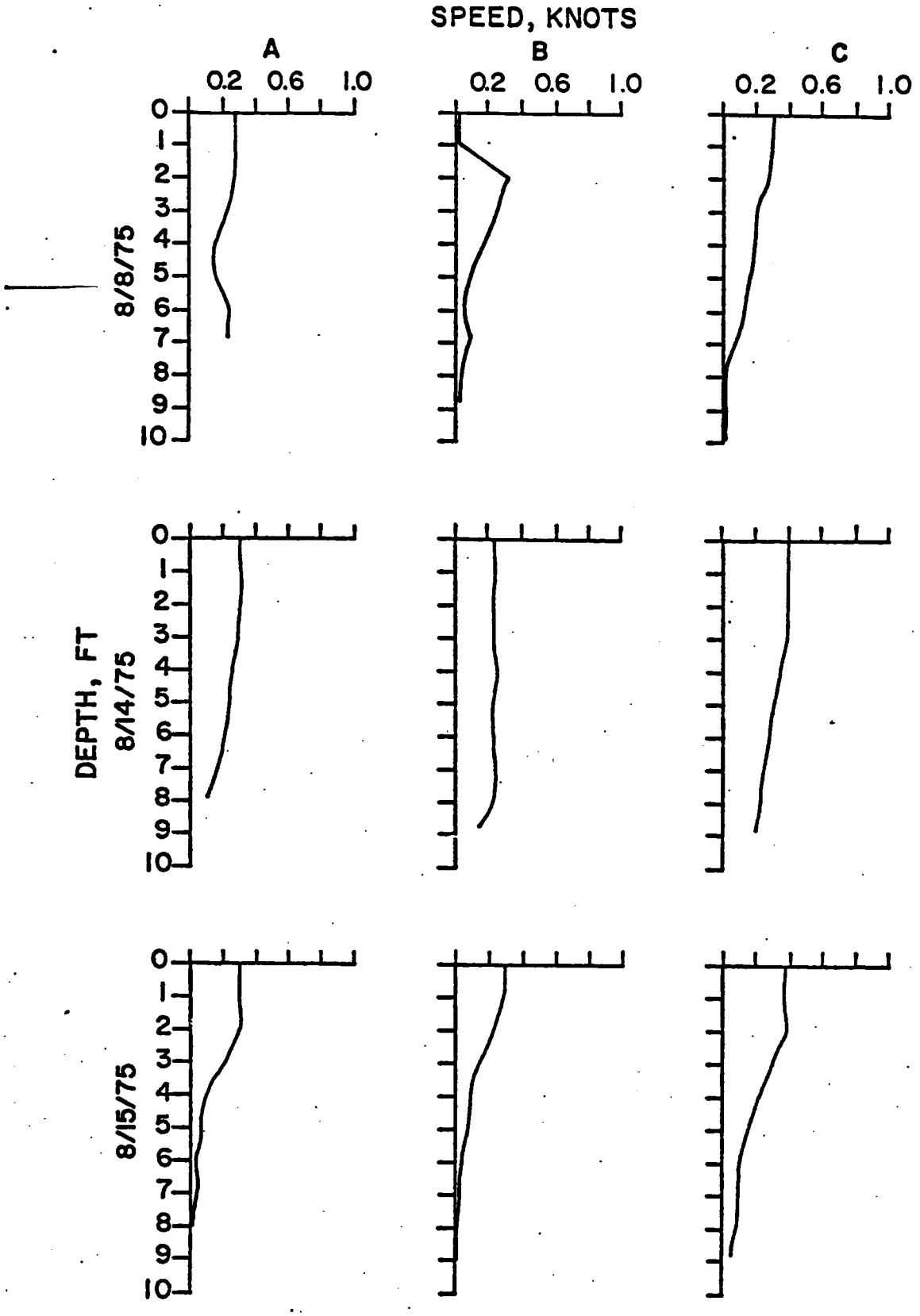
0.6
1.0
1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH, FT
12/3/75
10/24/75

Figure B-4j. Vertical current profiles at transect SUNN for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
8/8/75
8/14/75
8/15/75
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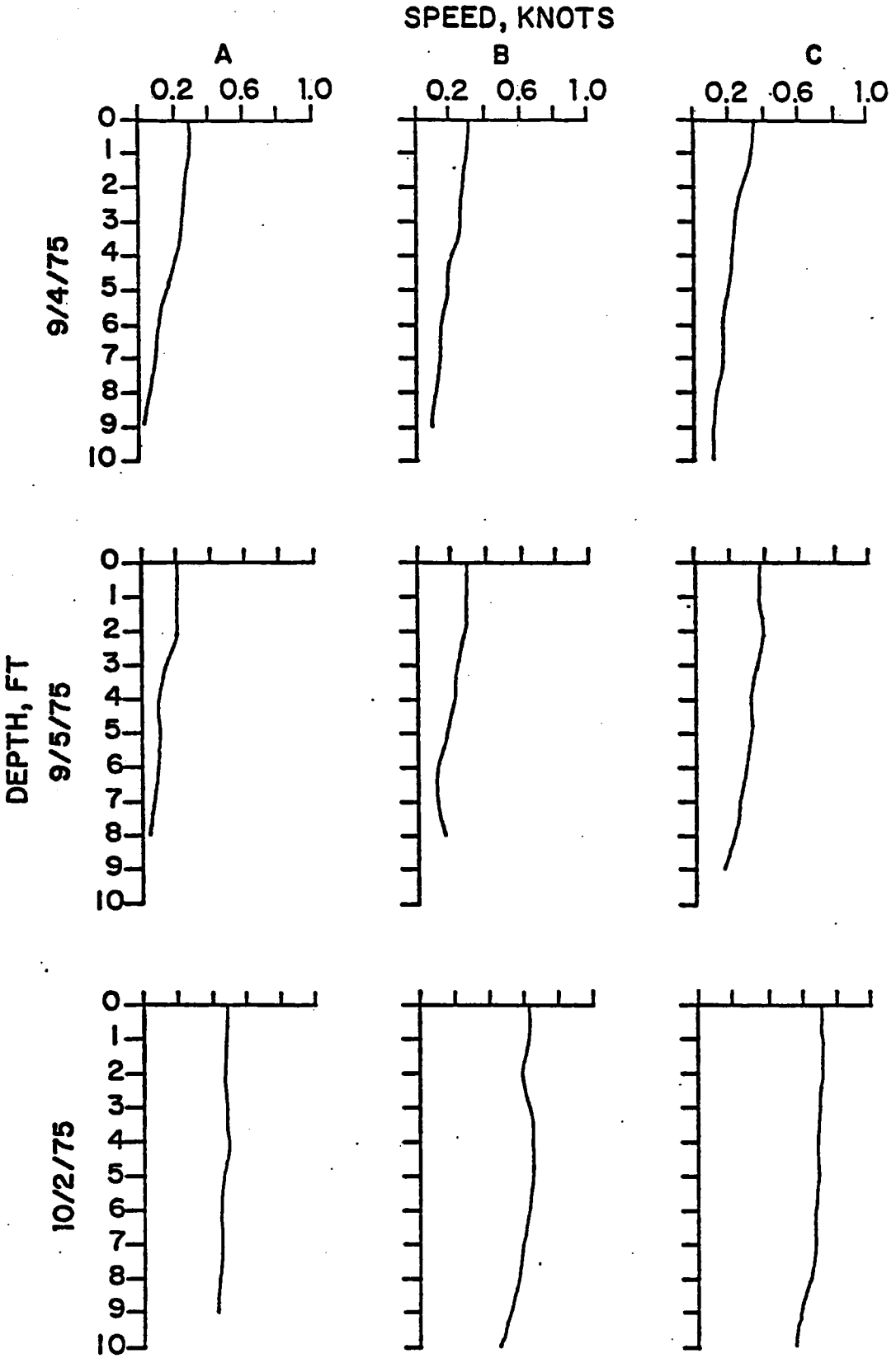
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
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B
C
0.2
0.6
1.0
DEPTH, FT
9/4/75
9/5/75
10/2/75
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2
3
4
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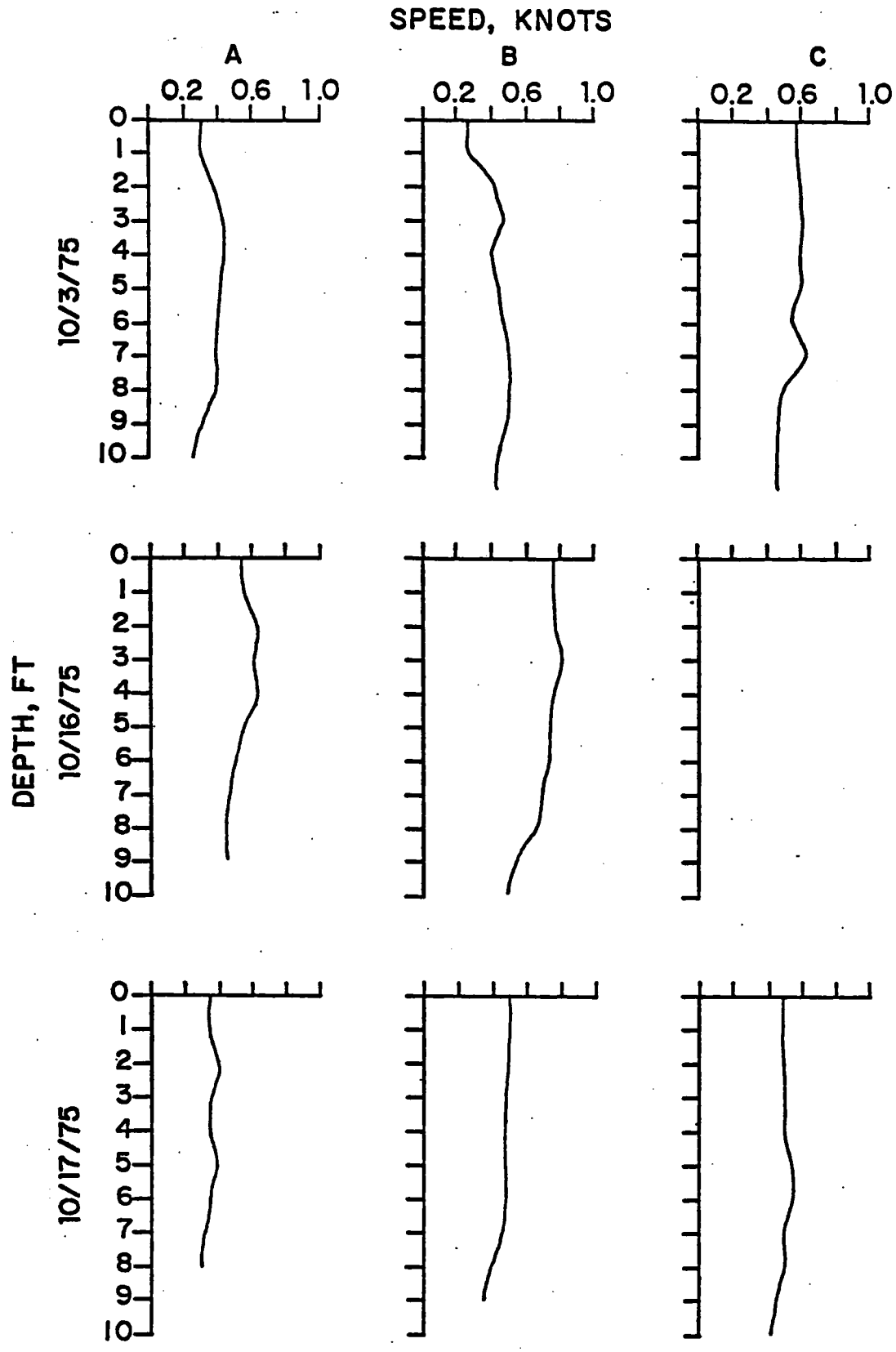
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/3/75
10/16/75
10/17/75
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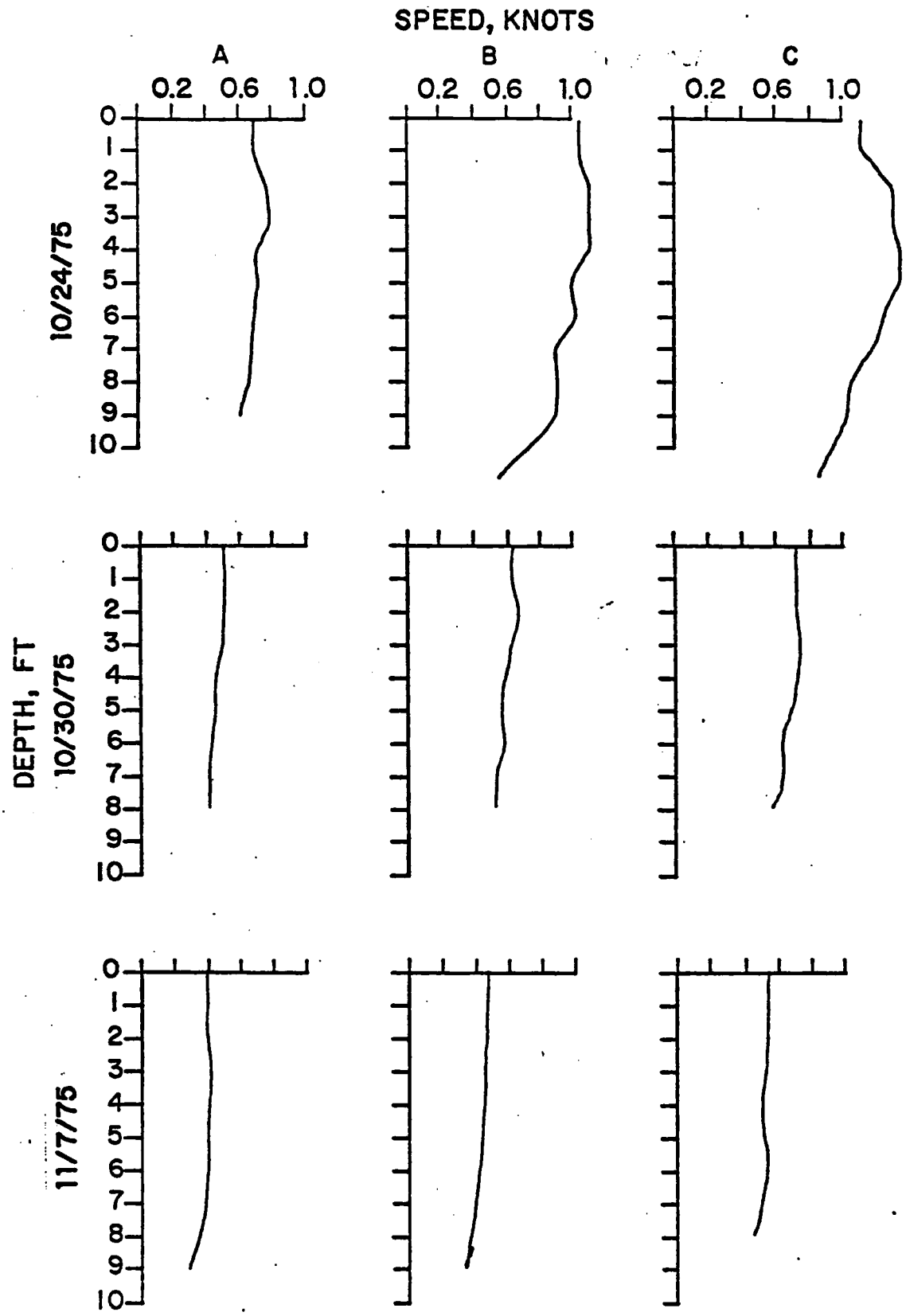
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/24/75
10/30/75
11/7/75
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1
2
3
4
5
6
7
8
9
10

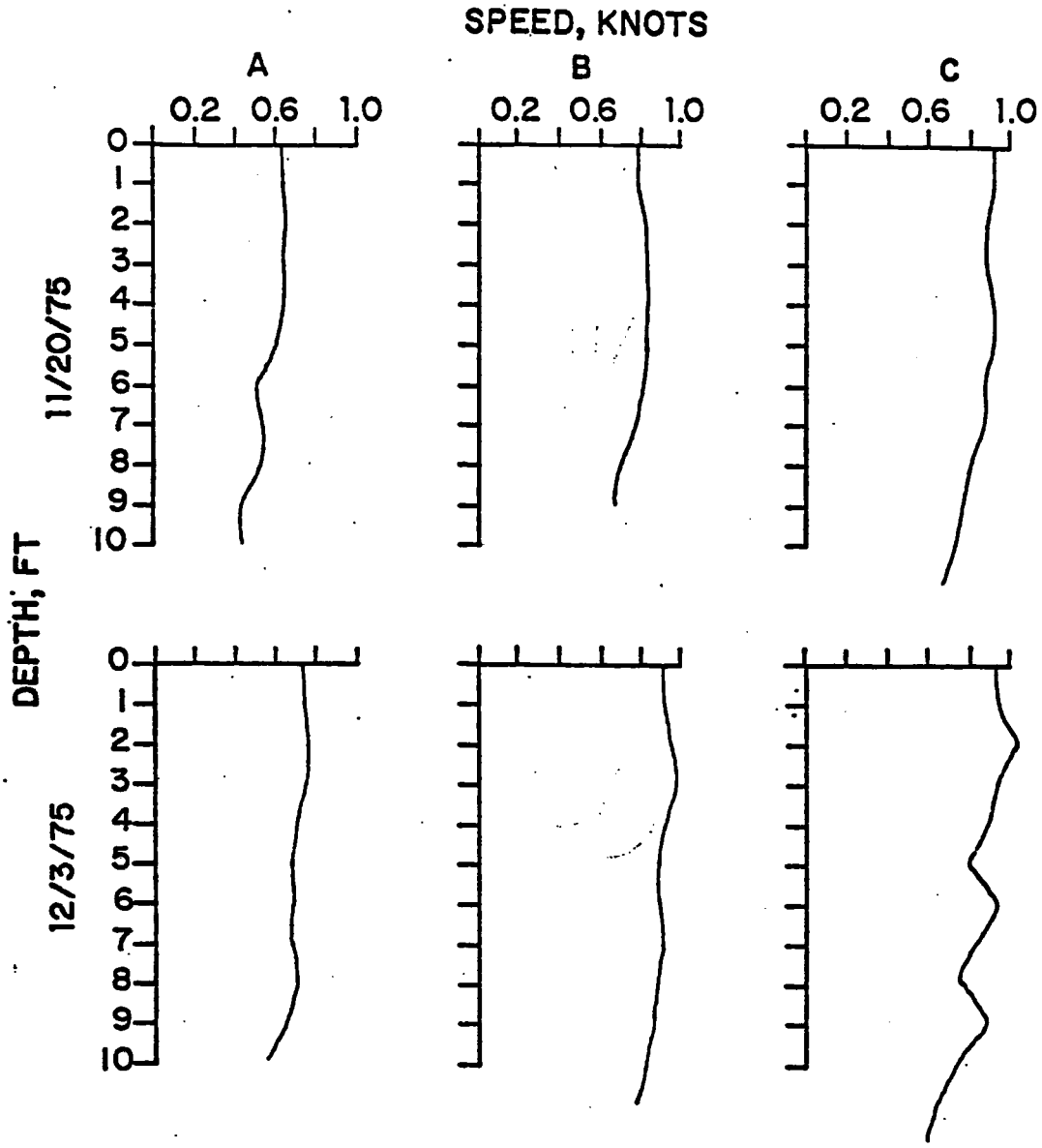
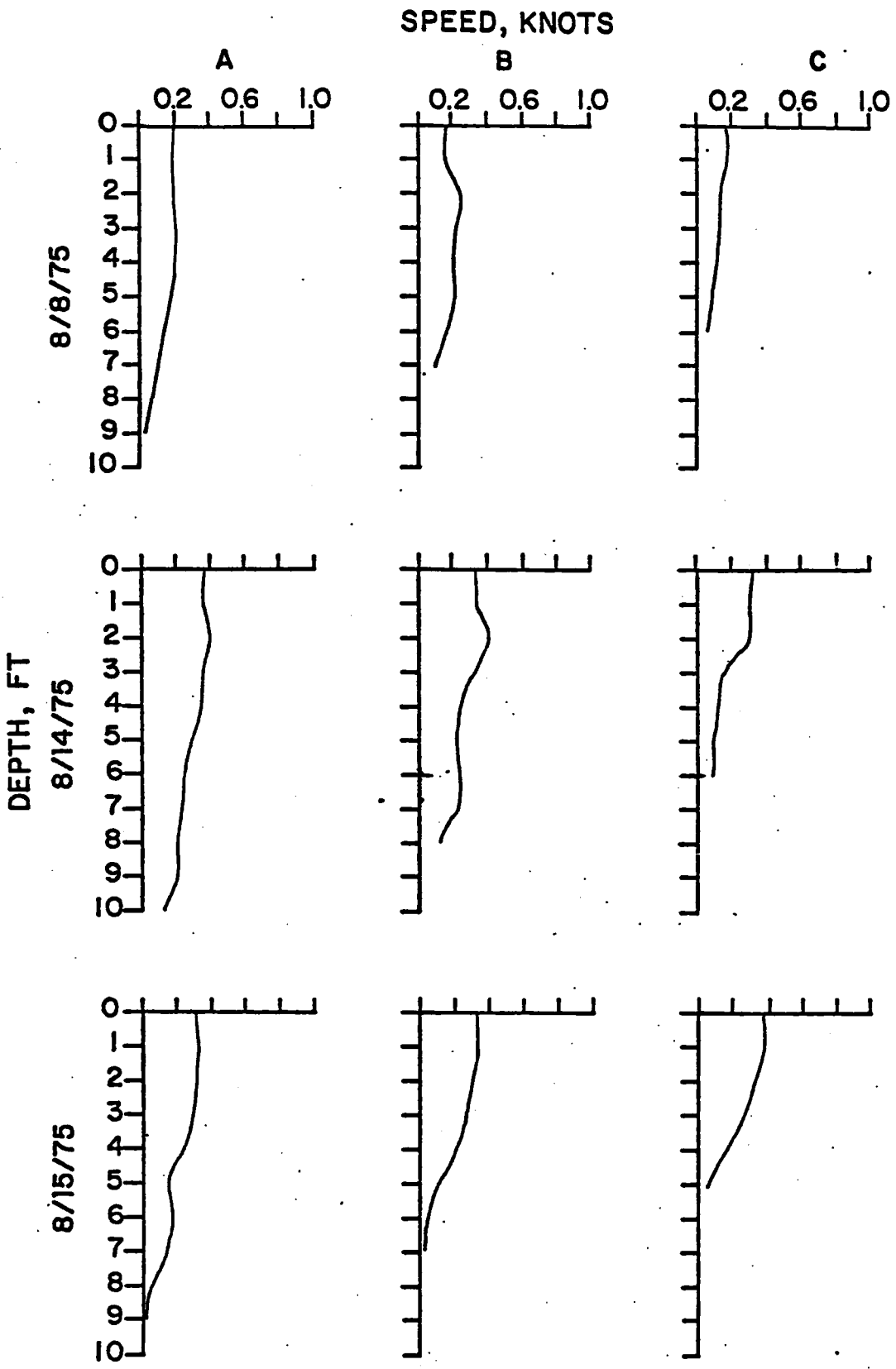

SPEED, KNOTS
A
B
C
0.2 0.6 1.0
0.2 0.6 1.0
0.2 0.6 1.0
DEPTH, FT
11/20/75
12/3/75
0
1
2
3
4
5
6
7
8
9
10

Figure B-4k. Vertical current profiles at transect SUNS for each of the field studies between August and December, 1975. Merrimack River Anadromous Fisheries Investigations, 1976.


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
8/8/75
8/14/75
8/15/75
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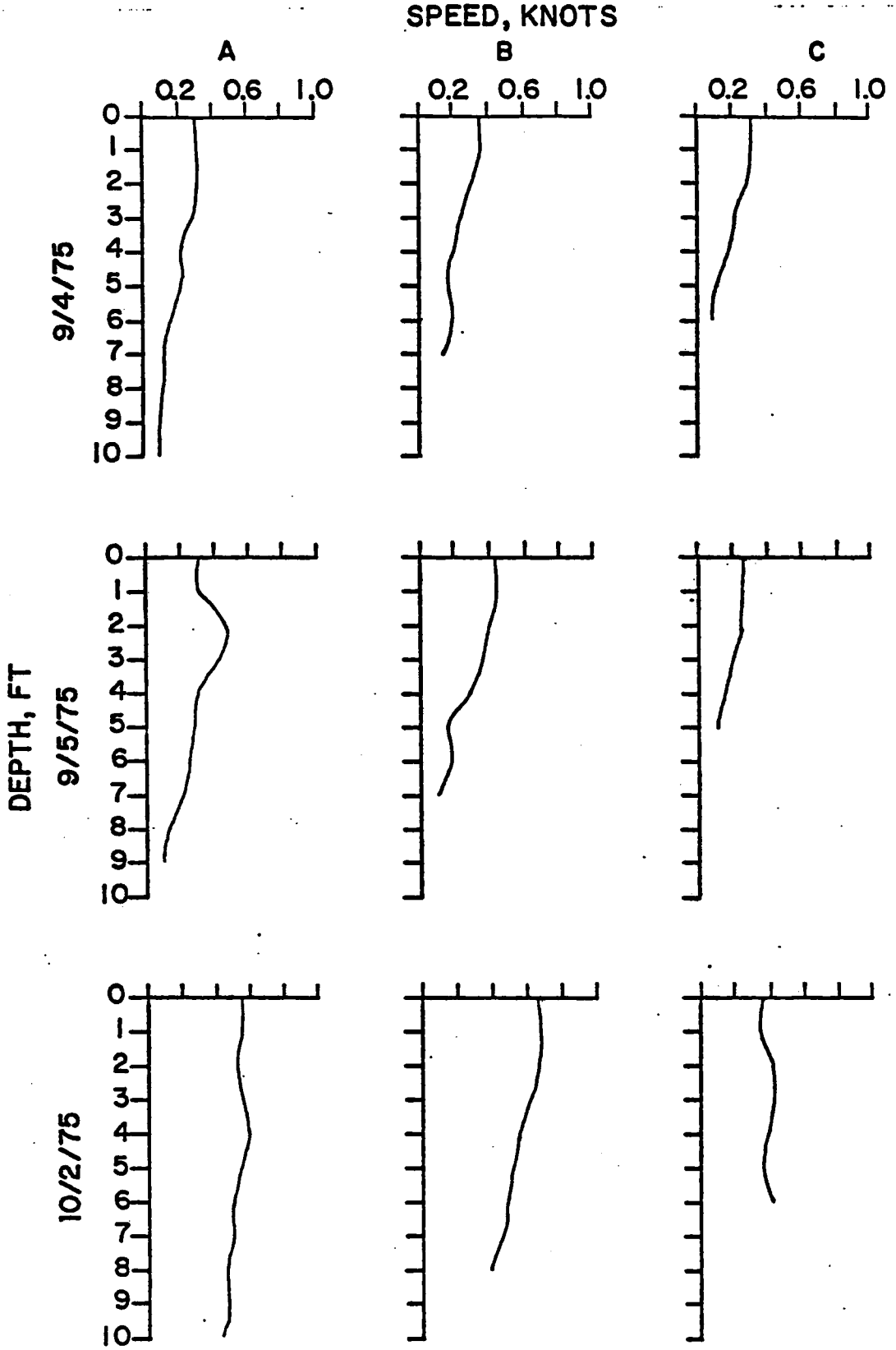
1
2
3
4
5
6
7
8
9
10


SPEED, KNOTS
A
B
C
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0.6
1.0
DEPTH, FT
9/4/75
9/5/75
10/2/75
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1
2
3
4
5
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7
8
9
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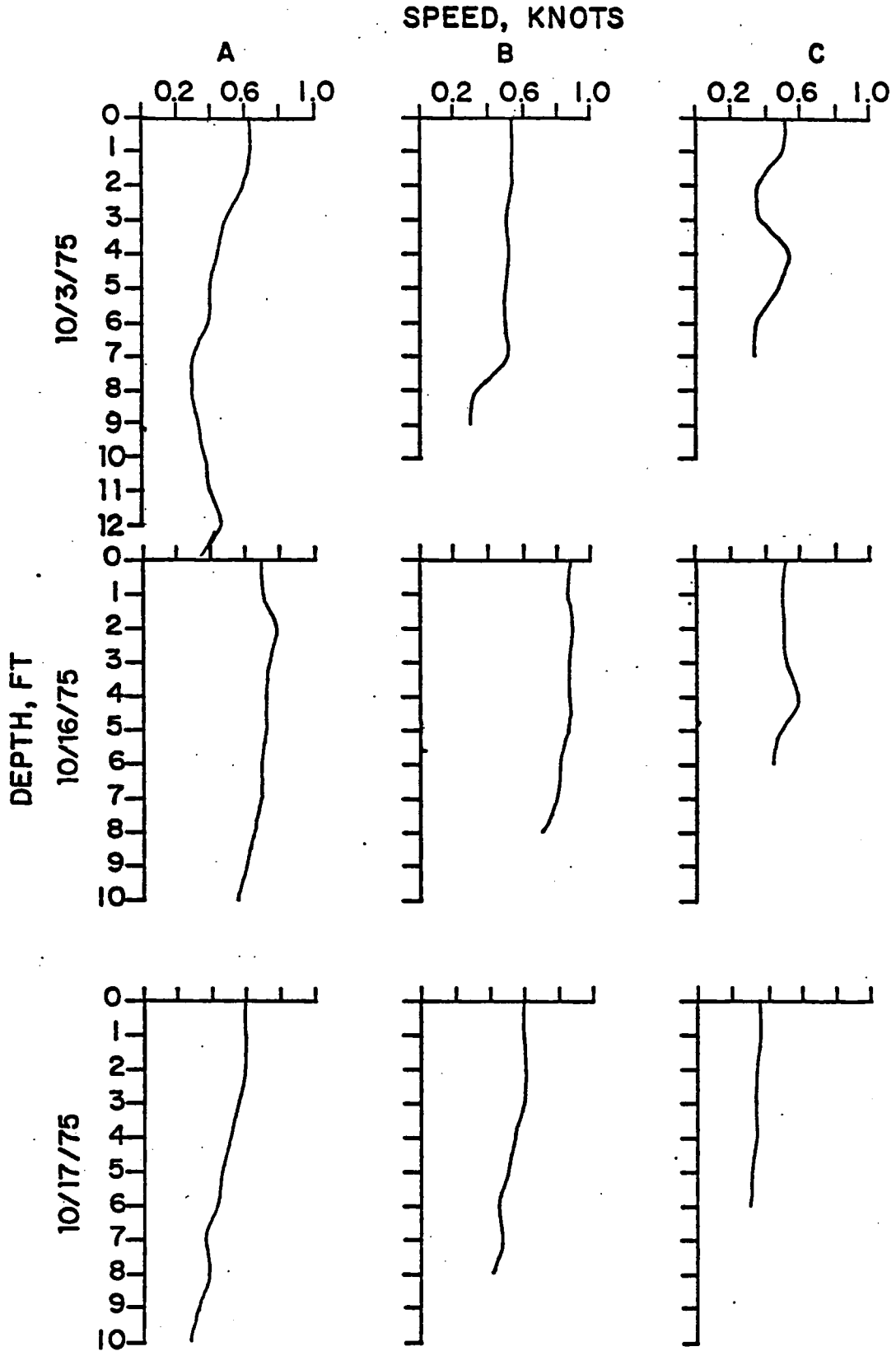
SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/3/75
10/16/75
10/17/75
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3
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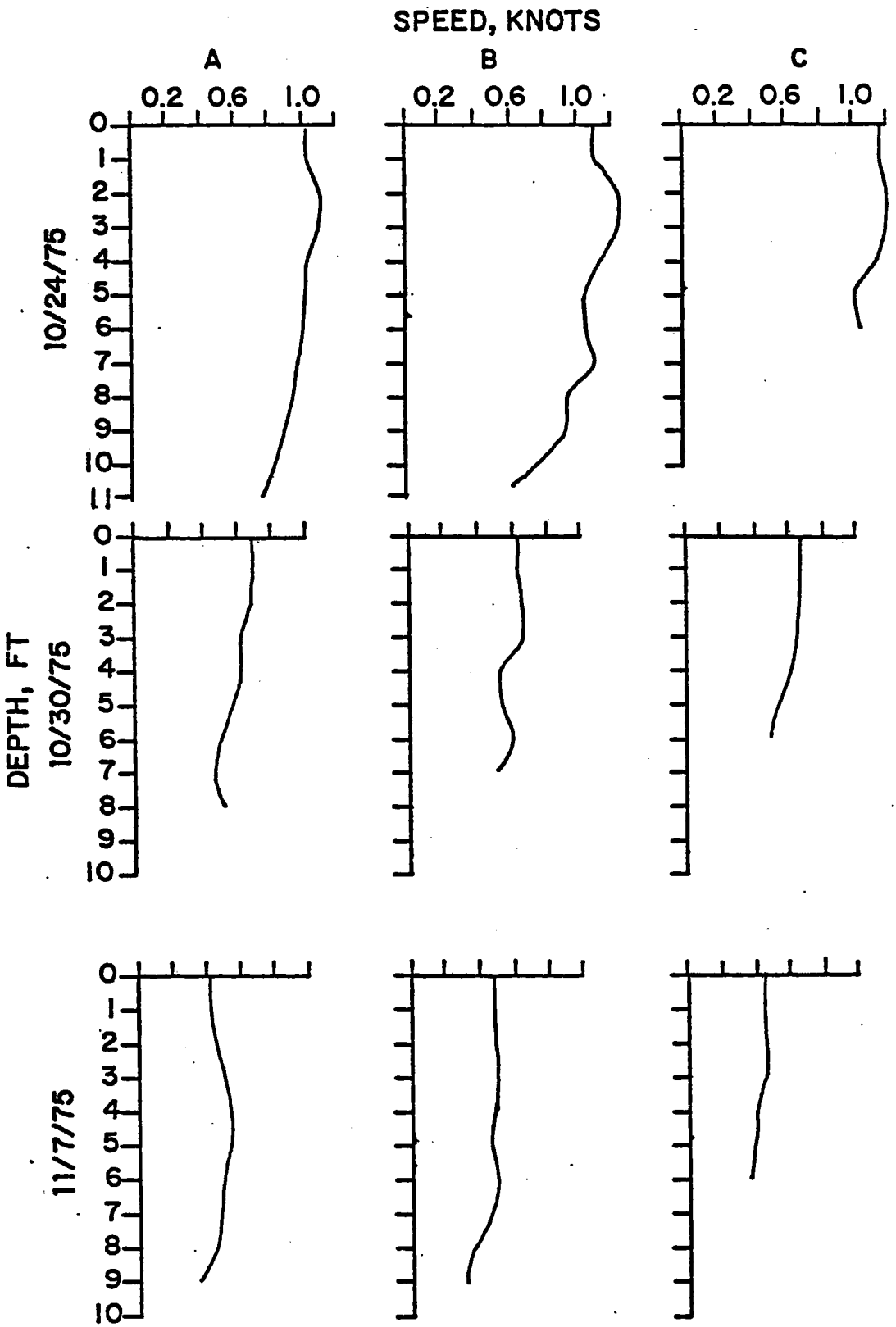
12


SPEED, KNOTS
A
B
C
0.2
0.6
1.0
DEPTH, FT
10/24/75
10/30/75
11/7/75
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2
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4
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9
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11

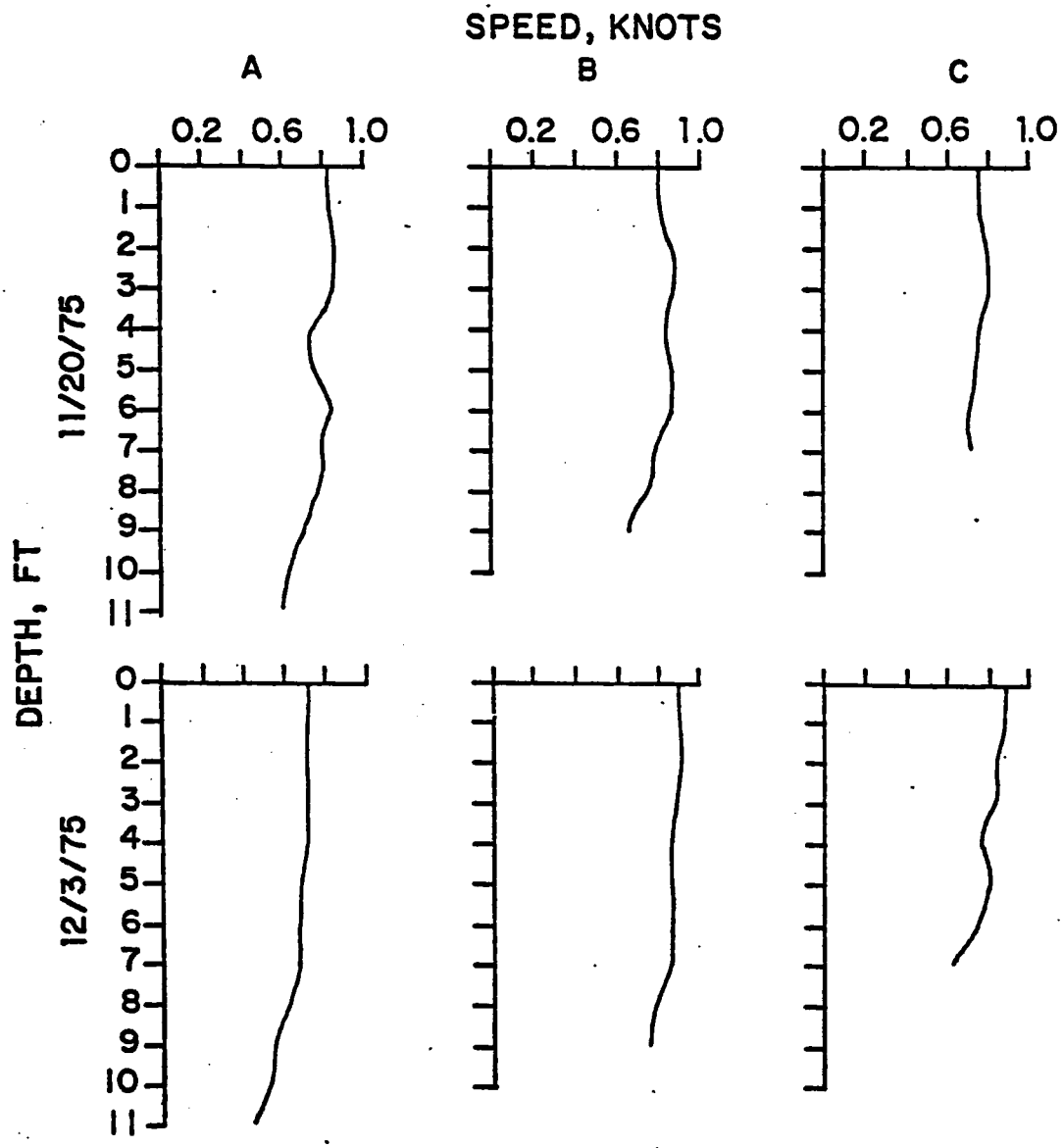
SPEED, KNOTS
A
B
C
0.2 0.6 1.0
DEPTH, FT
11/20/75
12/3/75
0
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TABLE B1. MEAN GROSS MERRIMACK STATION OUTPUT ($\overline{MW}$)* BASED ON HOURLY OBSERVATIONS FROM 0700 TO 1500 AND GARVIN'S FALLS DISCHARGE (cfs) ON DAYS CORRESPONDING TO HYDROGRAPHIC SURVEYS†. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

	GARVIN'S FALLS DISCHARGE (cfs)		GROSS MERRIMACK STATION OUTPUT ($\overline{MW}$)*		
DATE	DAILY AVERAGE	12-HR AVG 0600-1800	UNIT I	UNIT II	TOTAL
8 Aug 75	1511	1536	-0-	180.9	180.9
14 Aug 75	1687	2069	117.2	-0-	117.2
15 Aug 75	1201	1393	117.4	326.7	444.1
4 Sep 75	2037	2398	124.3	297.8	422.1
5 Sep 75	1590	1893	116.9	296.2	413.1
2 Oct 75	3992	3978	-0-	308.1	308.1
3 Oct 75	3871	3959	-0-	-0-	-0-
16 Oct 75	3917	3999	85.2	299.2	384.4
17 Oct 75	3762	3928	84.9	305.4	390.3
24 Oct 75	4764	4562	113.3	246.3	359.6
30 Oct 75	3515	3708	1.5	-0-	1.5
7 Nov 75	3816	3984	118.3	213.2	331.5
20 Nov 75	4225	4256	117.8	295.1	412.9
3 Dec 75†	4427	3403	116.2	332.6	448.8
16 Apr 76†	7155	7235	---	---	---
14 May 76†	9702	10250	---	---	---

*$\overline{MW} = [\sum_{i=1}^{h} kwh \cdot 100]/h$

†Current surveys only on these dates -- no temperature data collected; discharge data from Amoskeag Dam.

APPENDIX C

APPENDIX C

Appendix C represents more detailed information concerning the hydrodynamic model applied to Hooksett Pond. The descriptive information was excerpted from Celikkol and Reichard (1976). Figure C-1 is a graphical representation of the finite element grid selected for Hooksett Pond model application. Figure C-2 represents actual vs. calculated velocities resulting from model application.

HYDRODYNAMIC MODEL OF THE GREAT BAY ESTUARINE SYSTEM
PART I

by
Barbaros Celikkol
Ronnal Reichard

Report No.: UNH-SG-153

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University of New Hampshire
Mechanics Research Laboratory
August 1976

LIST OF NOTATION

A	-	Tidal amplitude
C	-	Generalized bottom friction coefficient
C_f	-	Connor and Wang bottom friction coefficient
C_h	-	Chezy bottom friction coefficient (Leendertse)
f	-	Coriolis effect ($f = 2\Omega\sin\phi$, where ϕ is the lattitude)
$F_{xx,\ yy,\ xy}$		Constitutive relations for eddy viscosity terms
F_p	-	Constitutive relation for pressure effects
g	-	Gravity
h	-	Water depth with respect to mean water level
H	-	Total water depth ($H = h + \eta$)
L	-	Tidal wavelength
p	-	Pressure
p'	-	Pressure fluctuation with respect to the ensemble average pressure
p''	-	Pressure fluctuation with respect to the vertical average pressure
$\overline{p}$	-	Ensemble average pressure
P	-	Vertical average of ensemble average pressure
P_a	-	Atmospheric pressure
$q_{x,\ y}$	-	Vertical average velocity times water depth ($q_x = HU$)
r_{ij}	-	Reynolds stress ($r_{ij} = \overline{\rho_o u_i' u_j'}$)
r_{ij}''	-	Fluctuation of Reynolds stress with respect to the vertical average Reynolds stress
R_{ij}	-	Vertical average Reynolds stress
t	-	Time
u_i	-	Tensor notation velocity component
u_i'	-	Fluctuation of the velocity component with respect to the ensemble average velocity component
u_i''	-	Fluctuation of the velocity component with respect to the vertical average velocity component
$\overline{u}_i$	-	Ensemble average velocity component
U_i	-	Vertical average of the ensemble average velocity component
U	-	Vertical average velocity component in the x direction
V	-	Vertical average velocity component in the y direction

x_i	-	Cartesian direction in tensor notation
x	-	Cartesian horizontal direction
y	-	Cartesian horizontal direction perpendicular to x
ξ_{ij}	-	Eddy viscosity coefficient
μ	-	Viscosity coefficient in the Navier-Stokes Equation
η	-	Water surface elevation with respect to mean water level
ρ	-	Water density
ρ_o	-	Average water density
$\tau_{ij,\ xx,\ yy,xy}$		Internal stress term (vertical average of products of vertical average velocity fluctuations)
τ^b	-	Bottom stress term
τ^s	-	Surface stress term
ω	-	Tidal frequency
Ω	-	Earth's frequency of rotation
ξ	-	Viscosity coefficient in the Navier-Stokes Equation

GOVERNING EQUATIONS

The equations governing the motion in an estuary are the three momentum equations and the continuity equation. In their general form, the analytical solutions are not available. The differences in theory among investigators are the simplifying assumptions imposed to obtain a solvable set of equations.

In tensor notation the generalized equations of momentum and continuity for estuaries can be expressed by the following two equations:

a) The time rate of change of momentum of a moving fluid particle is equal to the sum of the forces acting on it:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} - 2\,\varepsilon_{ij\ell}\,\Omega_j\,\rho u_\ell +$$

$$+ \rho g \delta_{i3} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} - \frac{2}{3}\,\delta ij\,\frac{\partial u_k}{\partial x_k}\right)\right] + \frac{\partial}{\partial x_j}\left(\xi\,\frac{\partial u_k}{\partial x_k}\right)$$

b) The mass of a moving element of fluid remains constant:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0$$

Where t is time, ρ density, u a velocity component, x a direction, P pressure, Ω the earth's rotation, g gravity, μ and ξ viscous coefficients.

Applying the following assumptions:

1) Incompressible flow $\left(\frac{\partial \rho}{\partial p} = 0\right)$

2) ρ(density) = ρ_o (constant) + $\delta\rho$ (a small perturbation term)

3) Viscosity coefficient is constant ($\mu = \mu_o$).

4) The second derivative of velocity with respect to perpendicular coordinates is small:

$$\left(\frac{\partial^2 u_i}{\partial x_j^2} = 0 \neq j\right).$$

The equations are simplified to obtain:

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}(u_i u_j) = -\frac{1}{\rho_o}\,\frac{\partial p}{\partial x_i} - 2\varepsilon_{ij\ell}\Omega_j u_\ell + g\delta_{i3}$$

$$\frac{\partial u_i}{\partial x_i} = 0$$

Representing the variables as the sum of their ensemble average and a fluctuation about the ensemble average,

$$u_i = \overline{u}_i + u'$$

$$p = \overline{p} + p'$$

Where the overbar denotes the ensemble average, and the prime denotes the fluctuation term, the equations can be ensemble averaged to obtain:

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial}{\partial x_j}(\bar{u}_i \bar{u}_j) = -\frac{1}{\rho_o}\frac{\partial \bar{p}}{\partial x_i} - 2\xi_{ij\ell}\Omega_j \bar{u}_\ell + g\delta_{i3}$$

$$-\frac{1}{\rho_o}\frac{\partial}{\partial x_j}\overline{\rho_o u_i' u_j'}$$

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

This averaging technique smooths the stochastic processes while retaining the deterministic processes. The additional term is called the Reynolds stress, r, and is the ensemble average of the product of velocity fluctuations with respect to the ensemble average velocity, multiplied by density:

$$r_{ij} = \overline{\rho_o u' i u' j}$$

Assuming vertical variations of the various parameters are small, the equations may be vertically averaged, and the vertical momentum equation reduced to the hydrostatic relation, without loss of meaing. Representing the variables as the sum of their vertical average and a fluctuation about the vertical average:

$$\bar{u}_i = U_i + u''_i$$

$$\bar{p} = P + p''$$

$$r_{ij} = R_{ij} + r''_{ij}$$

Where capital letters indicate the vertical average values, and double prime denotes the fluctuation about the vertical average, the vertically averaged equations are:

$$\frac{\partial U}{\partial t} + \frac{\partial U^2}{\partial x} + \frac{\partial (UV)}{\partial y} = -\frac{1}{\rho_o}\frac{\partial P_a}{\partial x} + fV + g\frac{\partial n}{\partial x}$$

$$-\frac{1}{\rho_o}\frac{\partial R_{xx}}{\partial x} - \frac{1}{\rho_o}\frac{\partial R_{xy}}{\partial y} + \frac{1}{\rho_o}\frac{\partial \tau_{xx}}{\partial x} + \frac{1}{\rho_o}\frac{\partial \tau_{yx}}{\partial y} + \frac{(\tau_x^b + \tau_x^s)}{\rho_o h}$$

$$\frac{\partial V}{\partial t} + \frac{\partial (UV)}{\partial x} + \frac{\partial V^2}{\partial y} = -\frac{1}{\rho_o}\frac{\partial P_a}{\partial y} - fU + g\frac{\partial n}{\partial y}$$

$$-\frac{1}{\rho_o}\frac{\partial R_{yy}}{\partial y} - \frac{1}{\rho_o}\frac{\partial R_{xy}}{\partial x} + \frac{1}{\rho_o}\frac{\partial \tau_{yy}}{\partial y} + \frac{1}{\rho_o}\frac{\partial \tau_{yx}}{\partial x} + \frac{(\tau_y^b + \tau_y^s)}{\rho_o h}$$

$$\frac{1}{H}\frac{\partial n}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

Where U and V are horizontal velocity components, P_a atmospheric pressure, f the coriolis effect, n the water height above mean water level (MWL), R the Reynolds stress, and H the total water depth. The product of two velocity fluctuations (with respect to the vertical average) are represented as the internal stress terms τ_{xx}, τ_{yy}, τ_{xy}, and the bottom stress τ_x^s, τ_y^s. Reynolds and internal stress terms cannot be directly included in the equations, and are usually neglected as being small. These effects can be included by assuming a functional

relationship with the horizontal velocity gradient as follows:

$$\frac{1}{\rho_o}(\tau_{ij} - R_{ij}) = \xi_{ij}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)$$

Where the coefficient ξ is called the eddy viscosity coefficient. The bottom stress τ_x^b, τ_y^b is assumed proportional to a quadratic function of velocity:

$$\frac{\tau_x^b}{\rho_o h} = \frac{CV\,(U^2 + V^2)^{1/2}}{h}$$

$$\frac{\tau_y^b}{\rho_o h} = \frac{CV\,(U^2 + V^2)^{1/2}}{h}$$

Where C is the bottom friction coefficient. The equations may now be expressed in the following form:

$$\frac{\partial U}{\partial t} + \frac{\partial U^2}{\partial x} + \frac{\partial (UV)}{\partial y} = fV + g\frac{\partial \eta}{\partial x}$$

$$+ \frac{\partial}{\partial x}\left(2\xi_{xx}\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial y}\left[\xi_{yx}\left(\frac{\partial V}{\partial x} + \frac{\partial U}{\partial y}\right)\right]$$

$$+ \frac{C\,U\,(U^2 + V^2)^{1/2}}{h}$$

$$\frac{\partial V}{\partial t} + \frac{\partial (UV)}{\partial x} + \frac{\partial V^2}{\partial y} = - fU + g\frac{\partial \eta}{\partial y}$$

$$+ \frac{\partial}{\partial y}\left(2\xi_{yy}\frac{\partial V}{\partial y}\right) + \frac{\partial}{\partial x}\left[\xi_{xy}\left(\frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}\right)\right]$$

$$+ \frac{CV\,(U^2 + V^2)^{1/2}}{h}$$

$$\frac{1}{H}\frac{\partial \eta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

The atmospheric pressure gradient and the surface stress terms have been omitted. They can be important for specific atmospheric conditions, but in general they are not important, and the difficulty in specifying these terms makes their inclusion questionable at best.

The left hand side of the momentum equations is composed of the termporal and convective acceleration terms. The right hand side of the equations is composed of the forces acting on a fluid particle. The surface slope and bottom friction terms are the dominant forces, while the coriolis force and eddy viscosity term are secondary effects. The surface slope, acting as a hydraulic head, forces the flow, while the bottom friction is the primary resisting force.

CONNOR AND WANG'S FINITE ELEMENT MODEL

The two-dimensional finite element solution technique developed by Connor and Wang is a unique and promising new approach. The two-dimensional vertically averaged conservation of momentum and mass equations used in the model are:

$$\frac{\partial q_x}{\partial t} + \frac{\partial (Uq_x)}{\partial x} + \frac{\partial (Uq_y)}{\partial y} = -\frac{\partial F_p}{\partial x} + g\frac{(hn)}{\partial x}$$

$$+ fq_y + \frac{\partial F_{xx}}{\partial x} + \frac{\partial F_{yx}}{\partial y} + (\tau_x^b - \tau_x^s)$$

$$\frac{\partial q_y}{\partial t} + \frac{\partial}{\partial x}(Vq_x) + \frac{\partial}{\partial y}(Vq_y) = -\frac{\partial F_p}{\partial y} + g\frac{\partial}{\partial y}(hn)$$

$$-fq_x + \frac{\partial F_{yy}}{\partial y} + \frac{\partial F_{xy}}{\partial x} + (\tau_y^b - \tau_y^s)$$

$$\frac{\partial n}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = q_i$$

with the constitutive relations:

$$F_{xx} = \int_{-h}^{n} (\tau_{xx} - \rho(u')^2)\, dz = \xi_{xx}\frac{\partial q_x}{\partial x}$$

$$F_{yy} = \int_{-h}^{n} (\tau_{yy} - \rho(v')^2)\, dz = \xi_{yy}\frac{\partial q_y}{\partial y}$$

$$F_{xy} = F_{yx} = \int_{-h}^{n} (\tau_{xy} - \rho(u'v'))\, dz = \xi_{xy}\left(\frac{\partial q_y}{\partial x} + \frac{\partial q_x}{\partial y}\right)$$

$$F_p = ghn + 1/2\, gn^2 + \frac{\Delta\rho}{2\rho_o} g H^2 + \frac{P^s}{\rho_o} H$$

$$\tau_x^b = \frac{C_f q_x (q_x^2 + q_y^2)^{1/2}}{\rho H^2}$$

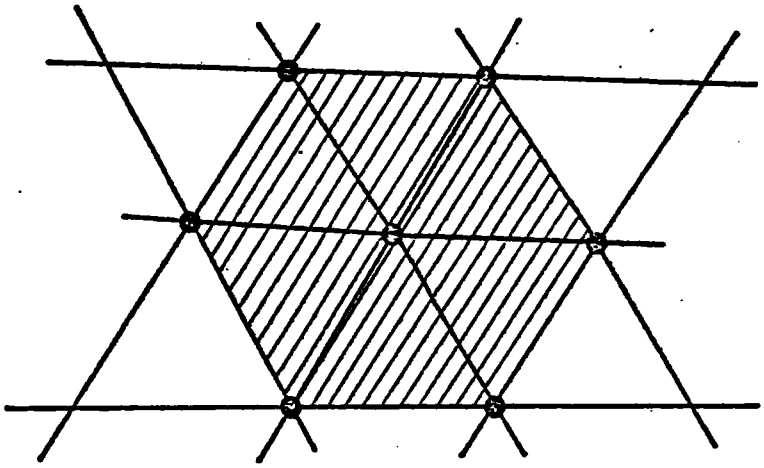
$$\tau_y^b = \frac{C_f q_y (q_x^2 + q_y^2)^{1/2}}{\rho H^2}$$

Where H is the total water depth, U and V the vertically averaged velocities, u' and v' the velocity fluctuations with respect to the ensemble average, q_x and q_y equal HU and HV respectively, h the depth of the water at MWL, n the height of the water surface above MWL, ρ_o the average density, $\Delta\rho$ the density fluctuation, C_f the bottom friction coefficient, τ_{xx}, τ_{yy}, τ_{xy} are internal stresses, and ξ_{xx}, ξ_{yy}, ξ_{xy} are eddy viscosity coefficients.

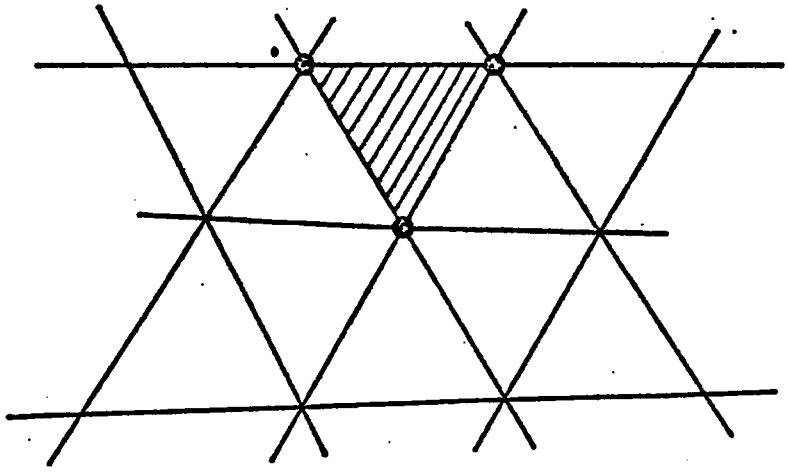
The finite element method approximates the solution of a boundary value problem with a function of piece-wise continuous polynomials. It is based on discretization of the continuum into an equivalent system of finite elements. Connor and Wang selected the simplest configuration, triangles with nodes at the angles. The values of the variables within the element have been assumed a linear function of the values at the nodes. The equations are transformed for application to an element using this linear polynominal representation. Treatment of the entire continuum is accomplished through summation of the contributions of

each element. The domain of influence of a nodal value and an element value are graphically displayed in Figure 3. Solutions for q_x, q_y and η are obtained at each node. Depth is selected at each node point, while bottom friction and eddy viscosity are selected for each element.

FIGURE 3
CONNOR AND WANG'S DOMAIN OF INFLUENCE FOR NODE AND ELEMENT VALUES



Domain for Influence for Node Values



Domain of Influence for Element Values

A node variable or parameter affects all of the adjacent elements (six in this example), as the value of the variable or parameter within each element is a function of the values at the nodes. An element parameter affects the three nodes of the element.

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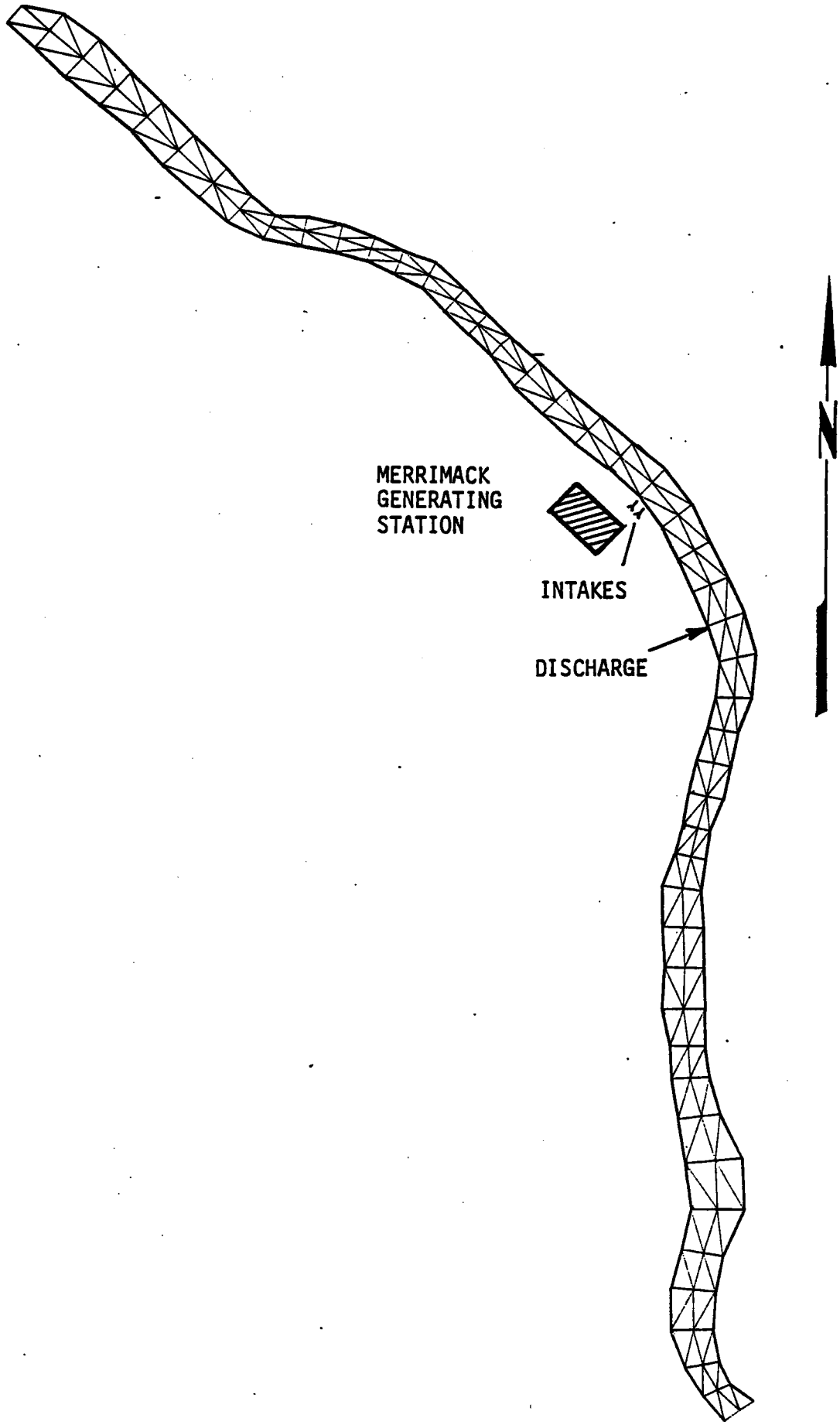


Figure C-1 Finite element grid selected for Hooksett Pond hydrodynamic model application. Merrimack River Anadromous Fisheries Investigations, 1976.

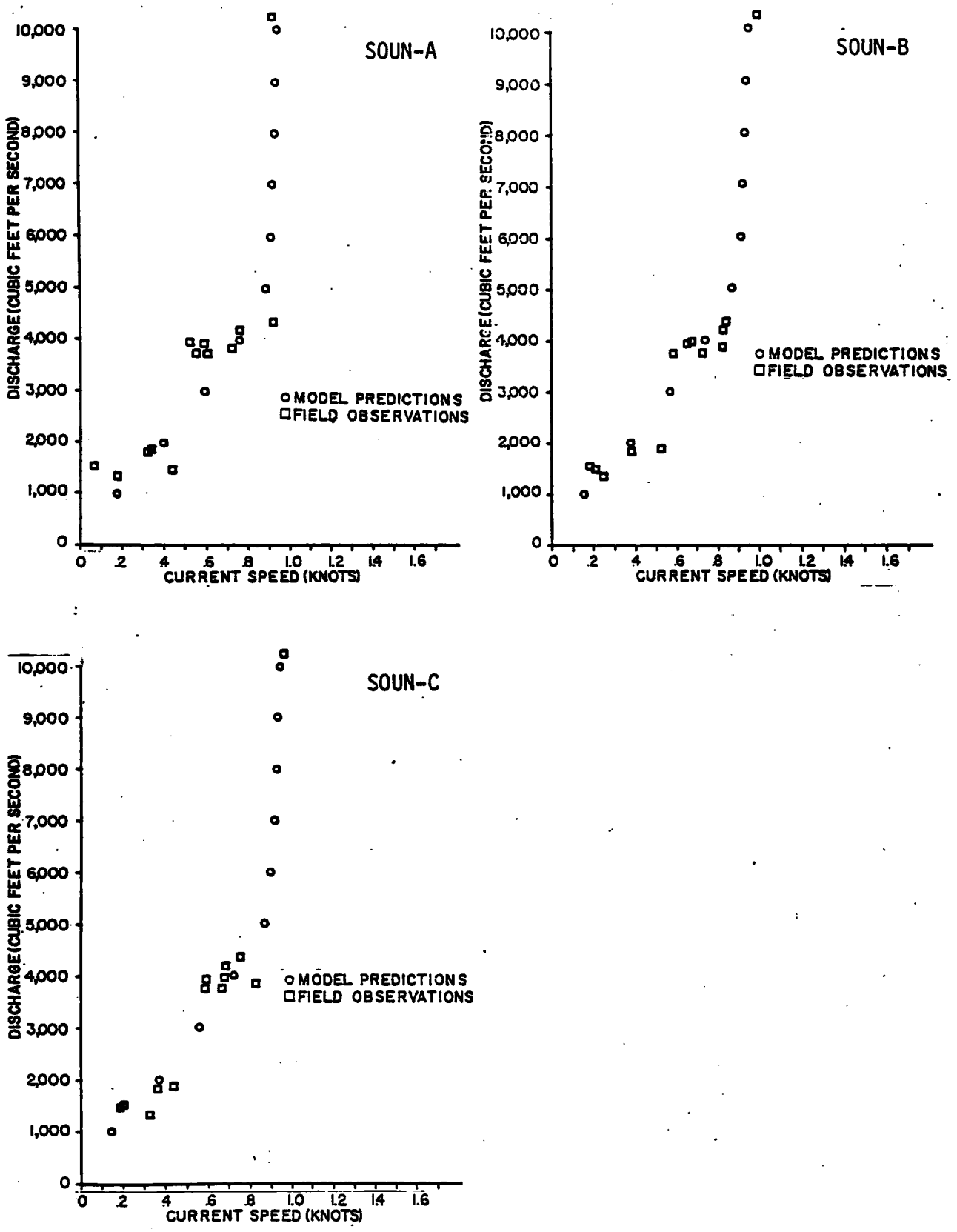
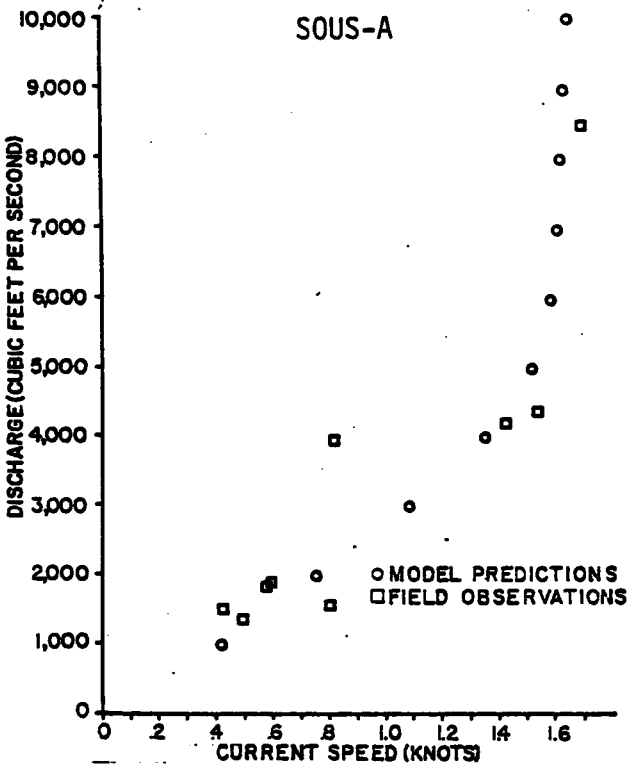


Figure C-2 Actual vs. calculated mean velocities, at various discharge levels, at the transects indicated. Merrimack River Anadromous Fisheries Investigations, 1976.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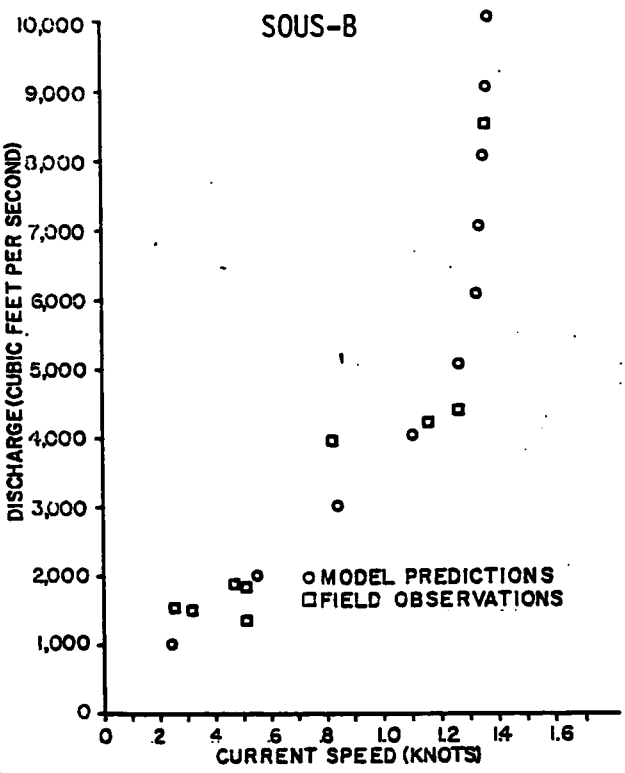
FIELD OBSERVATIONS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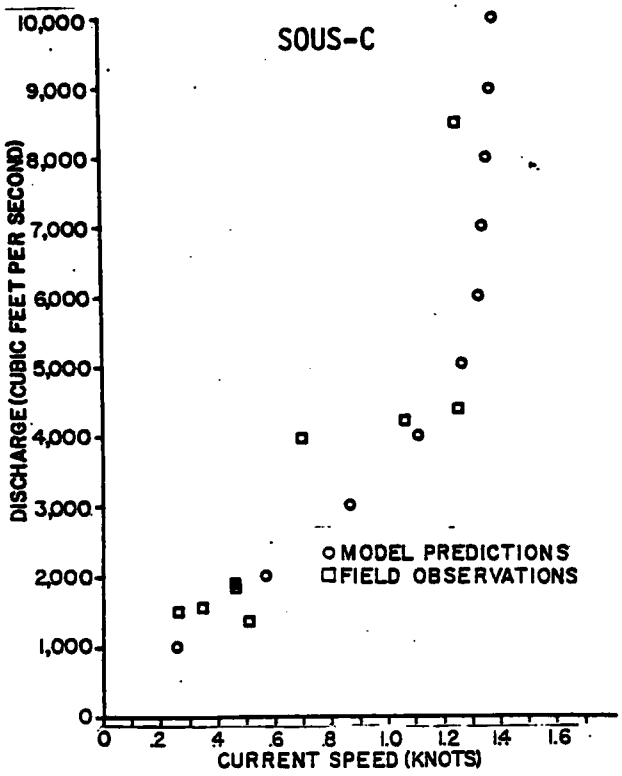
MODEL PREDICTIONS
FIELD OBSERVATIONS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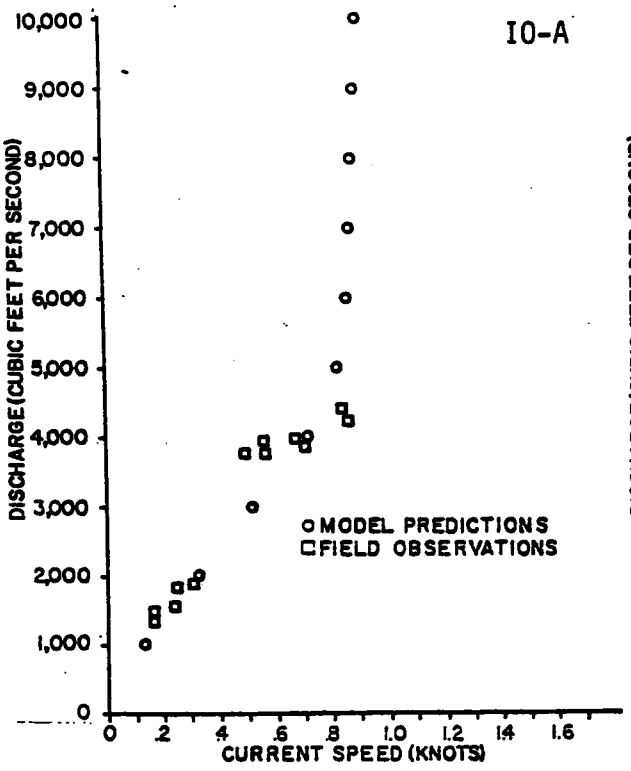
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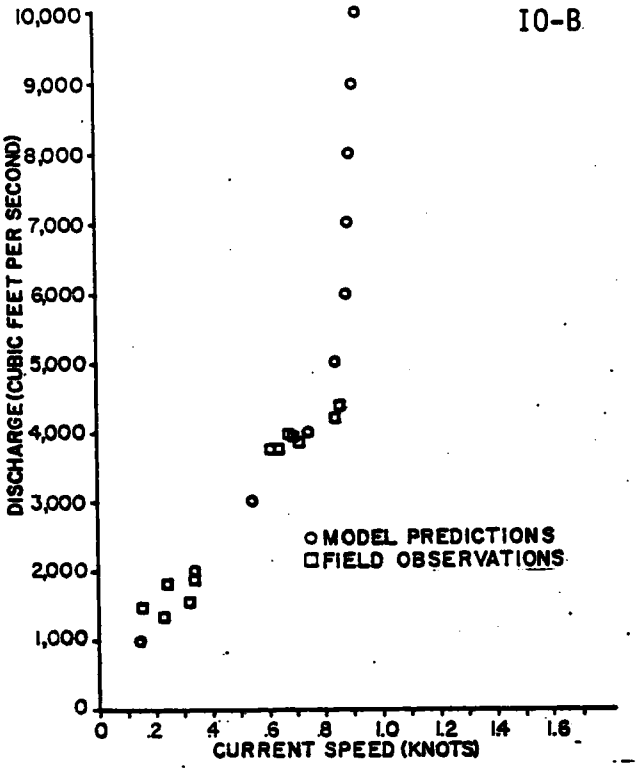
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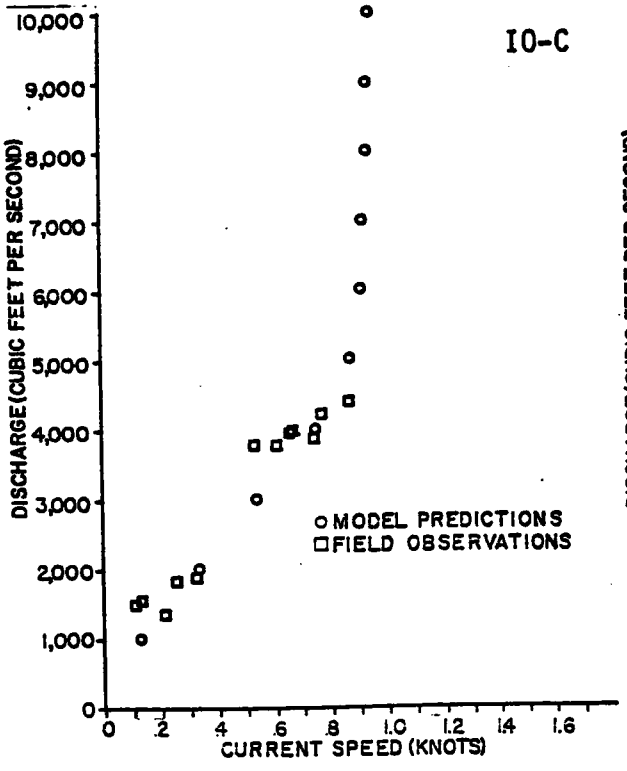
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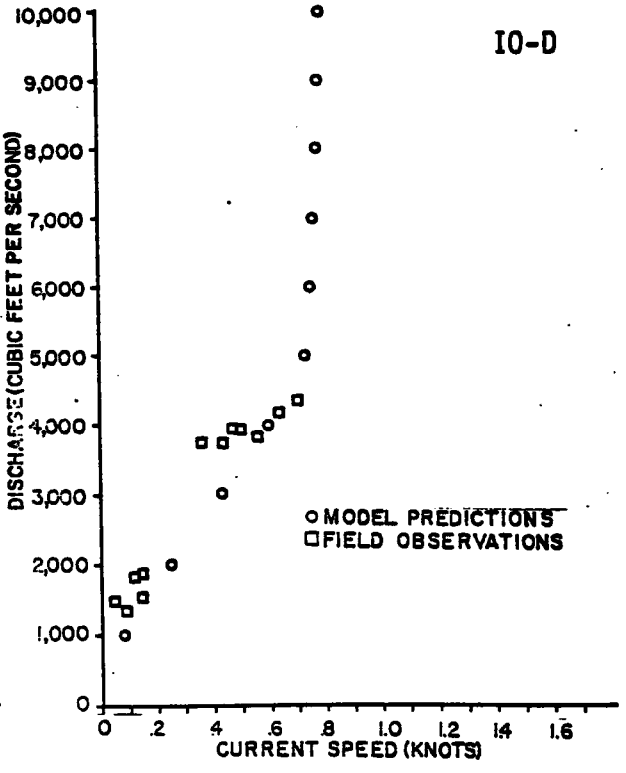
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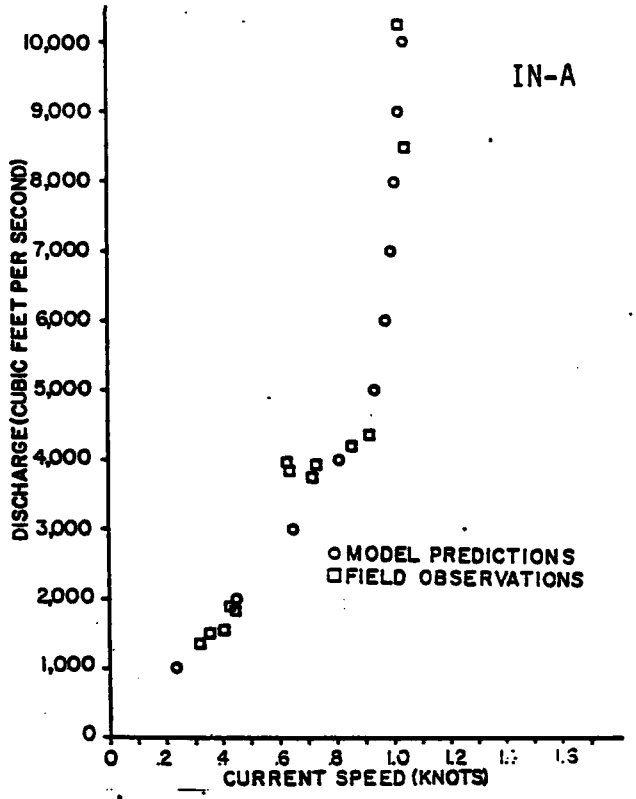
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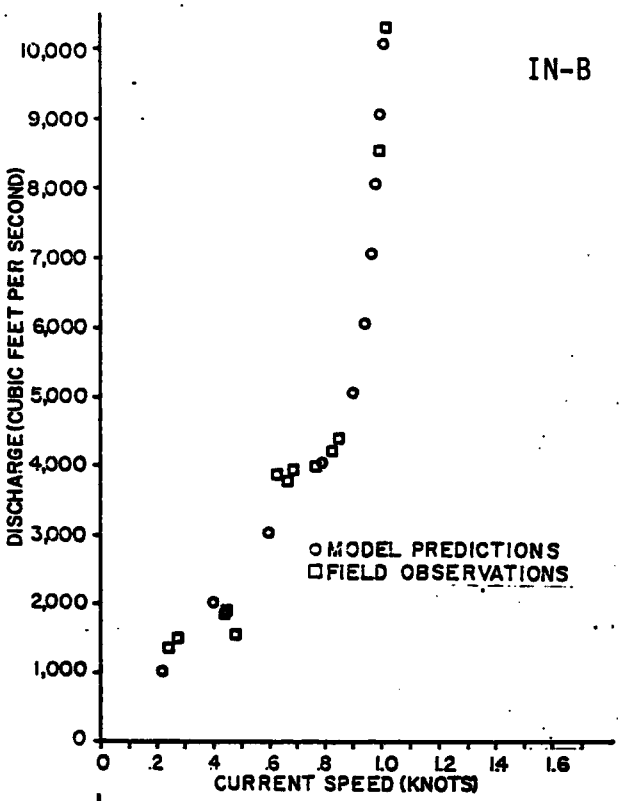
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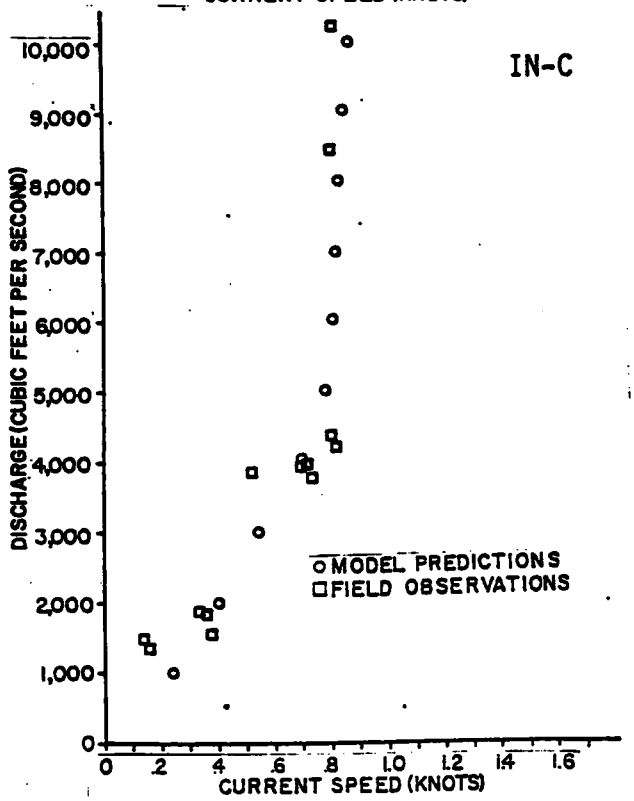
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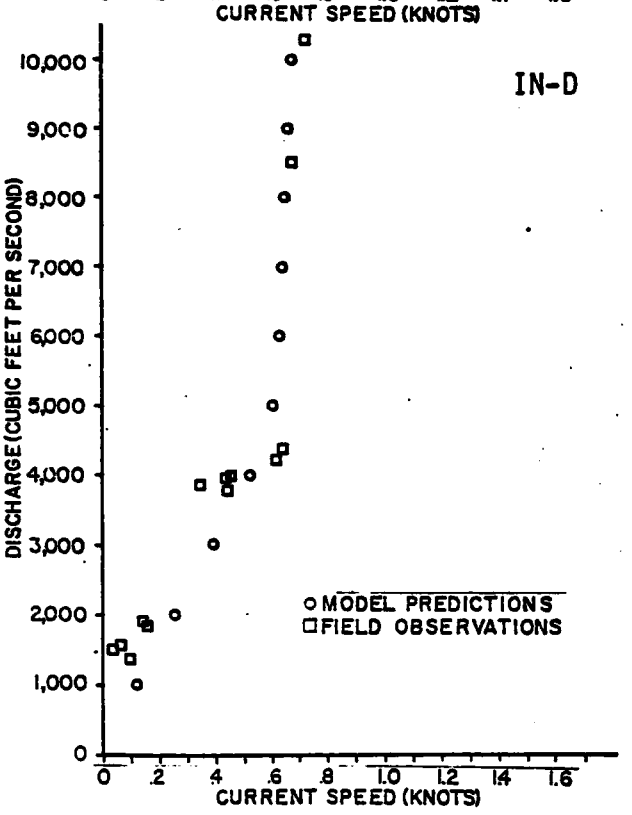
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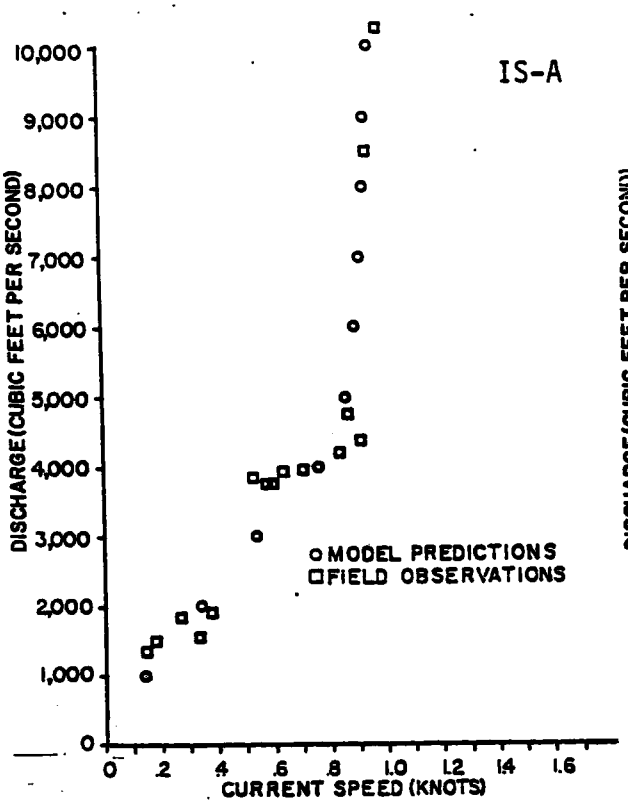
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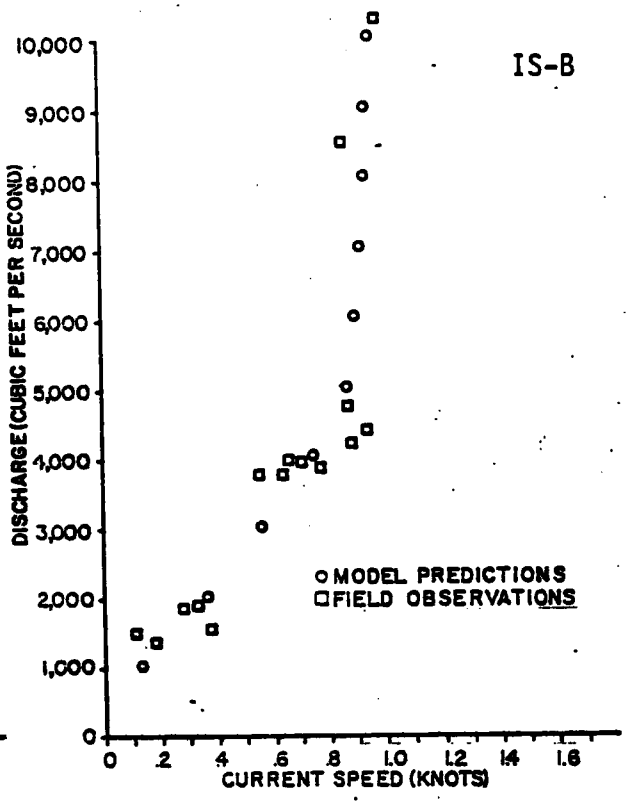
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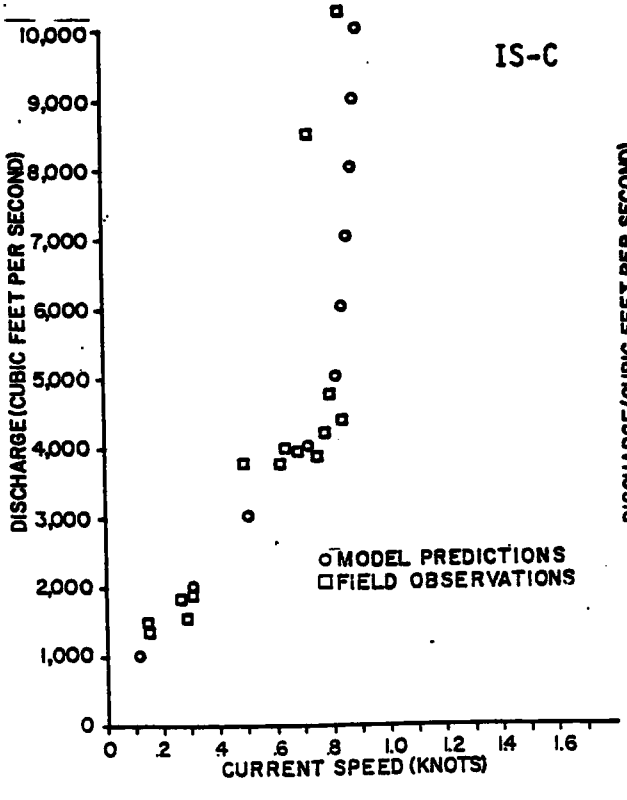
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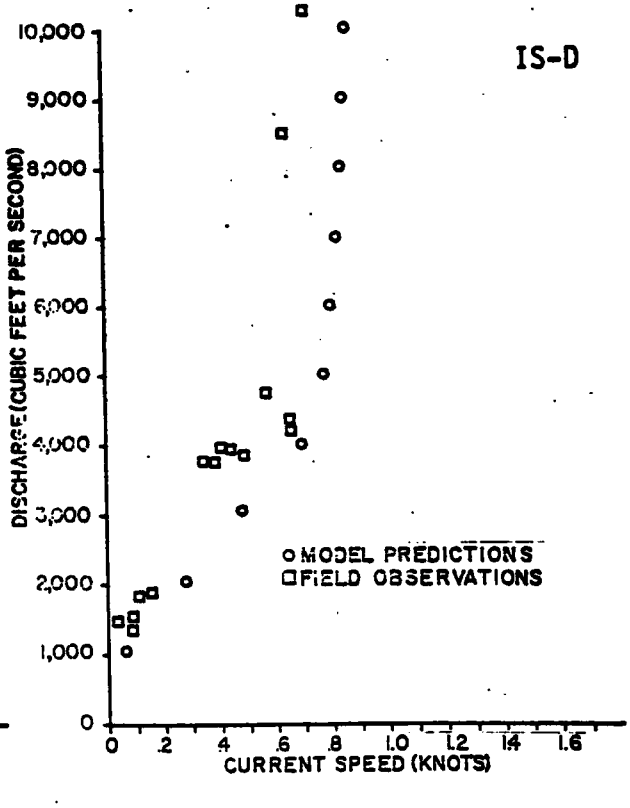
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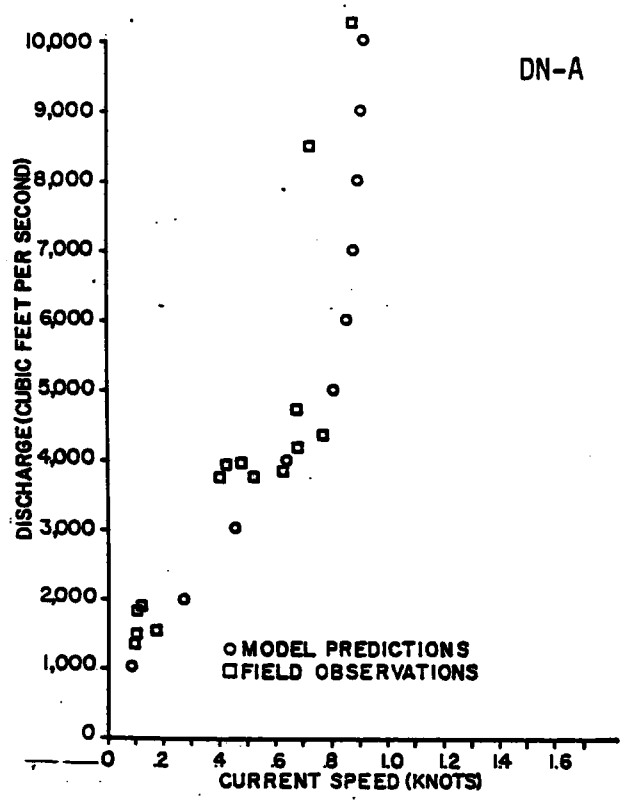
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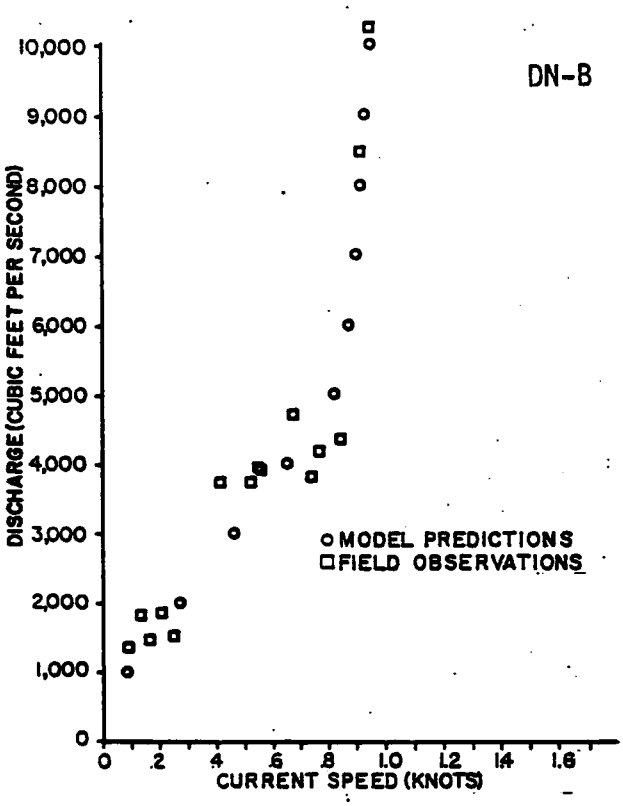
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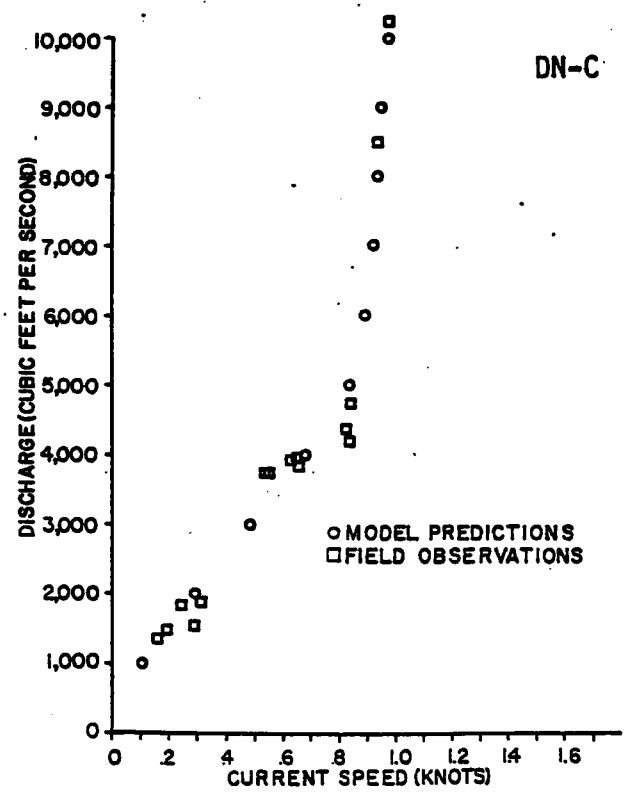
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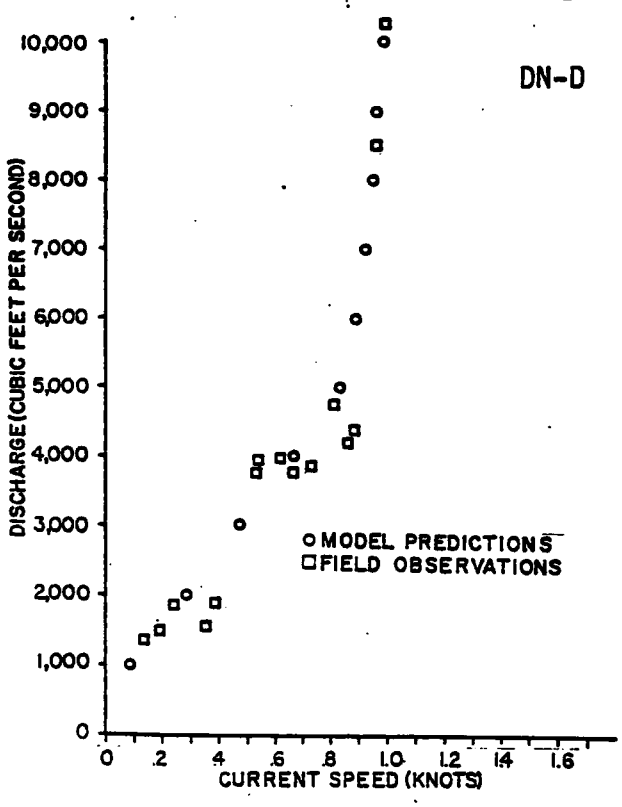
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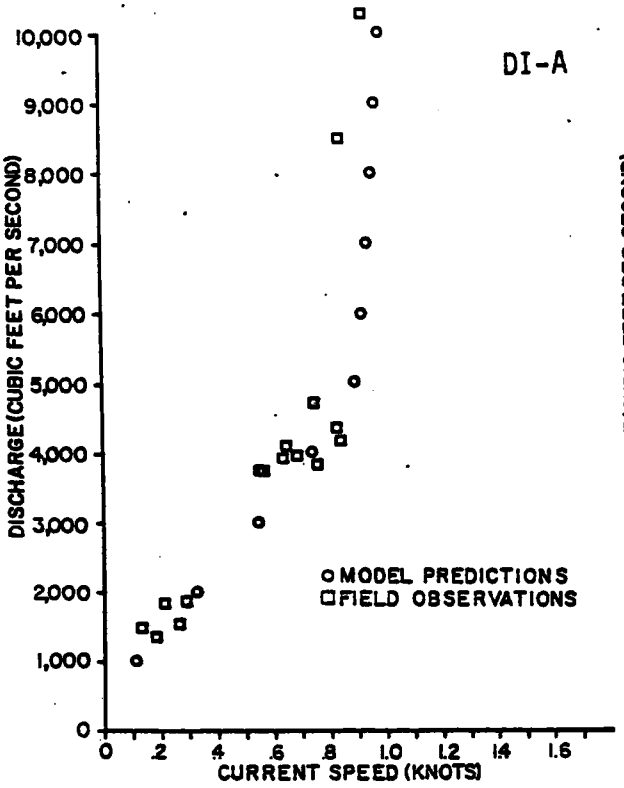
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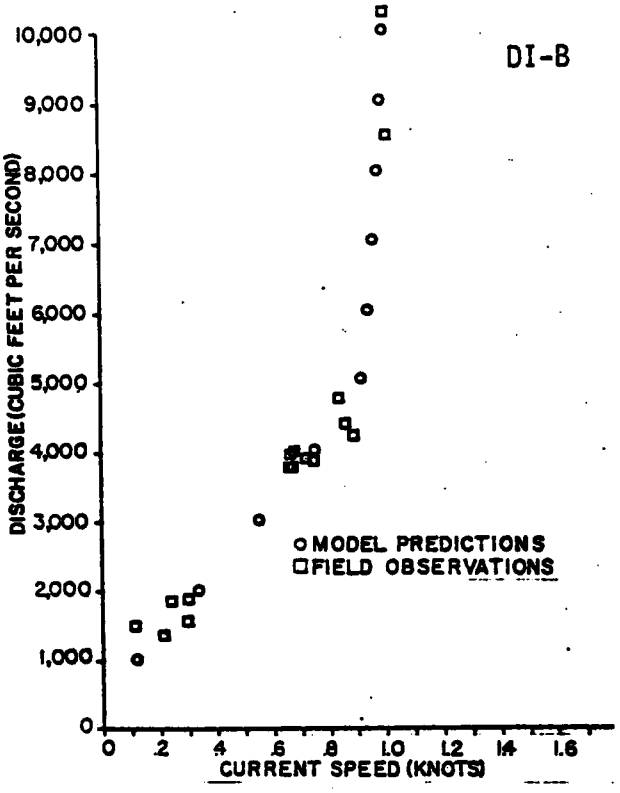
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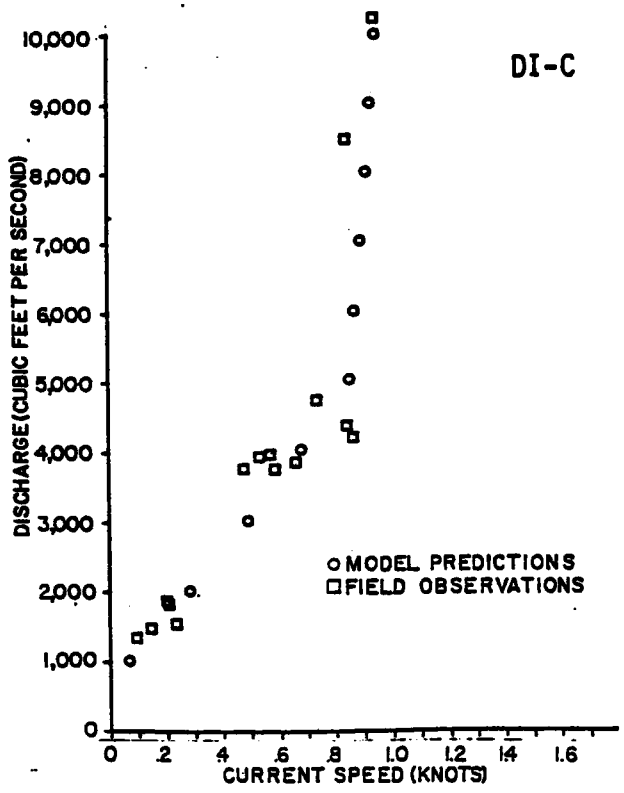
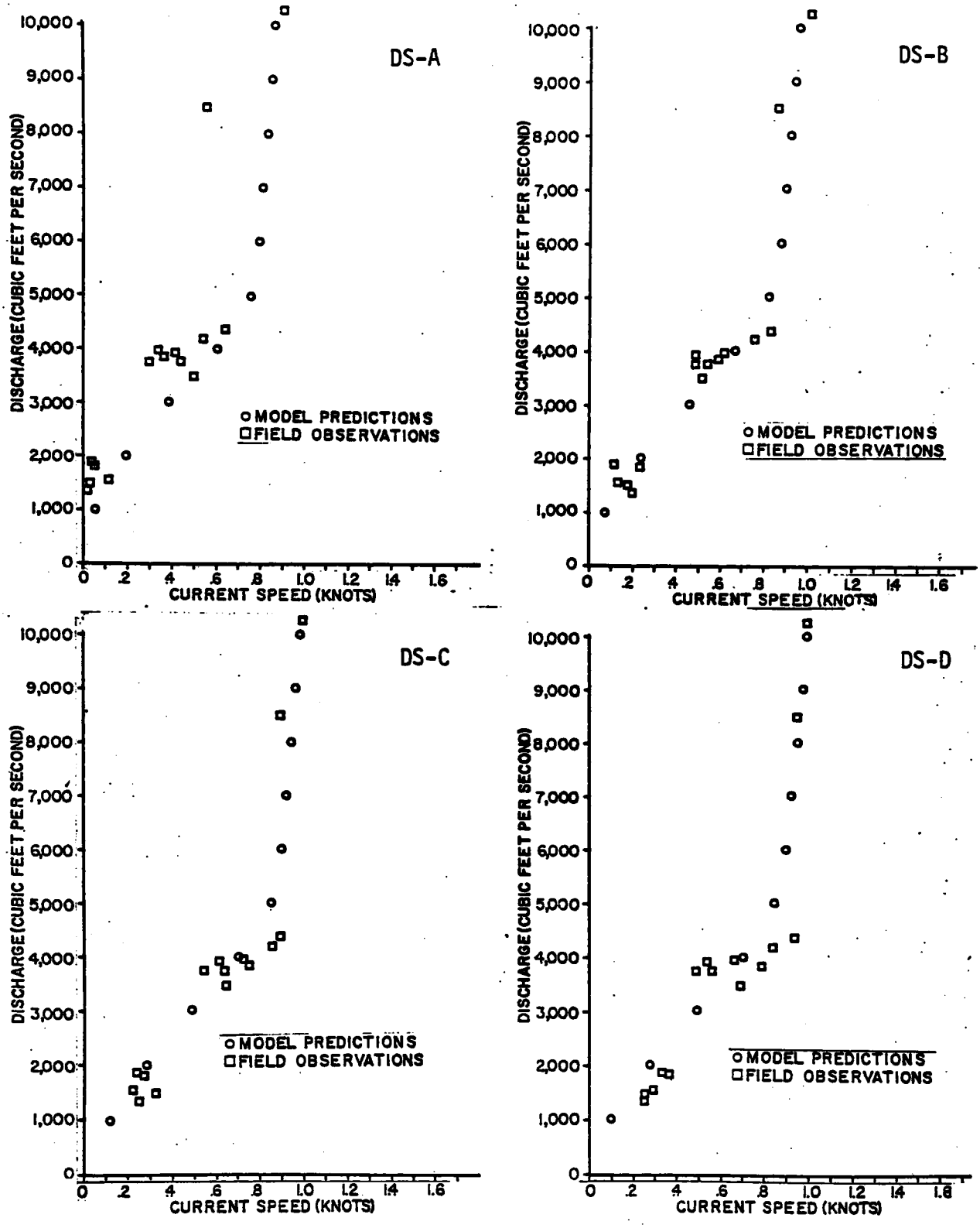
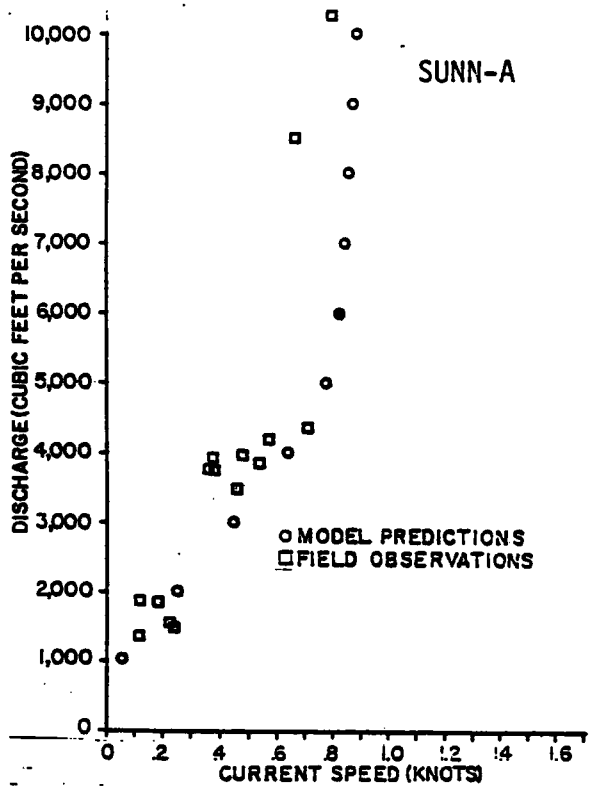
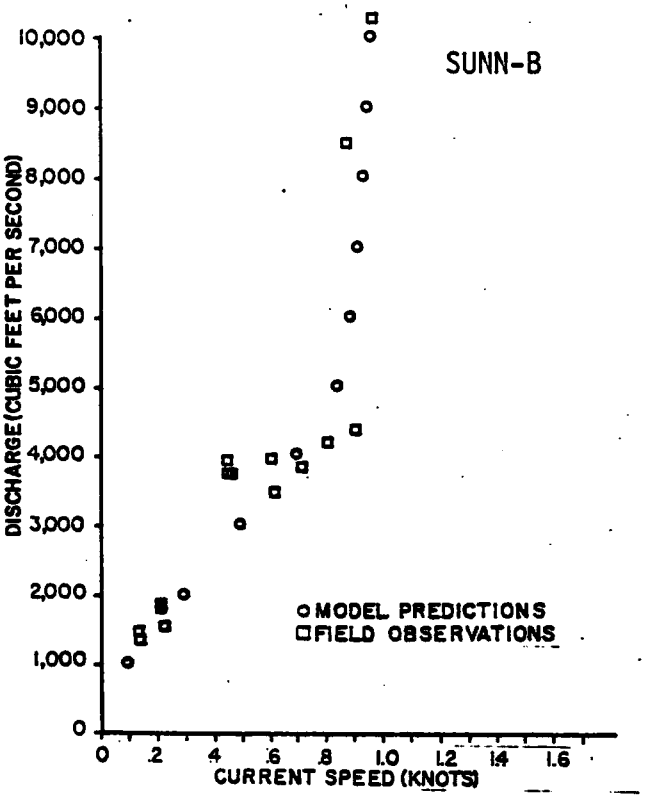
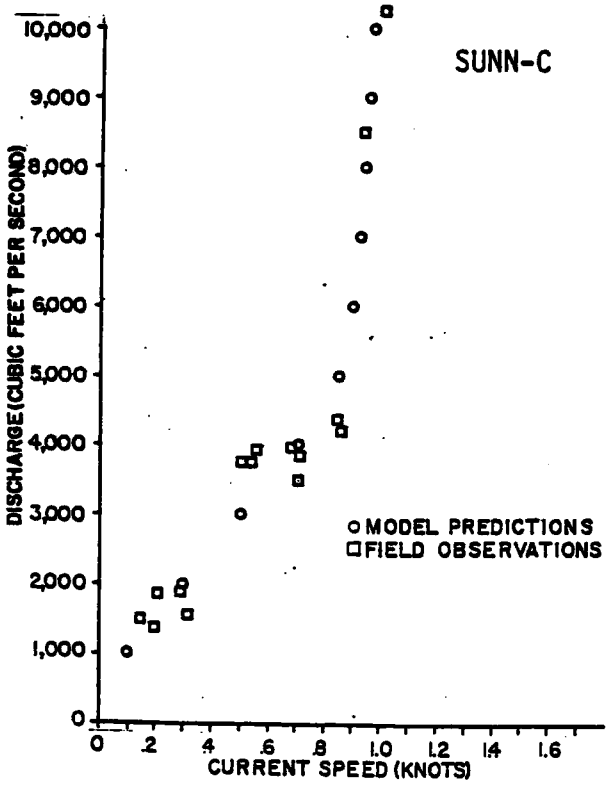
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)
O MODEL PREDICTIONS
□ FIELD OBSERVATIONS

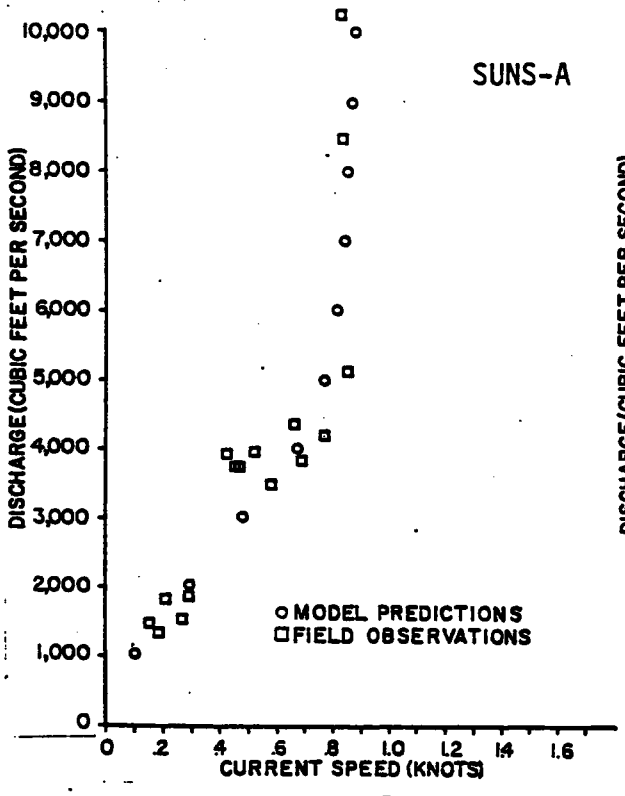

DI-C
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)
O MODEL PREDICTIONS
□ FIELD OBSERVATIONS

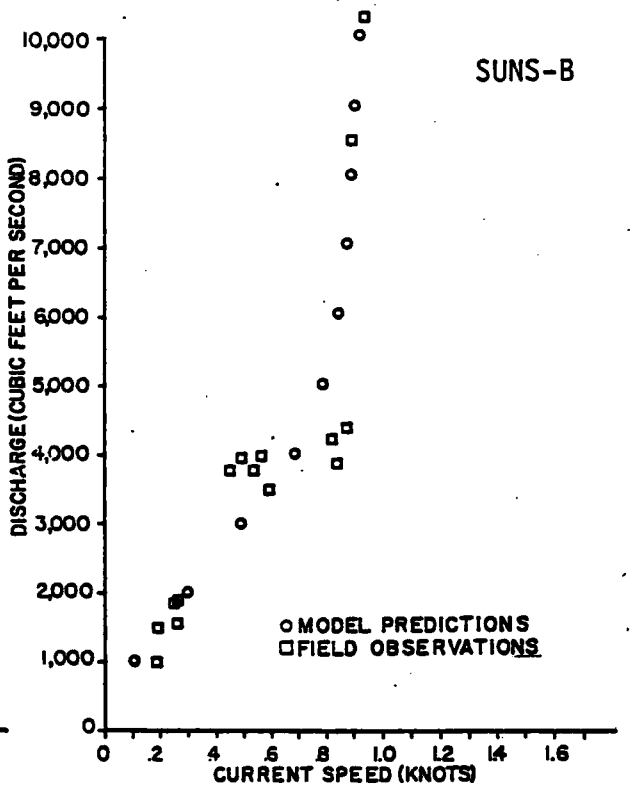

DS-A
DS-B
DS-C
DS-D
DISCHARGE (CUBIC FEET PER SECOND)
CURRENT SPEED (KNOTS)
MODEL PREDICTIONS
FIELD OBSERVATIONS
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
.2
.4
.6
.8
1.0
1.2
1.4
1.6

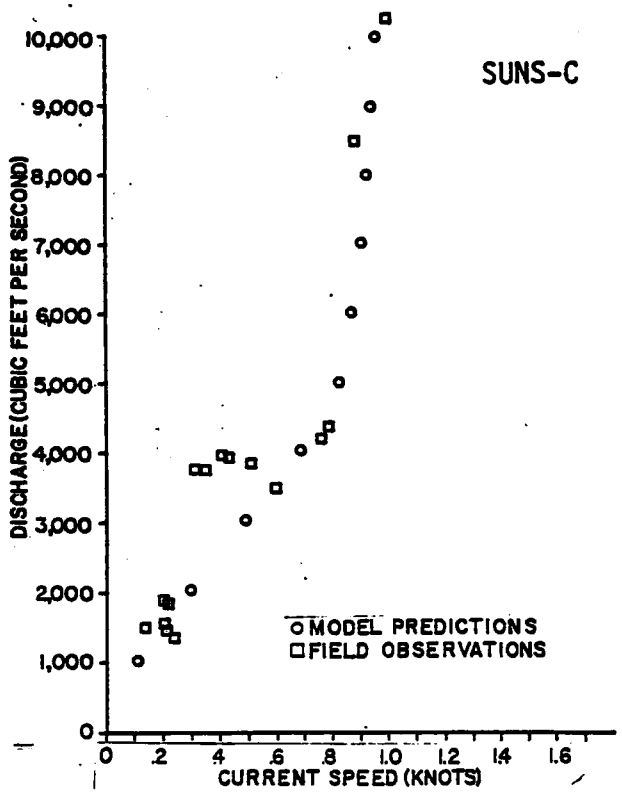

SUNN-A
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
MODEL PREDICTIONS
FIELD OBSERVATIONS
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)


SUNN-B
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
MODEL PREDICTIONS
FIELD OBSERVATIONS
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)


SUNN-C
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
MODEL PREDICTIONS
FIELD OBSERVATIONS
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)


SUNS-A
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)
o MODEL PREDICTIONS
□ FIELD OBSERVATIONS


SUNS-B
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)
o MODEL PREDICTIONS
□ FIELD OBSERVATIONS


SUNS-C
DISCHARGE (CUBIC FEET PER SECOND)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6
CURRENT SPEED (KNOTS)
o MODEL PREDICTIONS
□ FIELD OBSERVATIONS

APPENDIX D

APPENDIX D

Appendix D contains additional data derived from 1975-76 biological investigations. Table D1 contains natural and artificial egg fall velocity determinations from 1975. Table D2 represents a list of food items consumed by larval shad from the Connecticut River, and Table D3 is a list of plankton organisms in an Avery Point Pond plankton net sample (natural plankton used for feeding experiments at Avery Point). Table D4 a-i contains analysis of variance results for 1975 Drift Bioassay Series No. 1 and Table D5 a-i contains the batch-by-batch results of multiple regression performed on both years' drift bioassay data. Table D6 a-h presents results of 1976 Laboratory Bioassay regression analyses, and D7 a and b contains analysis of variance results for these laboratory experiments. Tables D-8 and D-9 contain, respectively, simple correlation coefficients among variables employed in the laboratory egg and larvae regression analyses.

Figures D1- D13 graph the survival of eggs and larvae against the exposure temperatures (°F) and Δ°F-min, the computed degree-minutes of exposure above ambient water temperature. Survival was measured as the proportion of living eggs at 8, 24 and 48 hrs after thermal shock; larval survival was tested at 1, 4 and 8 hrs. On each graph, both the raw proportion surviving and the transformed proportion (arcsin $\sqrt{p}$) are displayed.

Finally, Table D10 contains data used in the field bioassay regression analyses.

TABLE D-1. FALL VELOCITY DETERMINATIONS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

FIRST EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 1 — June 4, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	14	1.21	2100	22.1	
2		1.16			
3		1.28			some clouding
4		1.33			
5		1.20			
6		1.12			
7		1.12			
8		1.13			
9		1.21			
10		1.19			
11		1.16			
12		1.28			
13		1.38			
14		1.23			
15		1.31			
16		1.29			
17		1.02	2126	23.0	
18		1.12			
19		1.28			
20		1.33			
21		1.11			
22		1.28			cloudy
23		1.31			
24		1.38			
25		1.25			
26		1.31			
27		1.21			
28		1.35			
29		1.29			
30		1.11			
31		1.20			
32		1.13			
33		1.35			
34		1.33			
35		1.21		23.9	
36		0.917			cloudy
37		0.684			cloudy
38		0.724			cloudy
39		0.735			cloudy
40		0.735			cloudy
41		0.740			cloudy
42		0.781			cloudy
43		0.757			cloudy
44		0.787			cloudy
45		0.854			cloudy
46		0.714			cloudy
47		0.729			cloudy
48		0.787			cloudy
49		0.699			cloudy
50		0.675		24.0	cloudy
51		1.35			
52		1.149			
53		1.17			
54		1.23			
55		1.17			
56		1.29			
57		1.13			
58		1.21			
59		1.42			
60		1.47			
61	15	1.29	2200	24.1	

FIRST EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 3 — June 5, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	39.6	1.11	2240	21.2	
2		1.42			
3		1.28			
4		1.25			
5		1.56			
6		1.12			
7		1.25			
8		1.42			
9		1.11			
10		1.13			
11		1.28			
12		1.25			
13		1.25			
14		1.25			
15		1.38			
16		1.66			
17		1.28			
18		1.42			
19		1.23			
20		1.38			
21		1.42			
22		1.26			
23		1.31			
24		1.42			
25		1.35			
26		1.17			
27		1.42			
28		1.40			
29		1.49			
30		1.44			
31		1.66			
32		1.21			
33		1.42			
34		1.26			
35		1.42			
36		1.49			
37		1.42			
38		1.42			
39		1.42			
40	40.25	1.42	2315	21.2	

FIRST EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 4 — June 6, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments	Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	51	0.96	1000	21.7		32		1.22			
2		1.14				33		1.32			
3		1.30				34		1.30			
4		1.30				35		1.22			
5		1.14				36		1.25			
6		1.22				37		1.20			
7		1.11				38		1.25			
8		1.27				39		1.09			
9		1.16				40		1.25			
10		1.25				41		1.25			
11		1.14				42		1.22			
12		1.15				43		1.16			
13		1.14				44		1.35			
14		1.32				45		1.28			
15		1.28				46		1.35			
16		1.14				47		1.25			
17		1.30				48		1.25			
18		1.28				49		1.35			
19		1.25				50		1.32			
20		1.16		21.7		51		1.25			
21		1.05				52		1.28			
22		1.22				53		1.45			
23		1.14				54		1.09			
24		1.35				55		1.28			
25		1.28				56		1.19			
26		1.22				57		1.56			
27		1.28				58		1.14			
28		1.27				59		1.32			
29		1.23				60		1.09			
30		1.35				61	52	1.28	1100	21.7	
31		1.39									

FIRST EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 5 — June 7, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	75.7	1.18	1045	21.0	
2		1.23			
3		1.0			
4		1.18			
5		1.32			
6		1.22			
7		1.20			
8		1.25			
9		1.30			
10		1.25			
11		1.19			
12		1.06			
13		1.20			
14		1.15			
15		1.30			
16		1.11			
17		1.16			
18		1.19			
19		1.10			
20		1.11		21.0	
21		1.04			
22		0.98			
23		1.39			
24		1.43			
25		1.16			
26		1.19			
27		1.22			
28		1.25			
29		1.28			
30		1.28			
31		1.23			
33		1.02			
34		1.25			
35		1.09			
36		1.14			
37		1.30			
38		1.12			
39		1.27			
40		1.14		21.2	
41		1.39			
42		1.22			
43		1.25			
44		1.11			
45		1.37			
46		1.28			
47		1.27			
48		1.32			
49		1.32			
50		1.27			
51		1.16			
52		1.22			
53		1.18			
54		1.22			
55		1.39			
56		1.15			
57		1.04			
58		1.28			
59		1.14			
60	77	1.16	1200	21.4	

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 6 — June 10, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	4	1.20	0200	19.6	
2		1.23			
3		1.26			
4		1.27			
5		1.27			
6		1.32			
7		1.47			sm. diam.
8		1.22			
9		1.20			
10		1.33			
11		1.37			
12		1.35			
13		1.22			
14		1.19			
15		1.20			
16		1.28			
17		1.32			
18		1.14			
19		1.25			
20		1.30			
21		1.32		19.7	
22		1.16			
23		1.22			
24		1.22			
25		1.28			
26		1.67			sm. diam.
27		1.47			sm. diam.
28		1.67			sm. diam.
29		1.67			sm. diam.
30		1.32			
31		1.11			
32		1.20			
33		1.41			
34		1.56			sm. diam.
35		1.67			sm. diam.
36		1.68			sm. diam.
37		1.35			
38		1.28			
39		1.67			sm. diam.
40		1.67			sm. diam.
41		1.67		19.8	sm. diam.
42		1.22			
43		1.25			
44		1.25			
45		1.30			
46		1.32			
47		1.25			
48		1.22			
49		1.59			sm. diam.
50		1.59			sm. diam.
51		1.49			sm. diam.
52		1.59			sm. diam.
53		2.0			sm. diam.
54		1.61			sm. diam.
55		1.56			sm. diam.
56		1.52			sm. diam.
57		1.56			sm. diam.
58		1.49			sm. diam.
59		1.67			sm. diam.
60		1.79			sm. diam.
61		1.20			
62		1.30			
63		1.25			
64		1.23			
65		1.61			
66	5	1.41	0300	20.0	

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 7 — **June 10, 1975**

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	15	1.25	1300	21.4	
2		1.25			
3		1.32			
4		1.37			
5		1.43			
6		1.28			
7		1.39			
8		1.32			
9		1.37			
10		1.35			
11		1.25			
12		1.25			
13		1.47			
14		1.45			
15		1.35			
16		1.32			
17		1.30			
18		1.41			
19		1.25			
20		1.23			
21		1.19			
22		1.22			
23		1.33		20.8	
24		1.22			
25		1.23			
26		1.20			
27		1.41			
28		1.47			
29		1.61			
30		1.37			
31		1.49			
32		1.47			
33		1.30			
34		1.33			
35		1.18			
36		1.39			
37		1.37			
38		1.35			
39		1.33			
40		1.28			
41		1.28		21.0	
42		1.05			
43		1.25			
44		1.39			
45		1.23			
46		1.30			
47		1.28			
48		1.27			
49		1.39			
50		1.32			
51		1.30			
52		1.35			
53		1.19			
54		1.28			
55		1.37			
56		1.37			
57		1.25			
58		1.25			
59	16	1.20	1400	21.1	

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 8 — June 11, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	35	1.22	0900	20.6	
2		1.09			
3		1.14			
4		0.98			
5		1.18			
6		1.23			
7		1.04			
8		1.18			
9		1.23			
10		1.16			
11		1.22			
12		1.14			
13		1.03			
14		1.19			
15		1.02		20.8	
16		1.15			
17		1.19			
18		1.16			
19		1.23			
20		1.19			
21		1.12			
22		1.28			
23		1.23			
24		1.18			
25		1.22			
26		1.28			
27		1.25			
28		1.35			
29		1.19			
30		1.25		21.0	
31		1.22			
32		1.28			
33		1.25			
34		1.35			
35		1.19			
36		1.25			
37		1.22			
38		0.86			Cloudy
39		1.16			
40		1.22			
41		1.61			sm. diam.
42		1.61			sm. diam.
43		1.67			sm. diam.
44		1.52			sm. diam.
45		1.54			sm. diam.
46		1.67			sm. diam.
47		1.72			sm. diam.
48		1.59			sm. diam.
49		1.61			sm. diam.
50	35.8	1.61	0950	21.5	sm. diam.

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 8A — June 11, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	35.9	1.14	0955	10.2	
2		1.0			
3		1.19			
4		0.93			
5		1.11			
6		1.05			
7		1.11			
8		1.09			
9		1.22			
10		1.16			
11		0.98			
12		1.08			
13		1.11			
14		1.08		12.1	
15		1.08			
16		1.09			
17		1.08			
18		1.11			
19		1.09			
20		1.19			
21		1.09			
22		1.12			
23		1.10			
24		0.95			
25		1.11			
26		1.12			
27		1.12			
28		1.22			
29		1.08		13.0	
30		1.18			
31		1.10			
32		1.18			
33		1.09			
34		1.11			
35		1.12			
36		1.11			
37		1.15			
38		1.16			
39		1.09			
40		1.10			
41		0.99			
42		1.09			
43		1.11			
44		1.09			
45		1.10			
46		1.15			
47		1.14			
48		1.09			
49		1.20			
50	36.5	1.14	1030	13.8	

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 9 — June 12, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	60.6	1.16	1040	20.0	
2		1.09			
3		1.20			
4		1.11			
5		1.11			
6		1.14			
7		1.16			
8		1.22			
9		1.11			
10		1.20			
11		1.19			
12		1.11			
13		1.22			
14		1.10			
15		1.14		20.4	
16		1.22			
17		1.23			
18		1.19			
19		1.14			
20		1.09			
21		0.99			
22		1.11			
23		1.16			
24		1.11			
25		1.14			
26		1.12			
27		1.18			
28		1.19			
29		1.11			
30		1.14		20.8	
31		1.19			
32		1.22			
33		1.22			
34		1.18			
35		1.19			
36		1.16			
37		1.16			
38		1.27			
39		1.18			
40		1.23			
41		1.10			
42		1.14			
43		1.18			
44		1.20			
45		1.28			
46		1.0			
47		1.22			
48		1.18			
49		1.20			
50	61.5	0.99	1130	21.0	

SECOND EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 9A — June 12, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	61.5	1.18	1135	8.0	
2		1.04			
3		1.23			
4		1.20			
5		1.14			
6		1.20			
7		1.06			
8		1.10			
9		1.04			
10		1.03			
11		1.18			
12		1.02			
13		1.12			
14		1.10			
15		1.09		10.1	
16		1.05			
17		1.09			
18		0.95			
19		1.03			
20		1.14			
21		1.08			
22		1.04			
23		1.12			
24		1.14			
25		1.22			
26		1.06			
27		1.14			
28		1.12			
29		1.06		12.0	
30		1.11			
31		1.23			
32		1.10			
33		1.09			
34		1.11			
35		1.11			
36		1.22			
37		1.15			
38		1.09			
39		1.22			
40		1.11			
41		1.09			
42		1.05			
43		1.11			
44		1.12			
45		1.12			
46		1.18			
47		1.11			
48		1.25			
49	62.5	1.11	1230	14.0	

FALL VELOCITY MEASUREMENTS

Natural Shad Roe
Preserved in 5% Formalin

Eggs Preserved From Test No. 6 (June 19, 1975)

Run No.	Date	Velo. cm/sec	Water Temp. °C
1	7/29/75	1.82	19.8
2		1.72	
3		2.0	
4		1.69	
5		1.89	
6		1.89	
7		1.92	
8		1.96	
9		1.85	
10		1.89	20.0
11		2.08	
12		1.82	
13		1.85	
14		1.61	
15		1.85	
16		1.85	
17		1.92	
18		1.89	
19		1.96	
20		1.85	
21		1.89	
22		1.85	
23		1.69	
24		1.72	
25		1.92	20.0

Eggs Preserved From Test No. 7 (June 10, 1975)

Run No.	Date	Velo. cm/sec	Water Temp. °C
1	7/29/75	2.0	21.2
2		1.96	
3		1.89	
4		1.85	
5		1.92	
6		1.92	
7		2.0	
8		2.04	
9		1.88	
10		1.96	
11		1.89	
12		1.82	
13		1.89	
14		1.72	
15		2.0	
16		2.04	
17		1.89	
18		1.85	
19		1.72	
20		1.96	21.2
21		2.0	
22		1.92	
23		2.0	
24		1.96	
25		1.96	

Eggs Preserved From Test No. 8 (June 11; 1975)

1	7/29/75	1.96	21.3
2		1.96	
3		1.92	
4		1.92	
5		1.92	
6		1.89	
7		1.75	
8		2.0	
9		1.92	
10		1.92	
11		2.0	21.3
12		1.69	
13		2.1	
14		1.96	
15		2.0	
16		1.96	

Eggs Preserved From Test No. 9 (June 12, 1975)

1	7/29/75	1.72	21.4
2		1.78	
3		1.67	
4		1.92	
5		1.85	
6		2.0	
7		1.89	
8		1.82	
9		1.92	
10		1.82	21.6
11		1.79	
12		1.96	
13		2.08	
14		1.89	
15		1.61	
16		1.75	

FALL VELOCITY MEASUREMENTS (cont'd)

Test #8 cont.				Test #9 cont.			
Run No.	Date	Velo. cm/sec	Water Temp. °C	Run No.	Date	Velo. cm/sec	Water Temp. °C
17		1.82		17		1.82	
18		2.04		18		1.75	
19		2.0		19		1.67	
20		2.22	21.3	20		1.85	
21		1.89		21		1.89	
22		2.08		22		2.04	
23		1.85		23		1.79	
24		2.0		24		1.82	
25		2.0	21.4	25		1.82	21.8

FALL VELOCITY MEASUREMENTS

Artificial Shad Roe
July 29, 1975

Non-water Hardened Green			Water Hardened		
Run No.	Velo. cm/sec	Water Temp. °C	Run No.	Velo. cm/sec	Water Temp. °C
1	1.67	18.0	1	0.97	19.6
2	1.54		2	1.08	
3	1.59		3	1.03	
4	1.59		4	1.02	
5	1.47		5	1.03	
6	1.61		6	0.95	
7	1.59		7	1.08	
8	1.54		8	1.01	
9	1.54		9	1.09	
10	1.64	19.0	10	1.0	
11	1.45		11	0.99	19.9
12	1.54		12	1.02	
13	1.59		13	0.96	
14	1.56		14	0.92	
15	1.52		15	1.02	
16	1.59		16	0.98	
17	1.49		17	1.02	
18	1.49		18	1.05	
19	1.54		19	1.04	
20	1.47		20	0.97	
21	1.41		21	1.0	
22	1.61		22	1.15	
23	1.67		23	1.0	
24	1.64		24	1.03	
25	1.59		25	1.05	20.3
26	1.56				
27	1.56	19.1			

FIRST EXPERIMENTAL SEQUENCE

Fall Velocity Measurements
Natural Shad Roe

Test No. 2 — June 5, 1975

Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments	Run No.	Age Hrs.	Velo. cm/sec	Time EDST	Water Temp. °C	Comments
1	27	1.42	1000	21.0		31		1.31			
2		1.16				32		1.28			
3		1.26				33		1.28			
4		1.11				34		1.23			
5		1.13				35		1.38			
6		1.31				36		1.31			
7		1.40				37		1.23			
8		1.26				38		1.13			
9		1.25				39		1.08			
10		1.23				40		1.21			
11		1.29				41		1.16			
12		1.36				42		1.26			
13		1.42				43		1.25			
14		1.29				44		1.40			
15		1.17				45		1.40			
16		1.17				46		1.14			
17		1.33				47		1.20			
18		1.28				48		1.20			
19		1.19				49		1.35			
20		1.31				50		1.35			
21		1.26		21.2		51		1.25			
22		1.25				52		1.38			
23		1.31				53		1.25			
24		1.35				54		1.19			
25		1.16				55		1.25			
26		1.26				56		1.14		22.0	
27		1.20				57		1.40			
28		1.33				58		1.21			
29		1.47				59		1.23			
30		1.49				60	27.8	1.19	1050		

TABLE D2. ORGANISMS PRESENT IN CONNECTICUT RIVER SHAD LARVAE GUT CONTENTS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Alosa sapidissima larvae
Connecticut River
Sunderland, Massachusetts
23 June 1976
Collector: C. J. Schmitt
Gut Analysis by: A. L. Millar and R. O. Goodlett

stained with rose bengal and preserved with 5% buffered formalin to pH 7.0

RESULTS

LARVAE SIZE	GUT CLASSIFICATION*	CONTENTS
8.0 mm	Empty	Nothing
8.5 mm	Empty	2 whole diatoms (*Navicula* sp. and 1 *Gyrosigma/Pleurosigma* sp.) obscure green material in minute quantities
8.5 mm	Empty	Nothing
8.5 mm	Empty	Nothing
8.5 mm	Empty	1 blue-green coccoid colony (resembles centric diatom *Coscinodiscus*)
9.0 mm	Empty	Minute amount plant meterial
9.5 mm	Empty	Nothing
10.0 mm	1/2 full	5 cyclopoid copepods (0.56 mm avg) 1 *Daphnia* skeleton 1 copepod nauplii (possible harpacticoid)

(Continued)

TABLE D2 (Continued)

LARVAE SIZE	GUT CLASSIFICATION*	CONTENTS
10.5 mm	1/2 full	3 cyclopoid copepodites (0.54 average length) 1 Nauplii 1 *Daphnia* (0.42 mm) Skeletal remains of cyclopoid copepods
11.0 mm	Empty	Nothing
11.0 mm	1/4 full	2 diatoms (some unicellular greens and blue-greens) 2 pollen grains 1 cyclopoid copepod 1 harpacticoid copepod 1 copepod skeleton Other plant material 1 obscure animal (too digested)
11.0 mm	1/4 full	2.5 cyclopoid copepodites (*Eucyclops* or *Paracyclops*) Pieces of copepods 1 rotifer 1 copepod nauplii unicellular greens and blue-greens
12.5 mm	1/2 full	1 cyclopoid copepodite (0.48 mm) skeletal copepod remains
14.5 mm	1/4 full	skeletal copepod remains 6 eggs (unidentifiable) (0.16 mm)
23.0 mm	Full	2 insect pupae 1 cladoceran (1 mm) 1 dipteran larvae (4 mm) digested phytoplankton -- small unicellular green cells digested *Nitzschia* sp. and *Fragillaria* sp.

*Gut classification (empty, 1/4, 1/2, 3/4, full)

NOTE: Most of the cyclopoid copepods found were believed to be either *Paracyclops* or *Eucyclops*

APPENDIX TABLE D3. A LIST OF DOMINANT PLANKTON ORGANISMS PRESENT IN AVERY POINT POND #20 NET SAMPLE, 9 JUNE 1976. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

PHYTOPLANKTON

DIATOMS

Melosira sp.
Fragilaria sp.

GREEN ALGAE

Scenedesmus sp.

BLUE-GREEN ALGAE

Anabaena sp.

ZOOPLANKTON

CLADOCERA

Bosmina sp.

COPEPODA

Unidentified nauplii

TABLE D4a. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Live Larvae)}}{\text{(Total Eggs \& Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.011	4.539	NS
Total eggs and larvae	1	0.003	1.140	NS
Total eggs	1	0.003	1.340	NS
Total larvae	1	0.002	0.674	NS
Main Effects	3	0.175	74.064	0.001
Station	2	0.005	2.248	NS
Depth	1	0.523	222.037	0.001
Interactions	2	0.012	5.124	0.05
Station x Depth	2	0.012	5.124	0.05
Explained	8	0.072	30.757	0.001
Residual	6	0.002	---	---
Total	14	0.042	---	---

Multiple Classifications; Grand Mean = 0.39

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	-0.01	-0.02
S-4	4	-0.01	0.05
S-17	4	0.03	-0.01
Depth			
Surface	9	0.14	0.16
Bottom	6	-0.22	-0.25
Multiple R^2	---	---	0.936
Multiple R	---	---	0.967

TABLE D4b. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Live Larvae)}}{\text{(Total Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.001	4.500	NS
Total eggs and larvae	1	0.000	1.620	NS
Total eggs	1	0.000	1.381	NS
Total larvae	1	0.000	1.833	NS
Main Effects	3	0.048	175.971	0.001
Station	2	0.000	1.010	NS
Depth	1	0.143	522.723	0.001
Interactions	2	0.000	1.411	NS
Station x Depth	2	0.000	1.411	NS
Explained	8	0.019	68.029	0.001
Residual	6	0.000	---	---
Total	14	0.011	---	---

Multiple Classifications; Grand Mean = 0.22

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.02	0.00
S-4	4	-0.02	0.01
S-17	4	-0.01	-0.01
Depth			
Surface	9	0.08	0.09
Bottom	6	-0.12	-0.13
Multiple R^2	---	---	0.984
Multiple R	---	---	0.992

TABLE D4c. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{Hatching success = (Total Larvae)}}{\text{(Total Eggs and Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.049	10.274	0.01
Total eggs and larvae	1	0.000	0.011	NS
Total eggs	1	0.000	0.066	NS
Total larvae	1	0.000	0.078	NS
Main Effects	3	0.003	0.531	NS
Station	2	0.002	0.404	NS
Depth	1	0.004	0.911	NS
Interactions	2	0.003	0.638	NS
Station x Depth	2	0.003	0.638	NS
Explained	8	0.020	4.211	0.05
Residual	6	0.005	---	---
Total	14	0.013	---	---

Multiple Classifications; Grand Mean = 0.59

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	-0.04	-0.02
S-4	4	-0.02	0.02
S-17	4	0.09	0.02
Depth			
Surface	9	0.01	0.01
Bottom	6	-0.02	-0.02
Multiple R^2	---	---	0.817
Multiple R	---	---	0.904

TABLE D4d. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Live Eggs)}}{\text{(Total Eggs)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.061	3.132	NS
Total eggs and larvae	1	0.056	2.902	NS
Total eggs	1	0.051	2.627	NS
Total larvae	1	0.067	3.458	NS
Main Effects	3	0.113	5.832	0.05
Station	2	0.053	2.727	NS
Depth	1	0.257	13.198	0.01
Interactions	2	0.107	5.527	0.05
Station x Depth	2	0.107	5.527	0.05
Explained	8	0.092	4.743	0.05
Residual	6	0.019	---	---
Total	14	0.061	---	---

Multiple Classifications; Grand Mean = 0.58

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.08	0.04
S-4	4	0.08	0.10
S-17	4	-0.21	-0.17
Depth			
Surface	9	0.12	0.11
Bottom	6	-0.17	-0.17
Multiple R^2	---	---	0.612
Multiple R	---	---	0.782

TABLE D4e. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Live eggs)}}{\text{(Total Eggs \& Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.068	6.575	0.05
Total eggs and larvae	1	0.034	3.304	NS
Total eggs	1	0.029	2.846	NS
Total larvae	1	0.044	4.283	NS
Main Effects	3	0.063	6.166	0.05
Station	2	0.029	2.792	NS
Depth	1	0.144	14.014	0.01
Interactions	2	0.081	7.891	0.05
Station x Depth	2	0.081	7.891	0.05
Explained	8	0.069	6.751	0.05
Residual	6	0.010	---	---
Total	14	0.044	---	---

Multiple Classifications; Grand Mean = 0.47

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.08	0.03
S-4	4	0.06	0.07
S-17	4	-0.19	-0.13
Depth			
Surface	9	0.09	0.09
Bottom	6	-0.13	-0.13
Multiple R^2	---	---	0.637
Multiple R	---	---	0.798

TABLE D4f. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Deformed larvae)}}{\text{(Total Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.001	0.399	NS
Total eggs and larvae	1	0.001	0.405	NS
Total eggs	1	0.001	0.443	NS
Total larvae	1	0.001	0.352	NS
Main Effects	3	0.007	3.659	NS
Station	2	0.001	0.316	NS
Depth	1	0.020	10.538	0.05
Interactions	2	0.001	0.638	NS
Station x Depth	2	0.001	0.638	NS
Explained	8	0.003	1.681	NS
Residual	6	0.002	---	---
Total	14	0.003	---	---

Multiple Classifications; Grand Mean = 0.06

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.00	-0.01
S-4	4	0.00	0.01
S-17	4	0.01	0.01
Depth			
Surface	9	0.03	0.03
Bottom	6	-0.04	-0.05
Multiple R^2	---	---	0.626
Multiple R	---	---	0.791

TABLE D4g. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Deformed Larvae)}}{\text{(Total Eggs \& Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.000	0.356	NS
Total eggs and larvae	1	0.000	0.982	NS
Total eggs	1	0.000	0.986	NS
Total larvae	1	0.000	0.992	NS
Main Effects	3	0.002	5.595	0.05
Station	2	0.000	0.754	NS
Depth	1	0.007	15.954	0.01
Interactions	2	0.000	0.907	NS
Station x Depth	2	0.000	0.907	NS
Explained	8	0.001	2.458	NS
Residual	6	0.000	---	---
Total	14	0.001	---	---

Multiple Classifications; Grand Mean = 0.03

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	0.00	-0.01
S-4	4	0.00	0.01
S-17	4	0.01	0.01
Depth			
Surface	9	0.01	0.02
Bottom	6	-0.02	-0.03
Multiple R^2	---	---	0.696
Multiple R	---	---	0.834

TABLE D4h. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Premature Larvae)}}{\text{(Total Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.142	18.135	0.01
Total eggs and larvae	1	0.263	33.613	0.01
Total eggs	1	0.272	34.730	0.01
Total larvae	1	0.261	33.257	0.01
Main Effects	3	1.599	204.028	0.001
Station	2	0.011	1.475	NS
Depth	1	4.773	609.198	0.001
Interactions	2	0.011	1.460	NS
Station x Depth	2	0.011	1.460	NS
Explained	8	0.656	83.676	0.001
Residual	6	0.008	---	---
Total	14	0.378	---	---

Multiple Classifications; Grand Mean = 0.44

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	-0.06	0.01
S-4	4	0.16	-0.07
S-17	4	-0.06	0.05
Depth			
Surface	9	-0.42	-0.50
Bottom	6	0.62	0.74
Multiple R^2	---	---	0.987
Multiple R	---	---	0.993

TABLE D4i. ANOVA AND MULTIPLE CLASSIFICATION ANALYSIS FOR 1975 FIELD BIOASSAY, SERIES #1. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

Dependent Variable: $\frac{\text{(Premature larvae)}}{\text{(Total Eggs \& Larvae)}}$

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIG
Covariates	3	0.014	8.080	0.05
Total eggs and larvae	1	0.012	6.830	0.05
Total eggs	1	0.013	7.560	0.05
Total larvae	1	0.010	5.657	NS
Main Effects	3	0.075	44.243	0.001
Station	2	0.003	1.761	NS
Depth	1	0.223	132.586	0.001
Interactions	2	0.009	5.371	0.05
Station x Depth	2	0.009	5.371	0.05
Explained	8	0.035	20.964	0.001
Residual	6	0.002	---	---
Total	14	0.021	---	---

Multiple Classifications; Grand Mean = 0.09

VARIABLE & CATEGORY	N	UNADJUSTED DEVIATION FROM GRAND MEAN	ADJUSTED FOR COVARIATES
Station			
N-10	7	-0.02	0.01
S-4	4	0.01	-0.04
S-17	4	0.02	0.02
Depth			
Surface	9	-0.09	-0.11
Bottom	6	0.13	0.16
Multiple R^2	---	---	0.904
Multiple R	---	---	0.951

TABLE D5a. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 1 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	0.50900	0.00064 dose				0.853	10.72^{*}
Proportion of Live Eggs	0.95105	-0.00163 dose				0.863	11.63^{*}
Proportion of Live Larvae	1.22494	-0.00020 dose				0.351	0.56^{ns}
Proportion of Live Eggs and Larvae	0.04017	-0.00003 dose				0.594	2.18^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.50308	0.00000 dose				0.565	1.88^{ns}

TABLE D5b. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 2 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	0.20560	0.00278 dose				0.520	3.70^{ns}
Proportion of Live Eggs	0.02239	0.00011 dose				0.103	0.11^{ns}
Proportion of Live Larvae	0.76743	0.000885 dose				0.177	0.32^{ns}
Proportion of Live Eggs and Larvae	0.02633	0.00020 dose				0.335	1.26^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.45751	-0.00001 dose				0.223	0.52^{ns}

TABLE D5c. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 3 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT + V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
Proportion Hatching	0.58237	-0.00080 dose			0.549	1.72^{ns}
Proportion of Live Eggs	-0.08739	0.00222 dose			0.924	23.31^{**}
Proportion of Live Larvae	0.74401	0.00170 dose			0.428	0.90^{ns}
Proportion of Live Eggs and Larvae	0.02945	0.00010 dose			0.556	1.79^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.50305	-0.00000 dose			0.582	2.05^{ns}

TABLE D5d. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 4 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	-0.41369	0.00098 dose	0.01637 Tmax			0.630	1.32^{ns}
Proportion of Live Eggs	0.08364	-0.00031 dose	0.00078 age			0.311	0.22^{ns}
Proportion of Live Larvae	0.06425	0.02403 Δt	0.00010 dose			0.692	1.83^{ns}
Proportion of Live Eggs and Larvae	0.01415	-0.00010 dose	0.00040 age			0.468	0.56^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.51577	0.00014 Tmax	0.00000 dose			0.646	1.43^{ns}

TABLE D5e. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 5 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching		dose					
Proportion of Live Eggs	ALL INDEPENDENT VARIABLES BELOW TOLERANCE LEVEL OF 0.001						
Proportion of Live Larvae	0.77133	-0.00056 dose				0.512	0.71^{ns}
Proportion of Live Eggs and Larvae	0.14625	-0.00022 dose				0.547	0.85^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.55475	0.00001 dose				0.485	0.61^{ns}

TABLE D5f. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 6 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	0.88446	0.00239 age	0.00011 dose			0.827	3.24^{ns}
Proportion of Live Eggs	0.00735	0.00153 dose	-0.00020 age			0.472	0.43^{ns}
Proportion of Live Larvae	7.79052	-0.09846 Tmax	-0.00029 dose			0.924	8.70^{ns}
Proportion of Live Eggs and Larvae	0.10905	-0.00984 Δt	-0.00015			0.303	0.40^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.52042	0.00019 age	0.00000 dose			0.999	1193.20^{**}

TABLE D5g. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 7 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	1.09980	-0.00004 dose				0.125	0.02^{ns}
Proportion of Live Eggs	0.77467	-0.00115 dose				0.436	0.23^{ns}
Proportion of Live Larvae	1.01910	0.00064 dose				0.510	0.35^{ns}
Proportion of Live Eggs and Larvae	0.13394	0.00007 dose				0.735	1.18^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.60062	-0.00000 dose				0.762	1.38^{ns}

TABLE D5h. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 8 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	ALL INDEPENDENT VARIABLES BELOW TOLERANCE LEVEL OF 0.001						
Proportion of Live Eggs	ALL INDEPENDENT VARIABLES BELOW TOLERANCE LEVEL OF 0.001						
Proportion of Live Larvae	0.74023	-0.00054 dose				0.965	13.65^{ns}
Proportion of Live Eggs and Larvae	0.05666	-0.00004 dose				0.996	115.59^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.58624	0.00000 dose				0.996	143.35^{ns}

TABLE D5i. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 9 DRIFT SERIES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE =	CONSTANT +	V_1 +	V_2 +	V_3 +	V_4	MULTIPLE R	f
Proportion Hatching	0.27593	-0.00007 dose				0.484	0.30^{ns}
Proportion of Live Eggs	0.69354	-0.00013 dose				0.301	0.10^{ns}
Proportion of Live Larvae	0.71539	-0.00059 dose				0.724	1.10^{ns}
Proportion of Live Eggs and Larvae	0.09041	-0.00004 dose				0.632	0.66^{ns}
Net Change in Proportion of Live Eggs and Larvae	0.09041	-0.00004 dose				0.632	0.66^{ns}

TABLE D6a. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 2 EGGS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
			EGGS					
Percent alive at 8 hours	β i.v.[+]	1.71485	-0.00472 age	0.00072 dosage	-0.01772 Δt		.442	1.30^{ns}
Percent alive at 24 hours	β i.v.	1.65794	-0.01474 Δt	-0.00504 age	0.00070 dosage		.485	1.64^{ns}
Percent alive at 48 hours	β i.v.	1.50781	-0.00960 Δt	-0.00564 age	0.00087 dosage		.520	1.98^{ns}
Hatching success	β i.v.	1.06598	-0.00253 age	-0.00363 Δt			.105	0.09^{ns}
Time to 50% death	β i.v.	1.48002	-0.04442 Δt	-0.01046 age	0.00187 dosage		.668	4.31^{*}

[+]independent variables

$^{*}p < .05$

TABLE D6b. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 3 EGGS AND LARVAE. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
LARVAE								
Percent alive at 1 hour	β i.v.+	-3.94236	-0.00572 age	-0.02129 Δt	0.09084 ambient t	0.00047 dosage	.591	7.13***
Percent alive at 4 hours	β i.v.	-4.08494	-0.00285 age	-0.03428 Δt	0.00068 dose	0.07689 ambient t	.488	4.15**
Percent alive at 8 hours	β i.v.	-2.01730	-0.01251 Δt	-0.00100 age	0.03680 ambient t	0.00012 dosage	.306	1.36ns
Time to 50% death	β i.v.	-0.19948	-0.00018 age	-0.00126 Δt	0.00393 ambient t	0.00003 dosage	.522	4.97**
EGGS								
Percent alive at 8 hours	β i.v.	1.23000	0.00706 age	-0.00002 dosage	-0.00255 Δt		.674	4.44*
Percent alive at 24 hours	β i.v.	-73.00688	1.19503 ambient t	-0.00003 dosage	0.00292 Δt		.927	32.39***
Percent alive at 48 hours	β i.v.	-74.98805	1.22015 ambient t	0.02776 Δt	-0.00004 dose		.763	7.42**
Hatching success	β i.v.	-12.77865	0.03534 Δt	-0.00007 dosage	0.21277 ambient t		.579	2.68ns
Time to 50% death	β i.v.	0.61055	0.02383 Δt	-0.00012 dosage	0.00604 age		.622	3.37*

+independent variables

*p < .05

**p < .01

***p < .001

TABLE D6c. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 4 EGGS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+	V_1	+	V_2	+	V_3	+	V_4	MULTIPLE R	f
					EGGS							
Percent alive at 8 hours	β i.v.+	1.30348		0.00023 dosage		-0.00534 Δt					.447	$.88^{ns}$
Percent alive at 24 hours	β i.v.	1.17849		0.05571 Δt		-0.00075 dosage					.511	1.24^{ns}
Percent alive at 48 hours	β i.v.	1.07372		0.00173 dosage		-0.09824 Δt					.370	$.55^{ns}$
Hatching success	β i.v.	1.08675		-0.00211 dosage		0.10560 Δt					.493	1.13^{ns}
Time to 50% death	β i.v.	0.82031		-0.04742 Δt		0.00076 dosage					.367	$.55^{ns}$

+independent variables

TABLE D6d. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 5 LARVAE. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+	LARVAE V_1	+	V_2	+	V_3	+	V_4	MULTIPLE R	f
Percent alive at 1 hour	β i.v.+	0.94709		-0.05674 Δt		0.00058 dosage					.679	3.00^{ns}
Percent alive at 4 hours	β i.v.	0.41488		-0.02098 Δt							.531	3.14^{ns}
Percent alive at 8 hours	β i.v.	0.20254		-0.05128 Δt		0.00120 dosage					.451	0.89^{ns}
Time to 50% death	β i.v.	0.02067		-0.00246 Δt		0.00004 dosage					.540	1.44^{ns}

+independent variables

TABLE D6e. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 6 EGGS AND LARVAE. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
LARVAE								
Percent alive at 1 hour	β i.v.+	ALL INDEPENDENT VARIABLES BELOW TOLERANCE LEVEL OF .001						
Percent alive at 4 hours	β i.v.	1.44881	-0.00008 dosage				.238	0.48^{ns}
Percent alive at 8 hours	β i.v.	1.41092	-0.00022 dosage				.399	1.52^{ns}
Time to 50% death	β i.v.	0.53061	-0.00024 dosage				.551	3.48^{ns}
EGGS								
Percent alive at 8 hours	β i.v.	6.47440	-0.00035 dosage	-0.07147 ambient t			.657	6.46**
Percent alive at 24 hours	β i.v.	9.49915	-0.00042 dosage	-0.12763 age			.715	8.89*
Percent alive at 48 hours	β i.v.	-1.38004	-0.00099 dosage	0.01491 Δt	0.03831 ambient t		.775	8.02**
Hatching success	β i.v.	-135.57884	1.98632 ambient t	-0.00074 dosage	0.01837 Δt		.836	12.37***
Time to 50% death	β i.v.	-14.34571	-0.00082 dosage	0.02320 Δt	0.21913 ambient t		.633	3.57*

+independent variables

$^{*}p < .05$

$^{**}p < .01$

$^{***}p < .001$

TABLE D6f. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 7 EGGS AND LARVAE. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
LARVAE								
Percent alive at 1 hour	β i.v.+	14.55697	-0.21782 ambient t	-0.01310 Δt	0.00918 age	-0.00078 dosage	.536	2.52^{ns}
Percent alive at 4 hours	β i.v.	8.08804	0.01065 Δt	-0.12289 ambient t	-0.00150 dosage	0.00505 age	.630	4.11^{*}
Percent alive at 8 hours	β i.v.	8.87096	-0.00152 dosage	-0.14267 ambient t	0.00823 age	0.01690 Δt	.623	3.96^{*}
Time to 50% death	β i.v.	3.79976	-0.00068 dosage	-0.06471 ambient t	0.00496 age	0.01119 Δt	.522	2.34^{ns}
EGGS								
Percent alive at 8 hours	β i.v.	1.31978	0.00488 dosage	-0.12798 Δt			.672	2.47^{ns}
Percent alive at 24 hours	β i.v.	ALL INDEPENDENT VARIABLES BELOW TOLERANCE LEVEL OF .001						
Percent alive at 48 hours	β i.v.	1.10913	-0.12827 Δt	0.00469 dosage			.377	$.50^{ns}$
Hatching success	β i.v.	1.12008	-0.25410 Δt	0.00897 dosage			.790	4.97^{ns}
Time to 50% death	β i.v.	0.86352	-0.00517 dosage	0.13695 Δt			.611	1.79^{ns}

+independent variables

*$p < .05$

TABLE D6g. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 8 EGGS AND LARVAE. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
LARVAE								
Percent alive at 1 hour	β i.v.+	42.37368	-0.01717 age	-0.05085 Δt	-0.57289 ambient t	0.00099 dosage	.866	18.08***
Percent alive at 4 hours	β i.v.	57.62574	-0.01495 age	-0.03088 Δt	-0.80073 ambient t		.884	29.77***
Percent alive at 8 hours	β i.v.	43.03943	-0.01507 age	0.59279 ambient t	-0.00862 Δt	-0.00010 dosage	.947	52.21***
Time to 50% death	β i.v.	14.92415	-0.00405 age	-0.20824 ambient t	-0.00058 dosage	0.01150 Δt	.953	59.01***
EGGS								
Percent alive at 8 hours	β i.v.	29.69248	0.00171 Δt	-0.43245 ambient t	-0.00026 dosage		.489	1.67ns
Percent alive at 24 hours	β i.v.	28.75002	0.00246 Δt	-0.41884 ambient t	-0.00034 dosage		.428	1.10ns
Percent alive at 48 hours	β i.v.	-25.72382	-0.01532 Δt	0.40996 ambient t	0.00020 dosage		.514	1.91ns
Hatching success	β i.v.	23.25138	-0.34041 ambient t	-0.00277 dosage	0.08577 Δt		.521	1.99ns
Time to 50% death	β i.v.	-28.80435	-0.01659 Δt	0.45037 ambient t	0.00034 dosage		.490	1.69ns

+independent variables

***$p < .001$

TABLE D6h. RESULTS OF STEPWISE REGRESSIONS FOR BATCH 9 LARVAE.. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DEPENDENT VARIABLE	=	CONSTANT	+ V_1	+ V_2	+ V_3	+ V_4	MULTIPLE R	f
			LARVAE					
Percent alive at 1 hour	β i.v.+	1.9743	-0.00172 dosage	0.01332 Δt			.718	3.73^{ns}
Percent alive at 4 hours	β i.v.	0.94265	-0.00158 dosage	-0.01285 Δt			.789	5.780^{*}
Percent alive at 8 hours	β i.v.	0.87131	-0.00184 dosage	-0.00736 Δt			.869	10.80^{**}
Time to 50% death	β i.v.	0.13696	-0.00040 dosage	0.00103 Δt			.698	3.32^{ns}

+independent variable

*$p < .05$

TABLE D7a. RESULTS OF EGG LABORATORY BIOASSAY ANOVAS USING THE ARCSIN $\sqrt{P}$ TRANSFORMATION ON DEPENDENT VARIABLES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

		LEVELS OF SIGNIFICANCE		
BATCH	DEPENDENT* VARIABLE	DURATION (10,20,30 MINUTES)	TEXP** (°F)	DUR X TEXP INTERACTION
1	PA8	---	NS	---
	PA24	---	NS	---
	PA48	---	NS	---
	TD50	---	NS	---
2	PA8	0.01	0.01	0.01
	PA24	0.01	0.01	0.01
	PA48	0.01	0.05	NS
	TD50	0.01	0.01	0.01
3	PA8	0.05	NS	NS
	PA24	0.01	NS	NS
	PA48	0.01	NS	NS
	TD50	NS	NS	NS
4	PA8	---	NS	---
	PA24	---	NS	---
	PA48	---	NS	---
	TD50	---	NS	---
6	PA8	0.01	0.01	0.01
	PA24	0.01	0.01	0.01
	PA48	0.01	0.01	0.01
	TD50	0.05	0.01	0.01
7	PA8	---	NS	---
	PA24	---	NS	---
	PA48	---	NS	---
	TD50	---	NS	---
8	PA8	NS	NS	NS
	PA24	NS	NS	NS
	PA48	NS	0.05	NS
	TD50	NS	NS	NS

*PA n = Percent alive at n hours

**TEXP = Exposure Temperature (°F)

TD50 = Time to 50% mortality

TABLE D7b. RESULTS OF LARVAE LABORATORY BIOASSAY ANOVAS USING ARCSIN $\sqrt{P}$ TRANSFORMATION ON DEPENDENT VARIABLES. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

				LEVELS OF SIGNIFICANCE		
BATCH	EXPERIMENT	DURATION (MINUTES)	DEPENDENT* VARIABLE	DURATION	TEXP**	DUR X TEXP
3	5	10,20	PA1	NS	NS	.05
			PA4	NS	NS	NS
			PA8	NS	NS	NS
			TD50†	NS	NS	NS
3	6	10,20	PA1	.05	.05	NS
			PA4	NS	NS	NS
			PA8	NS	NS	NS
			TD50	NS	NS	NS
5	7	10	PA1	---	.05	---
			PA4	---	NS	---
			PA8	---	.05	---
			TD50	---	.01	---
6	8	20	PA1	---	NS	---
			PA4	---	NS	---
			PA8	---	NS	---
			TD50	---	.05	---
7	10,11,12	20	PA1	.05	.05	.05
			PA4	.01	.01	.01
			PA8	.05	.01	.01
			TD50†	NS	NS	NS
8	11,13,14	20	PA1	.01	.05	NS
			PA4	.01	.01	NS
			PA8	.01	NS	NS
			TD50	.01	NS	NS
9	14	20	PA1	---	NS	---
			PA4	---	NS	---
			PA8	---	.05	---
			TD50	---	NS	---

*PA n = Percent alive at n hours

TD50 = Time to 50% mortality

**TEXP = Exposure Temperature (°F)

TABLE D8. SIMPLE CORRELATION COEFFICIENTS FOR LARVAL BIOASSAYS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1976.

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
3	Proportion alive at 1 hour	-0.438	-0.001	-0.564	-0.148
	Proportion alive at 4 hours	-0.248	-0.062	-0.318	-0.313
	Proportion alive at 8 hours	-0.021	-0.182	-0.096	-0.264
	Time to 50% mortality	-0.335	-0.040	-0.442	-0.234
	Dose *				0.684
5	Proportion alive at 1 hour		-0.654		-0.676
	Proportion alive at 4 hours		-0.517		-0.531
	Proportion alive at 8 hours		-0.317		-0.370
	Time to 50% mortality		-0.486		-0.520
	Calculated dose				0.984
6	Proportion alive at 1 hour				
	Proportion alive at 4 hours		-0.238		-0.234
	Proportion alive at 8 hours		-0.399		-0.394

(Continued)

TABLE D8. (Continued)

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
6	Time to 50% mortality		-0.551		-0.549
	Calculated dose				0.999
7	Proportion alive at 1 hr	-0.387	-0.263	-0.291	-0.326
	Proportion alive at 4 hours	-0.312	-0.473	-0.258	-0.475
	Proportion alive at 8 hours	-0.308	-0.436	-0.215	-0.436
	Time to 50% mortality	-0.183	-0.332	-0.062	0.314
	Calculated dose*				0.929
8	Proportion alive at 1 hour	-0.285	-0.068	-0.800	-0.191
	Proportion alive at 4 hours	-0.372	-0.189	-0.745	-0.302
	Proportion alive at 8 hours	-0.364	0.037	-0.893	-0.084
	Time to 50% mortality	-0.426	-0.068	-0.841	-0.155
	Calculated dose				0.973
9	Proportion alive at 1 hour		-0.701		-0.505
	Proportion alive at 4 hours		-0.782		-0.715

(Continued)

TABLE D8. (Continued)

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
9	Proportion alive at 8 hours		-0.867		-0.763
	Time to 50% mortality		-0.696		-0.562
	Calculated Dose				0.840
All Larvae	Proportion alive at 1 hour	-0.230	-0.120	-0.402	-0.198
	Proportion alive at 4 hours	0.068	-0.183	-0.394	-0.239
	Proportion alive at 8 hours	0.194	-0.146	-0.384	-0.136
	Time to 50% Mortality	0.182	-0.123	-0.373	-0.092
	Calculated dose*				0.838

*Calculated dose = °F-min exposure above ambient temperature

TABLE D9. SIMPLE CORRELATION COEFFICIENTS FOR EGG BIOASSAYS. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATION, 1976.

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
2	Proportion alive at 8 hours		0.211	-0.317	0.236
	Proportion alive at 24 hours		0.314	-0.291	0.342
	Proportion alive at 48 hours		0.463	-0.143	0.481
	Hatching success		-0.077	-0.081	-0.071
	Time to 50% Mortality		0.436	-0.371	0.463
	Calculated dose*				0.985
3	Proportion alive at 8 hours	0.639	-0.278	0.639	-0.126
	Proportion alive at 24 hours	0.920	-0.208	0.920	0.112
	Proportion alive at 48 hours	0.588	0.048	0.588	0.523
	Hatching success	0.155	0.076	0.155	0.548
	Time to 50% Mortality	0.362	-0.176	0.362	0.415
	Calculated dose				0.412
4	Proportion alive at 8 hours		0.445		0.436
	Proportion alive at 24 hours		0.424		0.459

(Continued)

TABLE D9. (Continued)

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
4	Proportion alive at 48 hours		0.112		0.062
	Hatching success		-0.396		-0.352
	Time to 50% Mortality		-0.125		-0.171
	Calculated dose*				0.991
6	Proportion alive at 8 hours	-0.303	-0.651	-0.303	-0.554
	Proportion alive at 24 hours	-0.435	-0.680	-0.435	-0.534
	Proportion alive at 48 hours	-0.350	-0.757	-0.350	-0.600
	Hatching success	0.812	0.107	0.812	-0.142
	Time to 50% Mortality	-0.223	-0.520	-0.223	-0.335
	Calculated dose				0.892
7	Proportion alive at 8 hours		0.218		0.186
	Proportion alive at 24 hours		0.013		-0.024
	Proportion alive at 48 hours		-0.159		-0.176
	Hatching success		-0.598		-0.623
	Time to 50% Mortality		-0.088		-0.057
	Calculated dose				0.999

(Continued)

TABLE D9. (Continued)

BATCH	DEPENDENT VARIABLE	AMBIENT TEMPERATURE	CALCULATED DOSE	AGE	Δt
8	Proportion alive at 8 hours	-0.151	-0.388	0.151	-0.432
	Proportion alive at 24 hours	-0.057	-0.380	0.057	-0.395
	Proportion alive at 48 hours	0.157	-0.461	-0.157	-0.483
	Hatching success	-0.369	0.221	-0.369	-0.010
	Time to 50% Mortality	0.135	-0.372	-0.135	-0.425
	Calculated dose*				0.913
All Egg Batches	Proportion alive at 8 hours	-0.035	-0.249	0.108	-0.223
	Proportion alive at 24 hours	-0.010	-0.239	0.208	-0.156
	Proportion alive at 48 hours	-0.247	-0.159	0.134	-0.101
	Hatching success	0.071	-0.062	0.039	-0.038
	Time to 50% Mortality	-0.417	-0.142	-0.219	-0.059
	Calculated dose				0.616

*Calculated dose = °F-min exposure above ambient temperature

APPENDIX TABLE D10. DRIFT BIOASSAY EXPERIMENTS CONDUCTED DURING 1975-1976. MERRIMACK RIVER ANADROMOUS FISHERIES INVESTIGATIONS, 1976.

DRIFT	DATE	BATCH	AGE*	STATION	AMBIENT t (°F)	MAXIMUM t (°F)	Δt (°F)	CALCULATED DOSE Δ°F-MIN	DRIFT TIME (MINS)
1	06-04-75	1	36	N-10	65	80	15	0.0	67
				S-4	65	80	15	182.5	18
				S-17	65	80	15	313.0	67
2	06-96-75	2	40	N-10	63	75	12	0.0	48
				S-4	63	75	12	69.5	14
				S-17	63	75	12	97.0	48
3	06-09-75	3	88	S-4	59	73	14	104.0	12
				S-17	59	73	14	186.5	38
4	06-02-76	4	86	N-10	64	81	16	0.0	114
				S-4	64	81	16	178.0	28
				S-17	64	81	16	361.0	114
5	06-04-76	4	136	N-10	65	70	15	0.0	112
				S-4	65	70	15	184.0	77
		5	86	N-10	65	70	15	0.0	112
				S-4	65	70	15	184.0	77
				S-17	65	70	15	246.0	112
		6	14	N-10	65	70	15	0.0	112
				S-4	65	70	15	184.0	77
				S-17	65	70	15	246.0	112

(Continued)

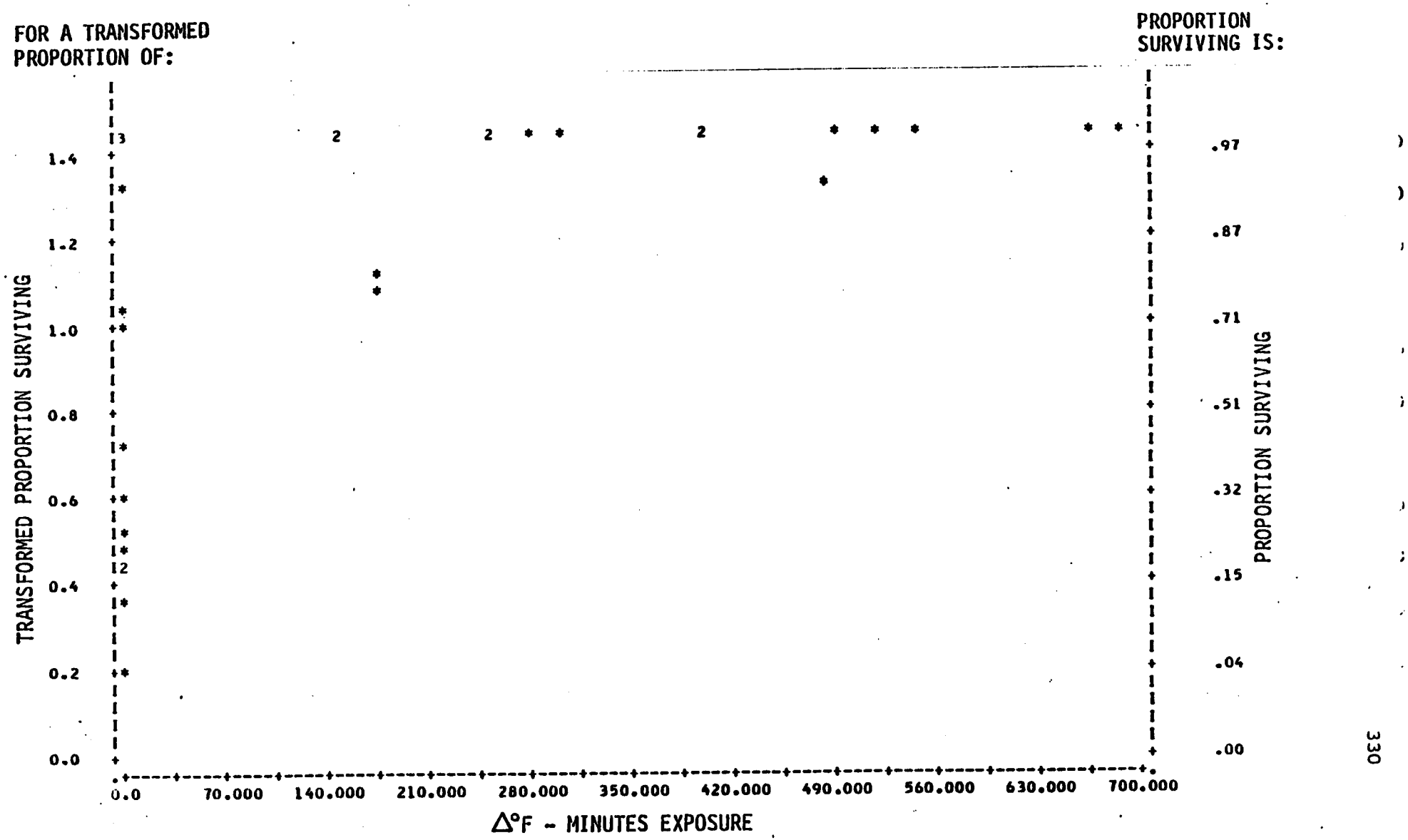
APPENDIX TABLE D10. (Continued)

DRIFT	DATE	BATCH	AGE*	STATION	AMBIENT t (°F)	MAXIMUM t (°F)	Δt (°F)	CALCULATED DOSE Δ°F-MIN	DRIFT TIME (MINS)
6	06-09-76	6	135	N-10	69	75	6	0.0	130
				S-4	69	75	6	144.7	52
				S-17	69	75	6	441.7	130
		7	39	N-10	69	75	6	0.0	130
				S-4	69	75	6	144.7	52
				S-17	69	75	6	441.7	130
7	06-17-76	8	61	N-10	75	89	14	0.0	131
				S-4	75	89	14	420.0	34
				S-17	75	89	14	1444.5	131
		9	13	N-10	75	89	14	0.0	131
				S-4	75	89	14	420.0	34
				S-17	75	89	14	1444.5	131

*hr since fertilization

Figure D-1. Batch 2 egg survivorship vs. thermal exposure

a) PA 8 vs. calculated dose (Δ°F-min)
b) PA 24 " " " "
c) PA 48 " " " "
d) PA 8 vs. maximum exposure temperature (°F)
e) PA 24 " " " " "
f) PA 48 " " " " "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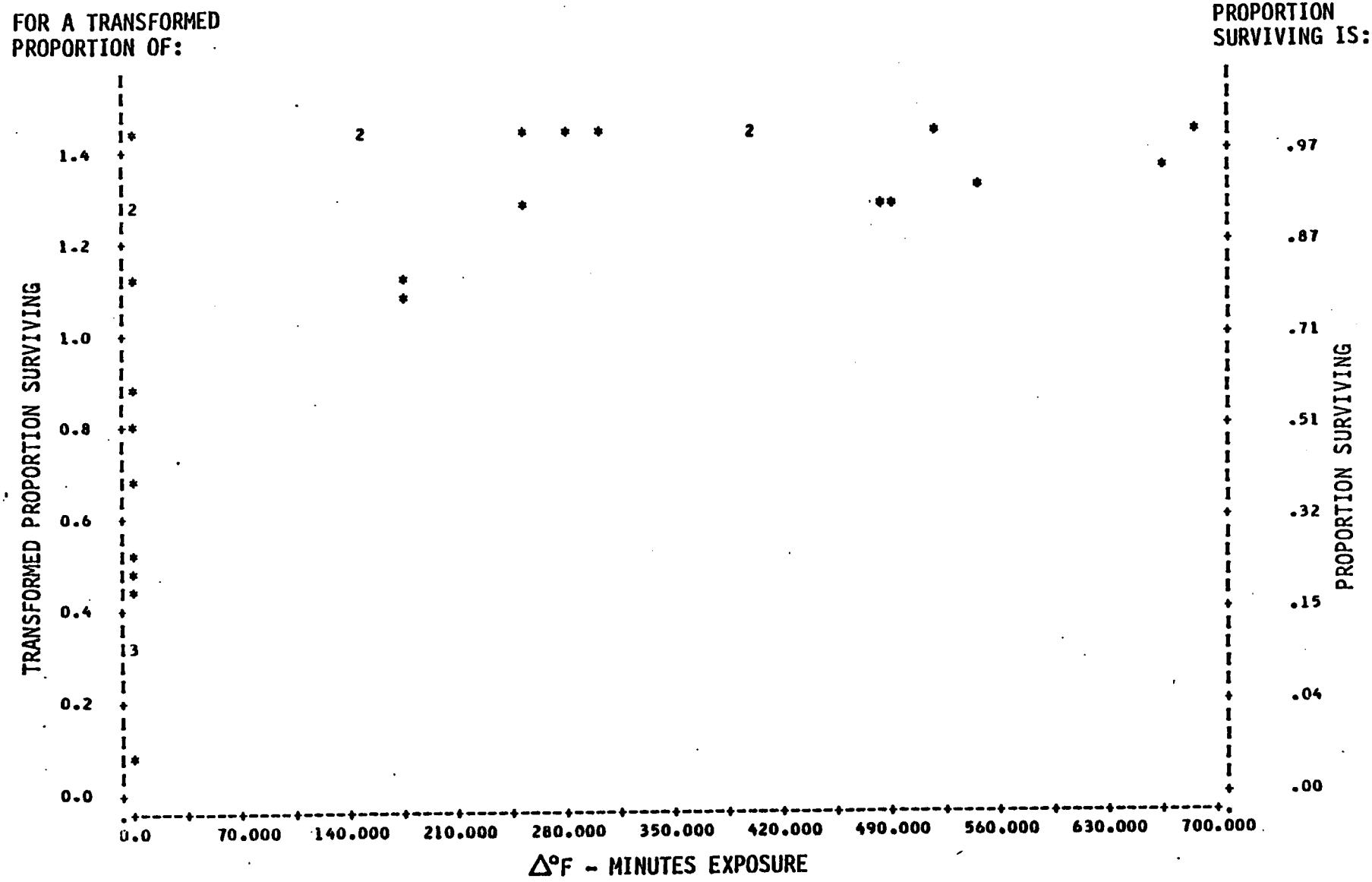
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
70.000
140.000
210.000
280.000
350.000
420.000
490.000
560.000
630.000
700.000
ΔºF - MINUTES EXPOSURE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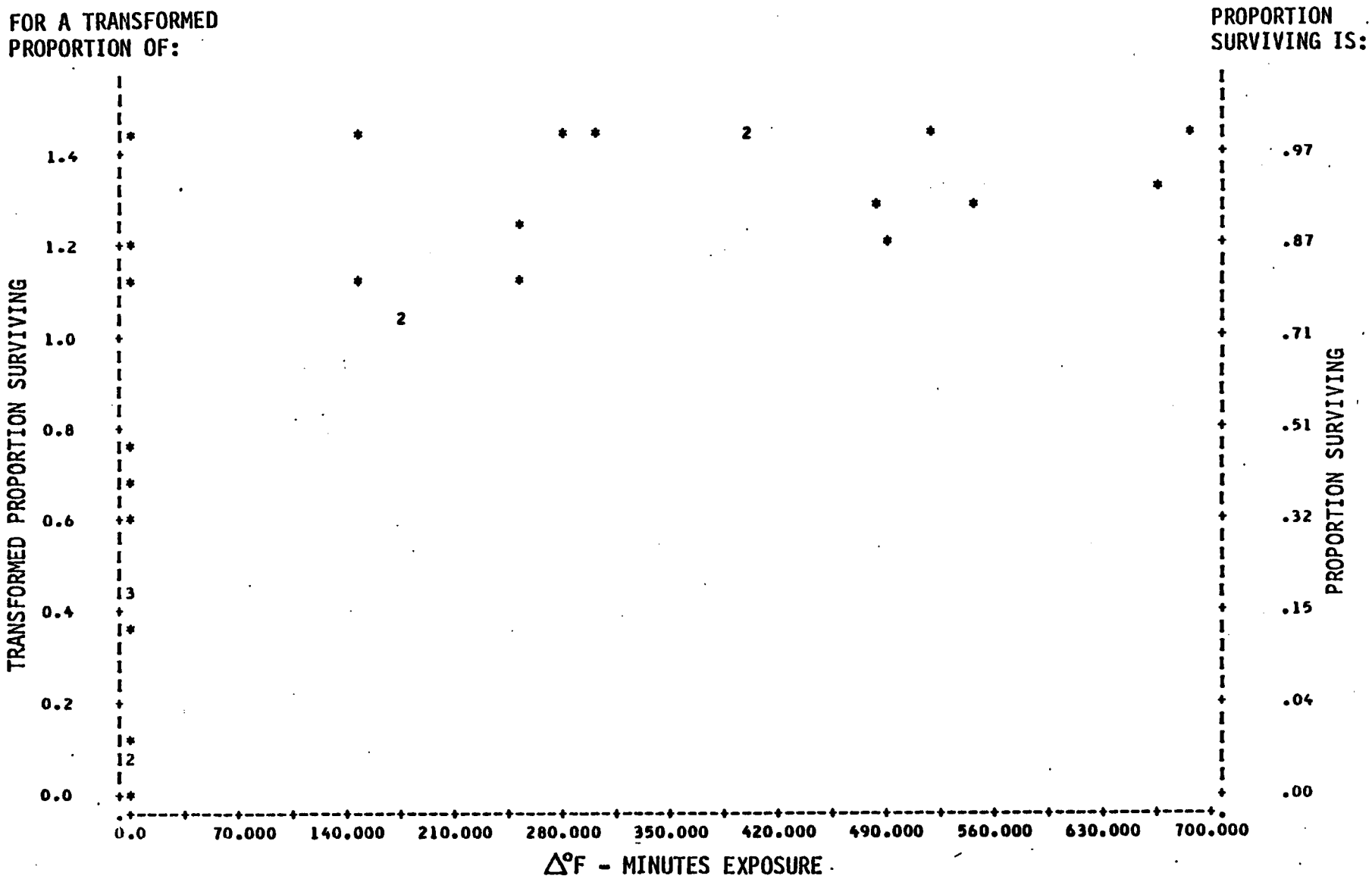
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
70.000
140.000
210.000
280.000
350.000
420.000
490.000
560.000
630.000
700.000
ΔºF - MINUTES EXPOSURE

Figure D.1b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0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
70.000
140.000
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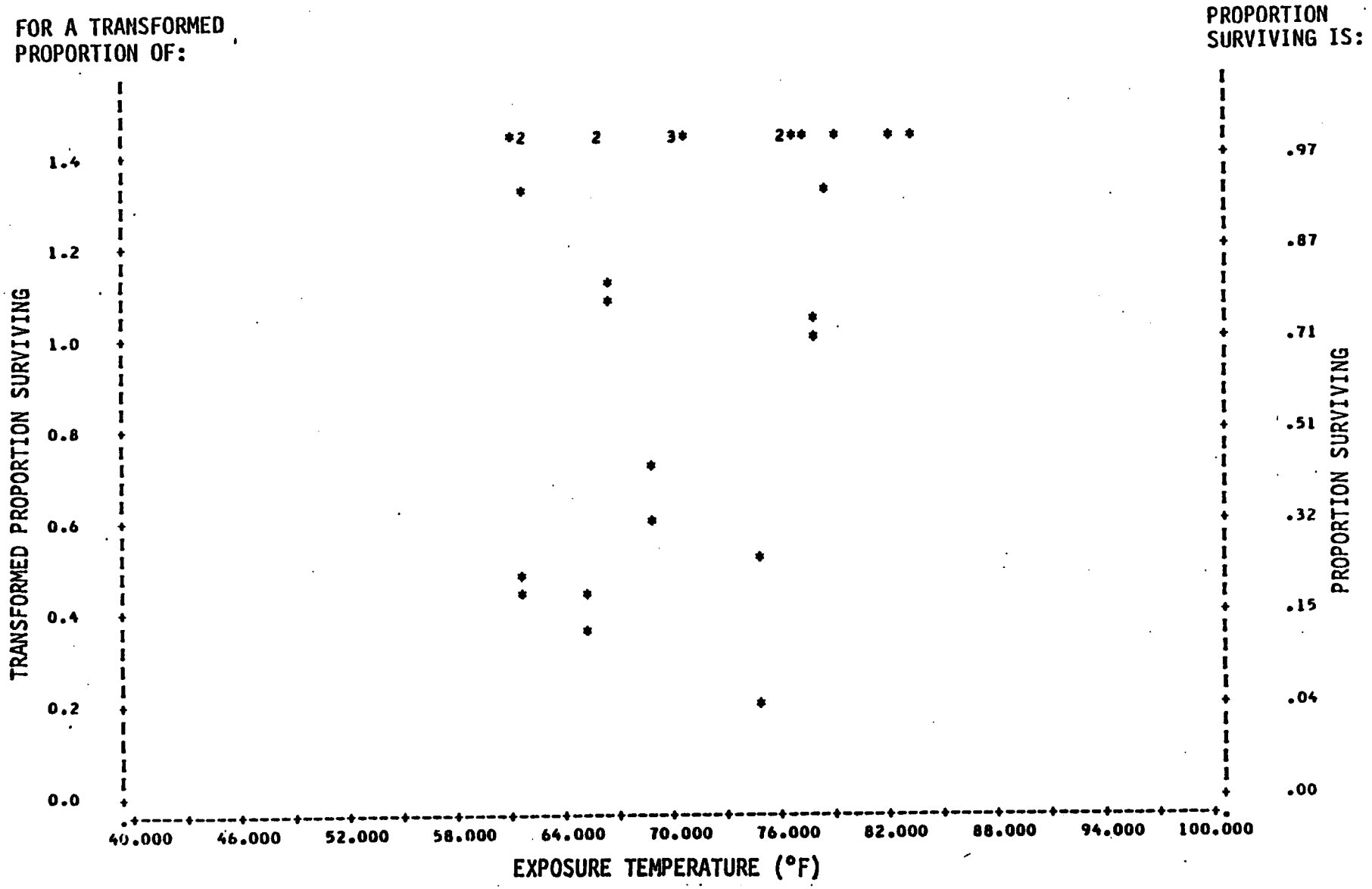
280.000
350.000
420.000
490.000
560.000
630.000
700.000
Δ°F - MINUTES EXPOSURE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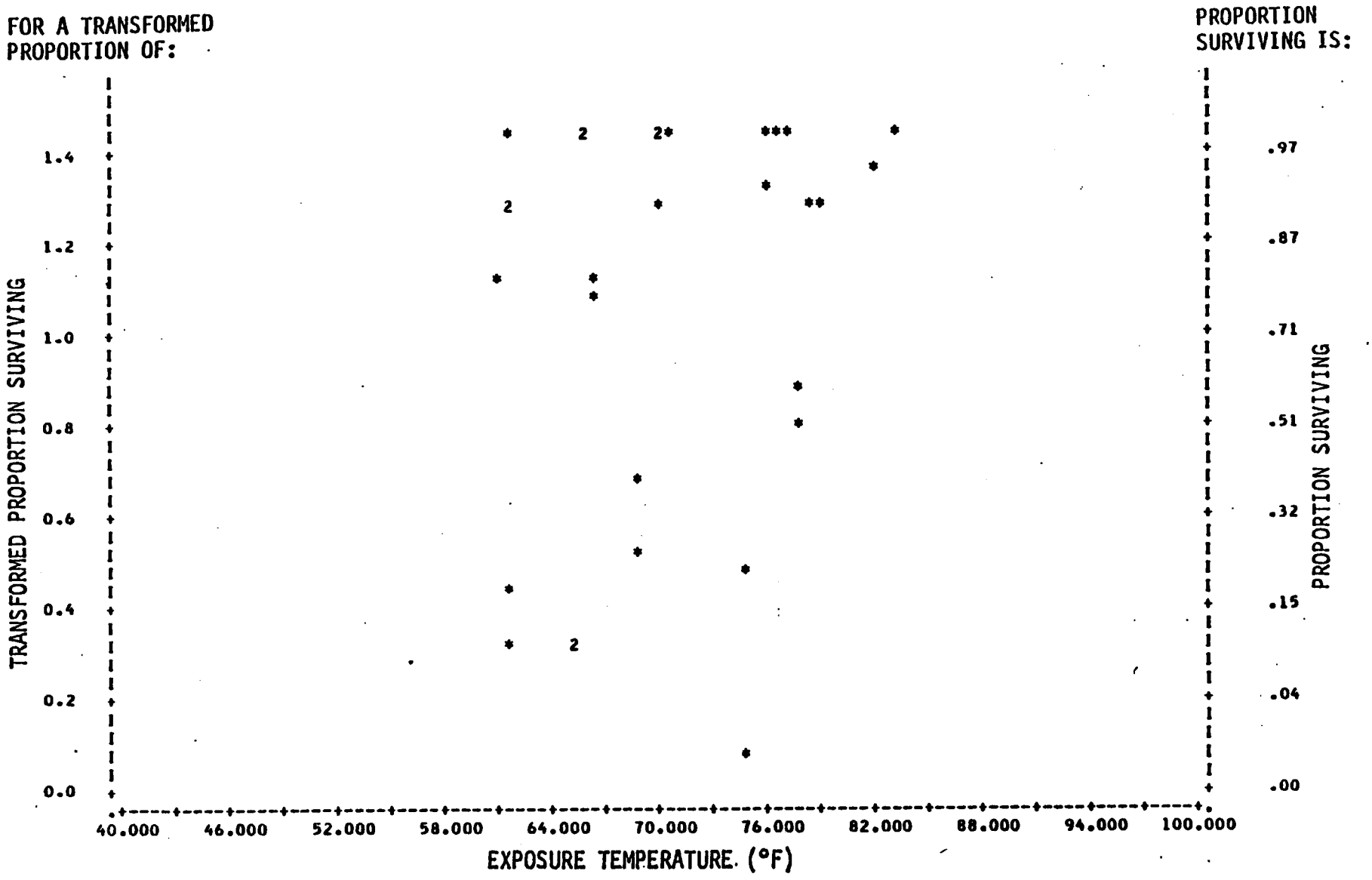
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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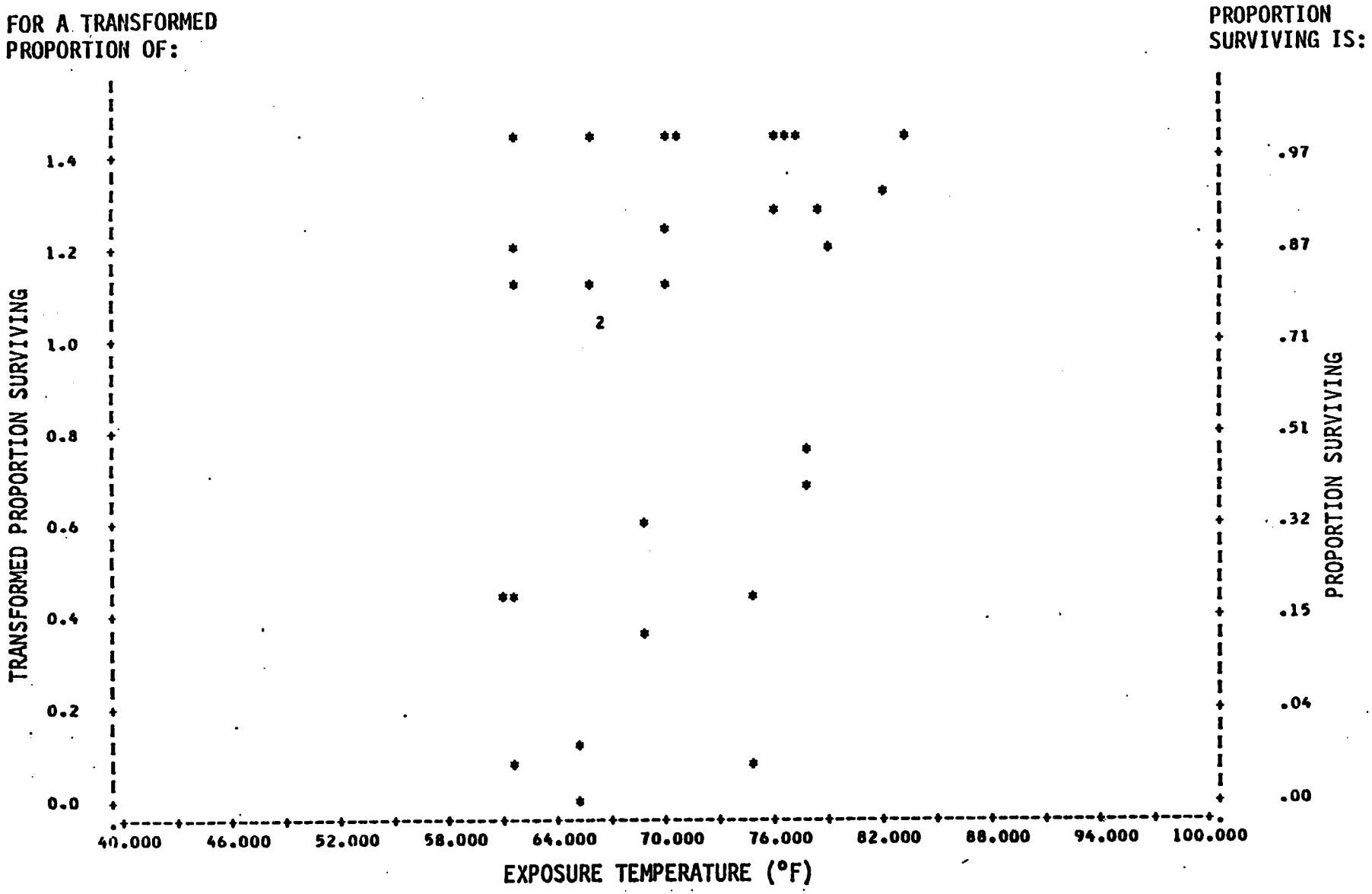
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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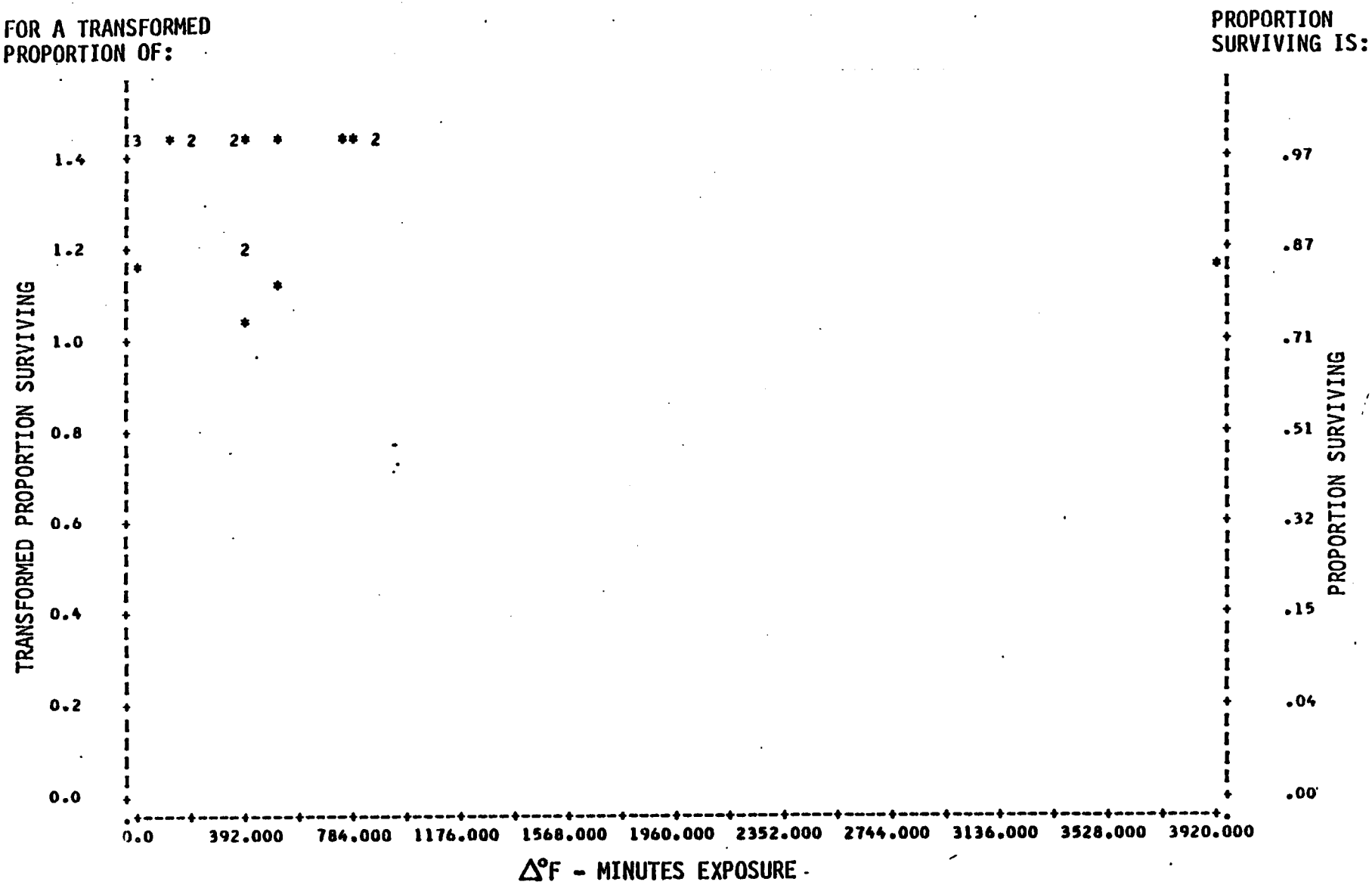
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-2 Batch 3 egg survivorship vs. thermal exposure

a) PA 8 vs. calculated dose (Δ°F-min)
b) PA 24 " " "
c) PA 43 " " "
d) PA 8 vs. maximum exposure temperature (°F)
e) PA 24 " " " "
f) PA 48 " " " "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1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
392.000
784.000
1176.000
1568.000
1960.000
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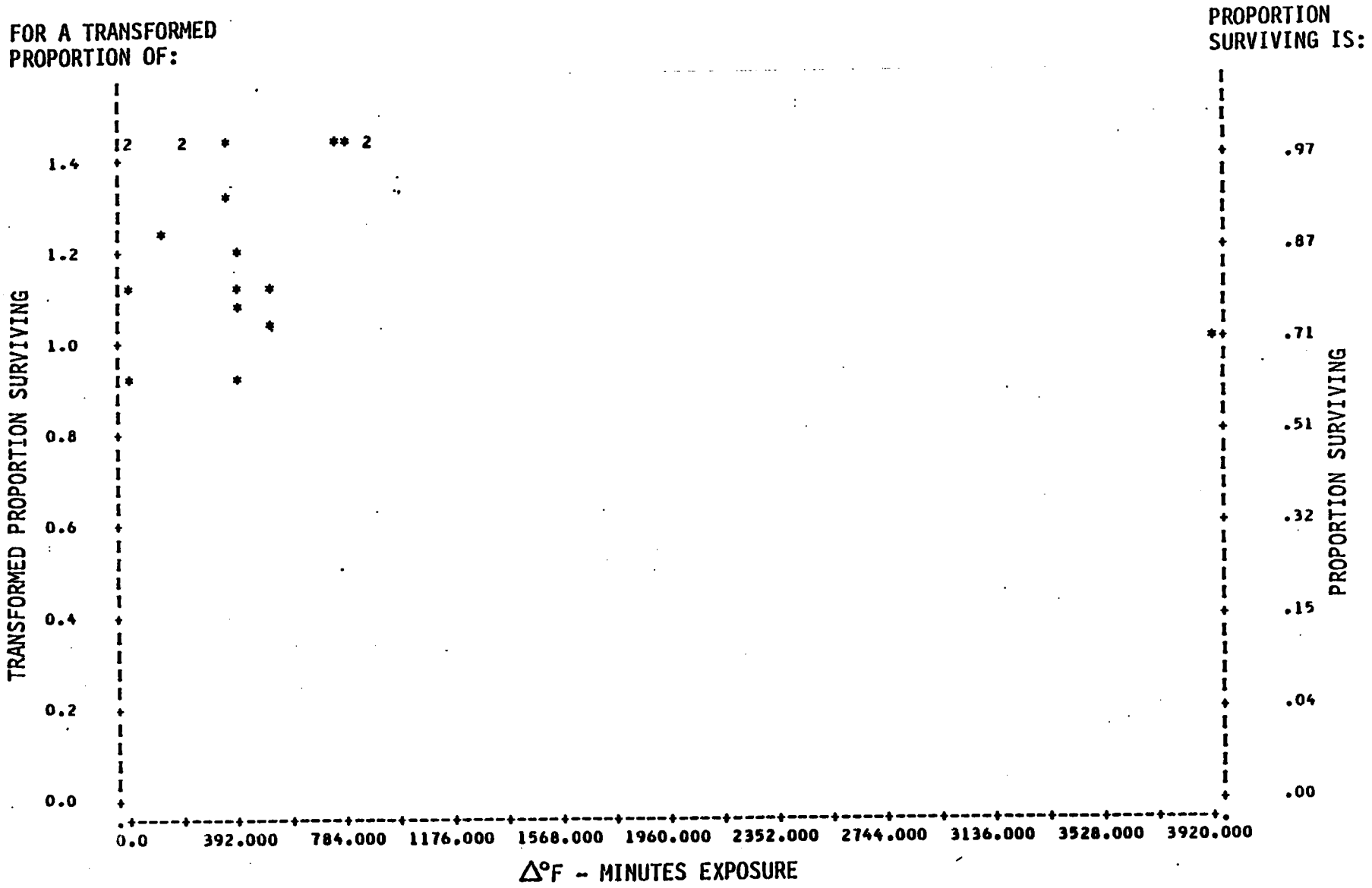
2744.000
3136.000
3528.000
3920.000
Δ°F - MINUTES EXPOSURE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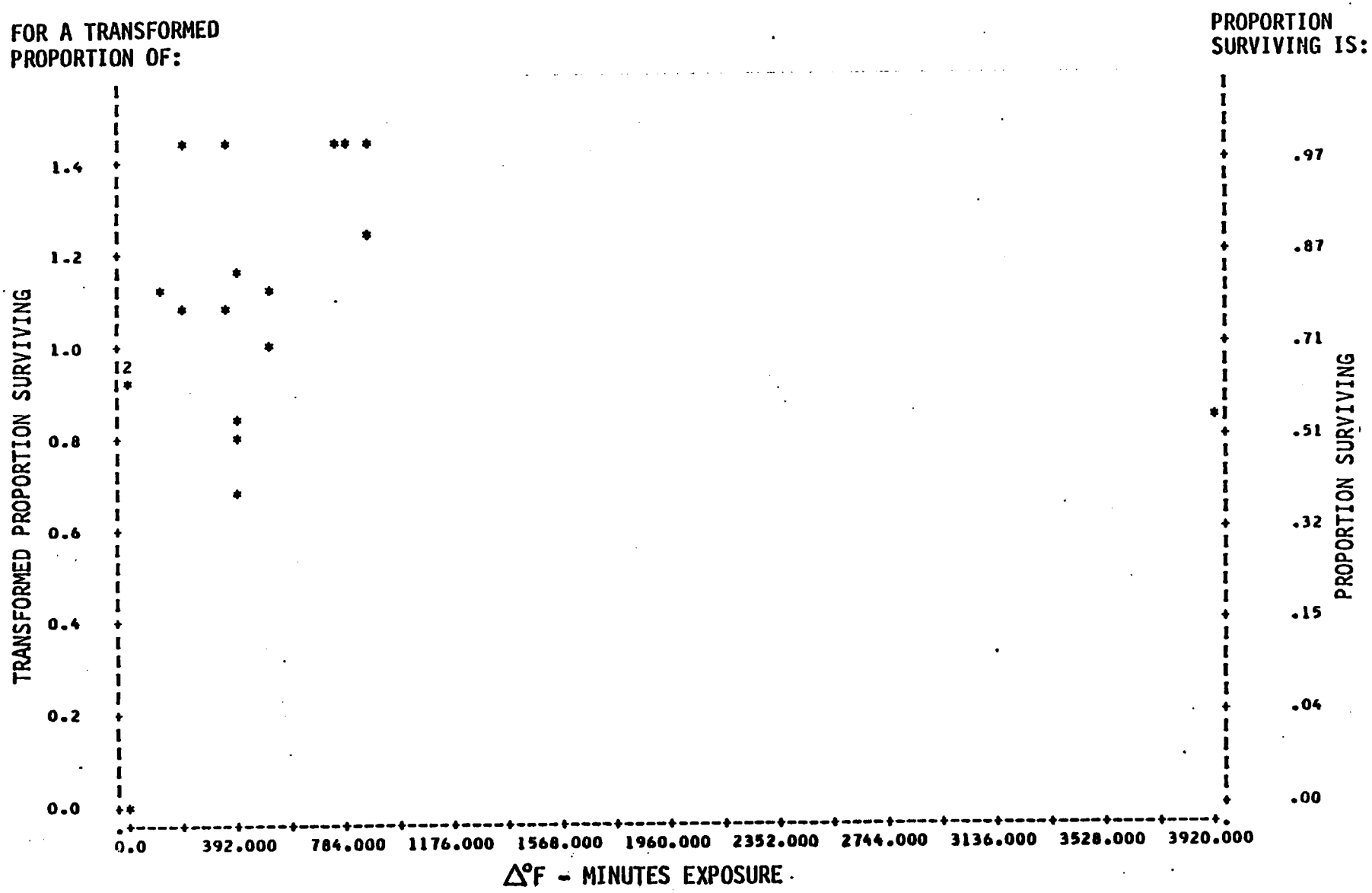
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
392.000
784.000
1176.000
1568.000
1960.000
2352.000
2744.000
3136.000
3528.000
3920.000
ΔºF - MINUTES EXPOSURE

Figure D-2b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1.0
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0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2
0.0
392.000
784.000
1176.000
1568.000
1960.000
2352.000
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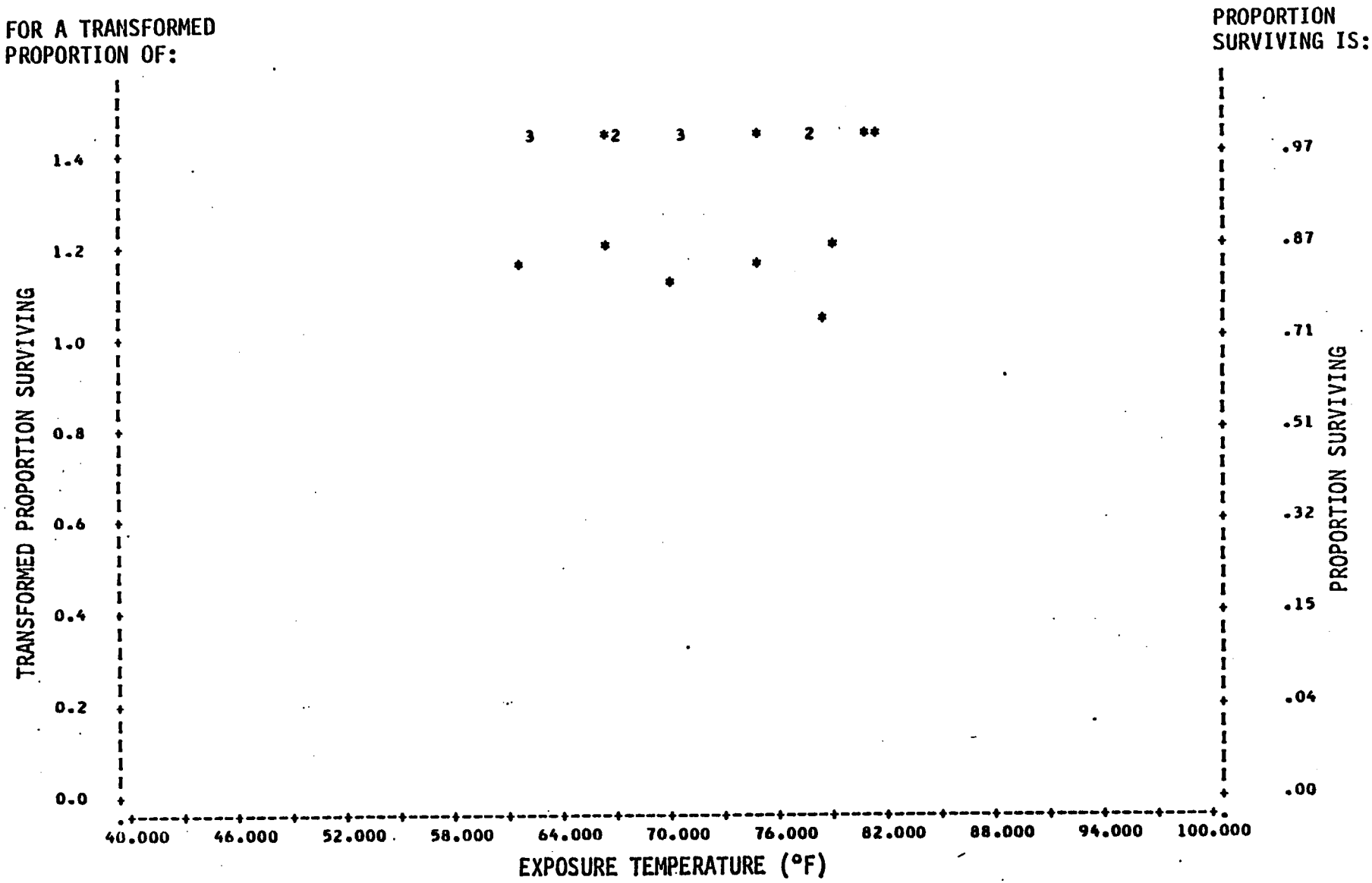
3136.000
3528.000
3920.000
ΔºF - MINUTES EXPOSURE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0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
3 *2 3 * 2 **
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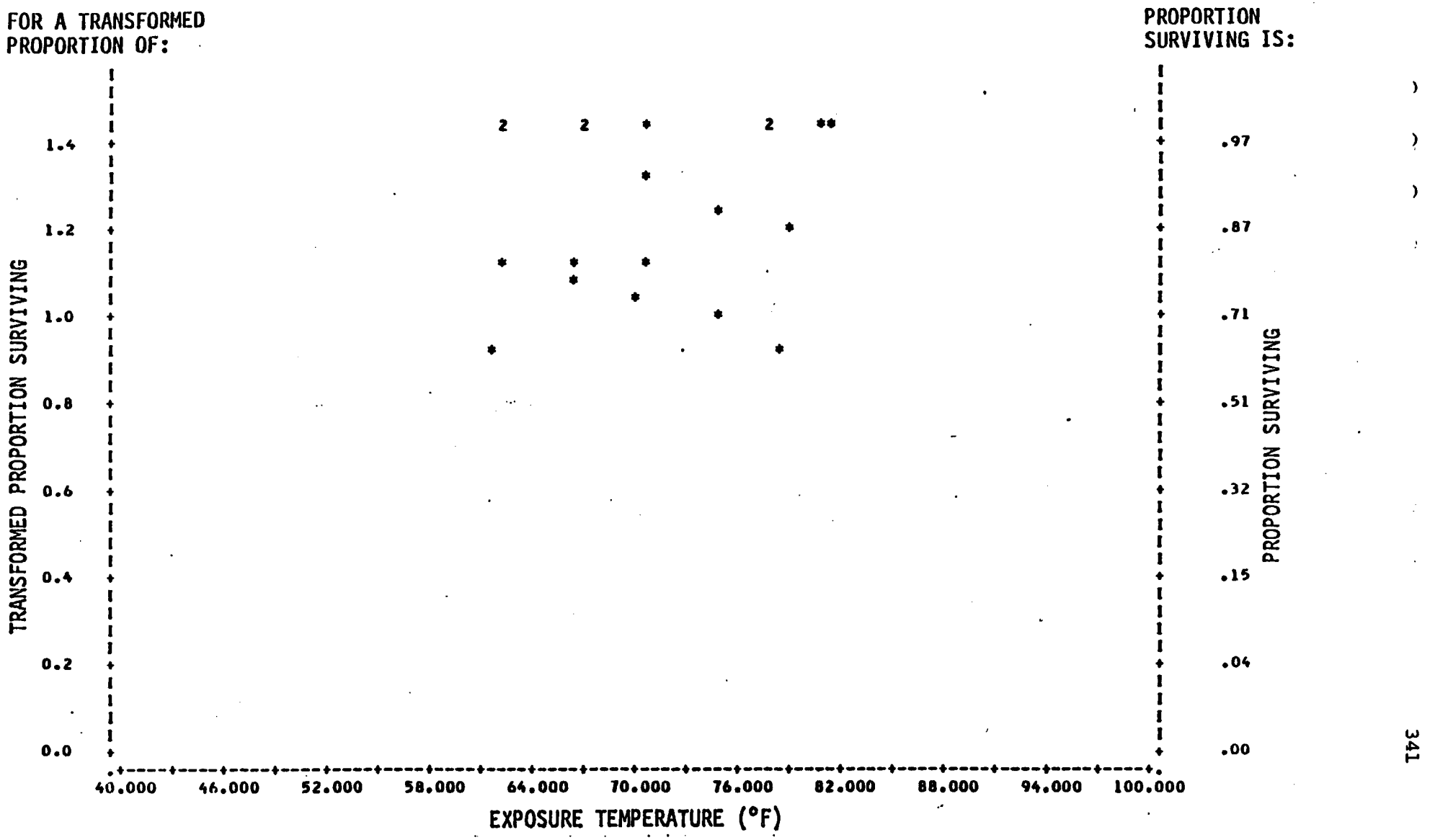
EXPOSURE TEMPERATURE (°F)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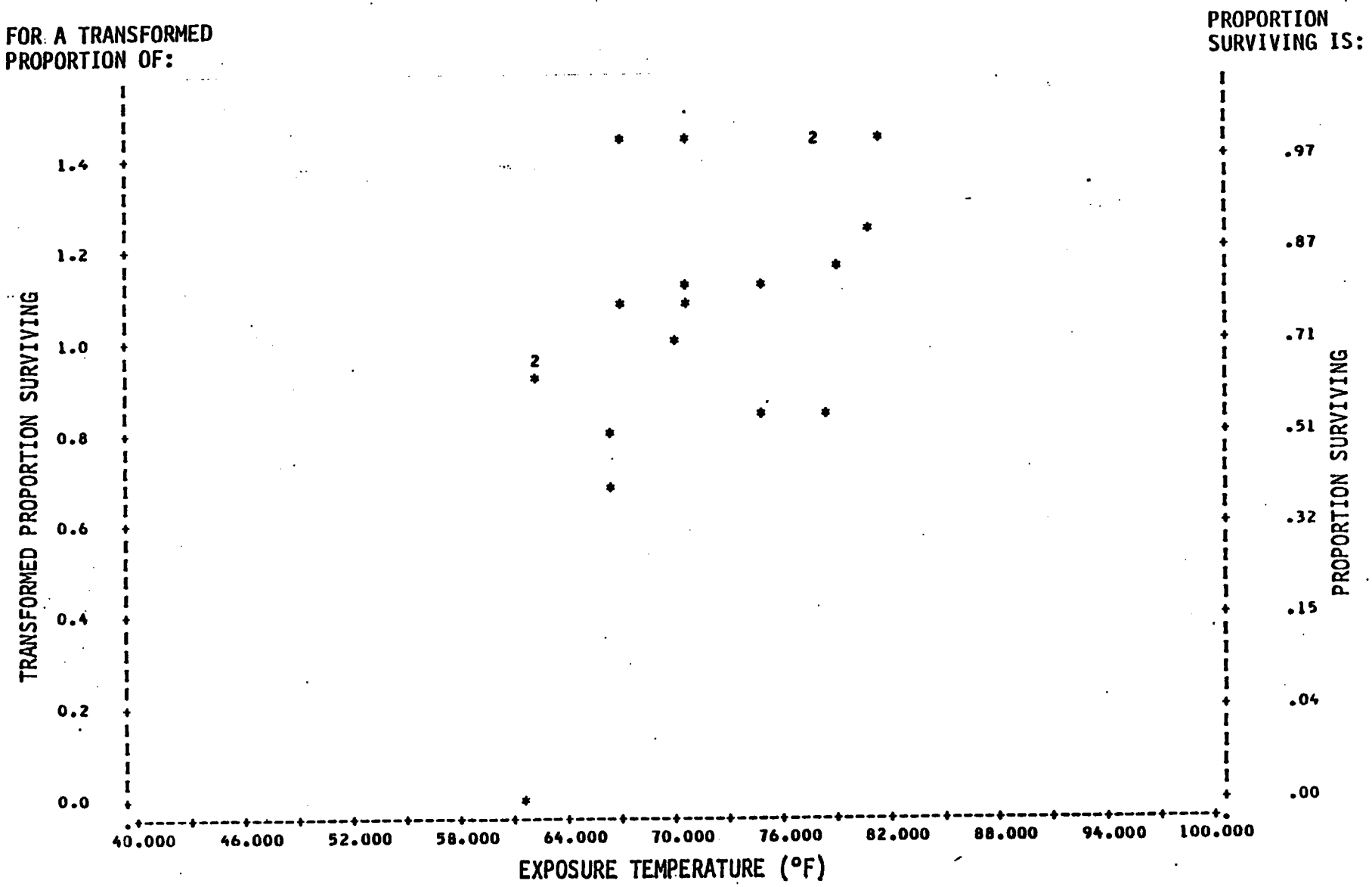
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D.2e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0.4
0.2
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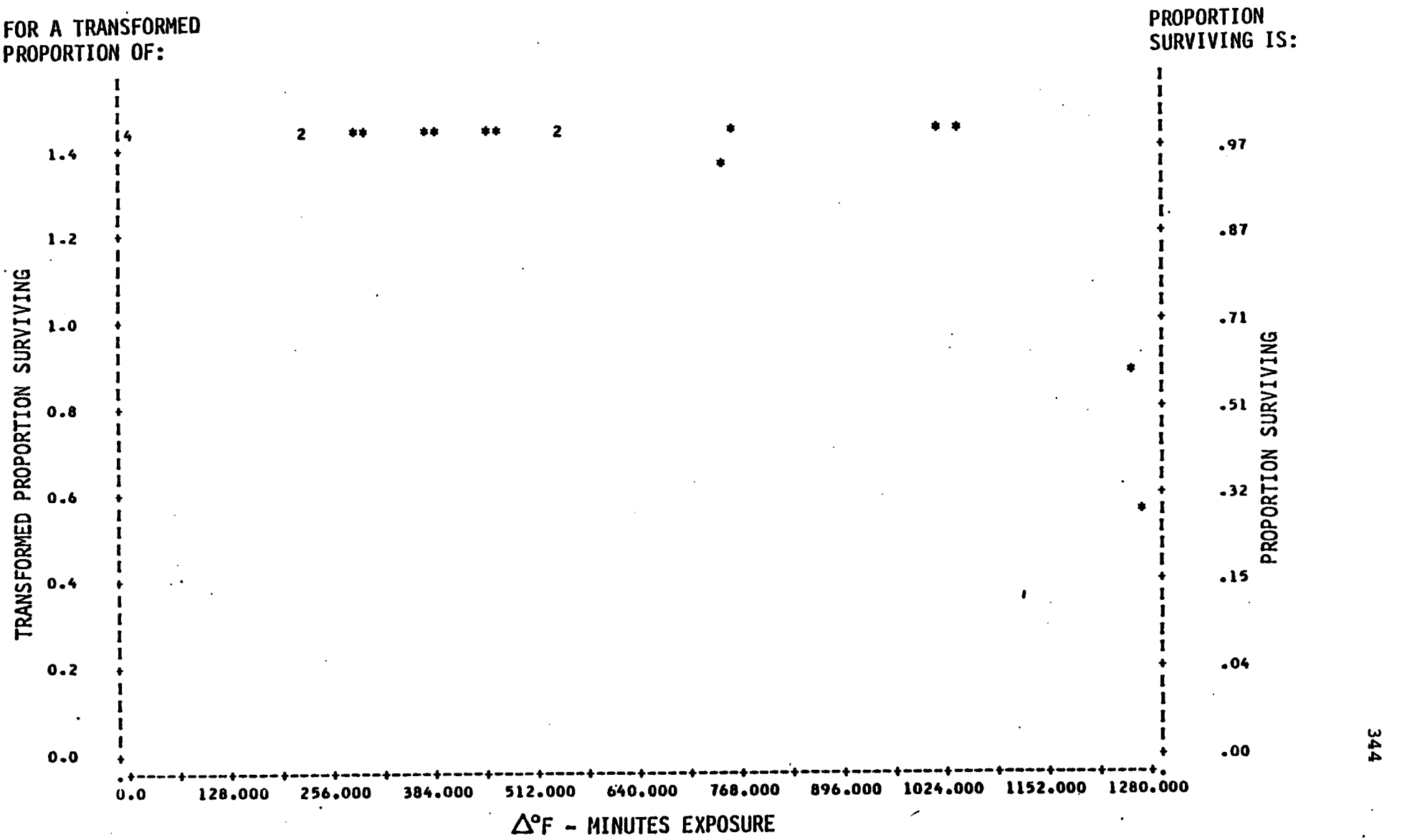
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

FIGURE D-3 Batch 6 egg survivorship vs. thermal exposure

a) PA8 vs. calculated dose (Δ°F-min)
b) PA24 " " "
c) PA43 " " "
d) PA 8 vs. maximum exposure temperature (°F)
e) PA24 " " " " "
f) PA48 " " " " "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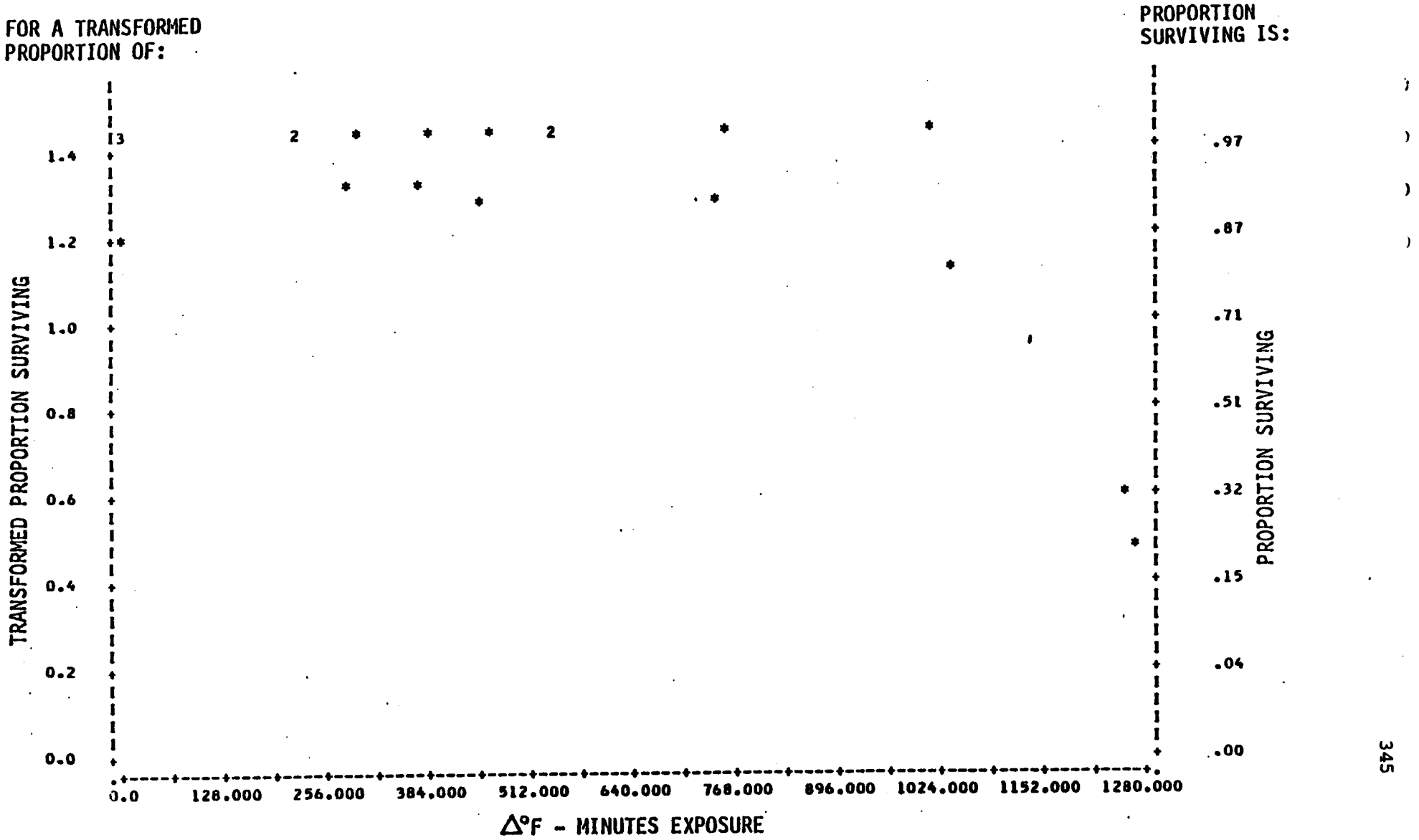
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
128.000
256.000
384.000
512.000
640.000
768.000
896.000
1024.000
1152.000
1280.000
ΔºF - MINUTES EXPOSURE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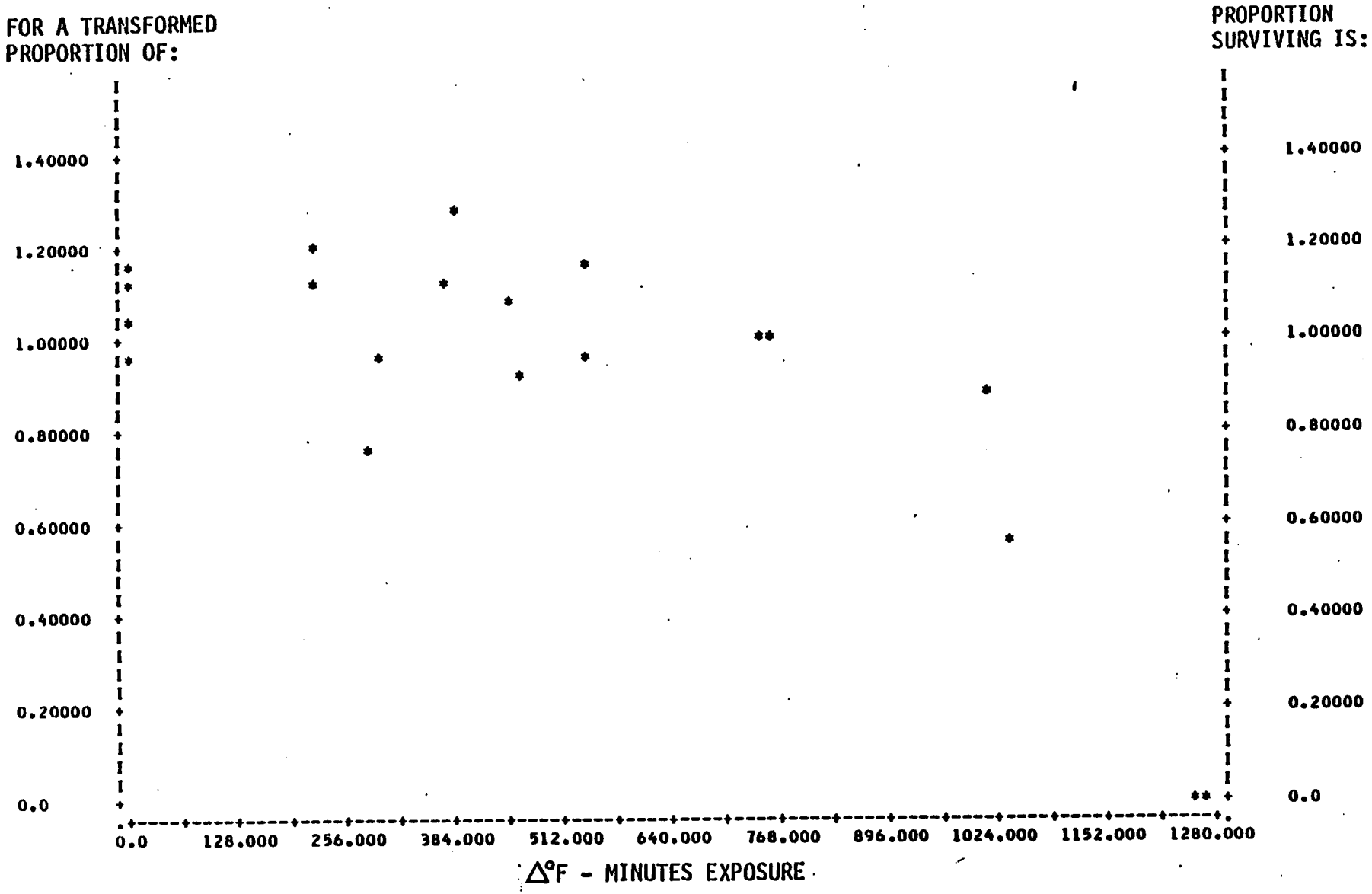
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
128.000
256.000
384.000
512.000
640.000
768.000
896.000
1024.000
1152.000
1280.000
Δ°F - MINUTES EXPOSURE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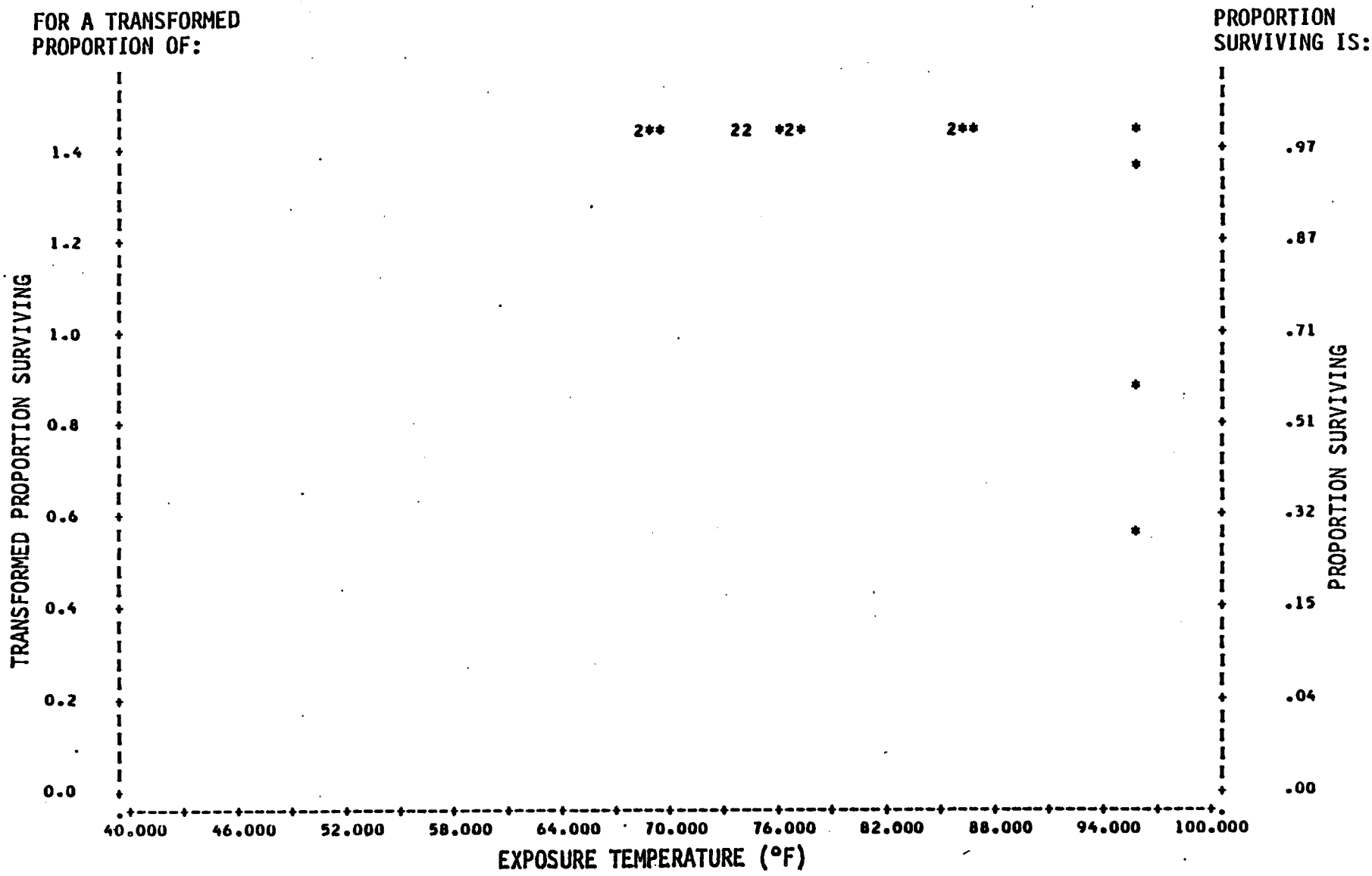
ΔºF - MINUTES EXPOSURE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0.4
0.2
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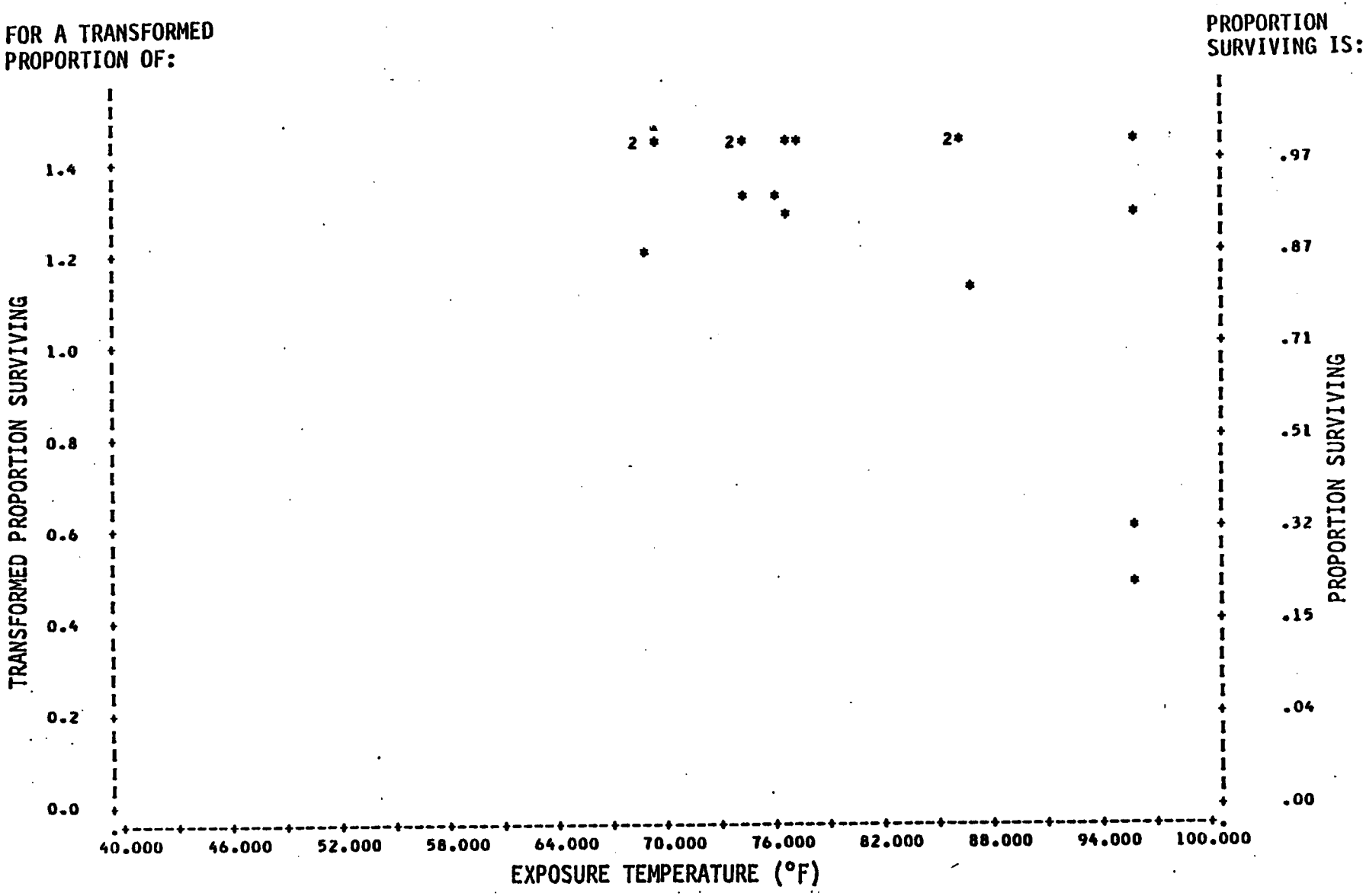
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2**
22
2
2**
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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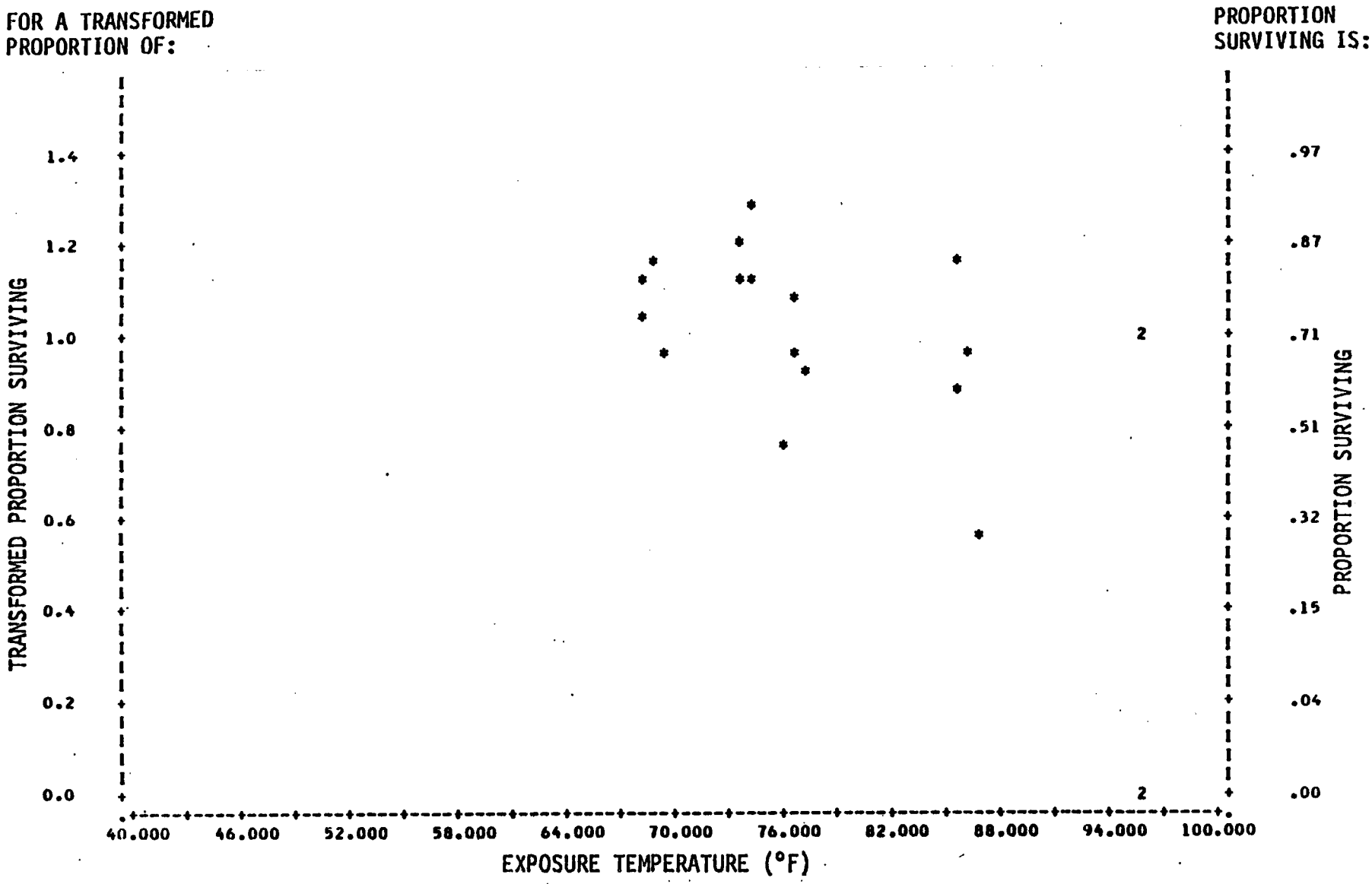
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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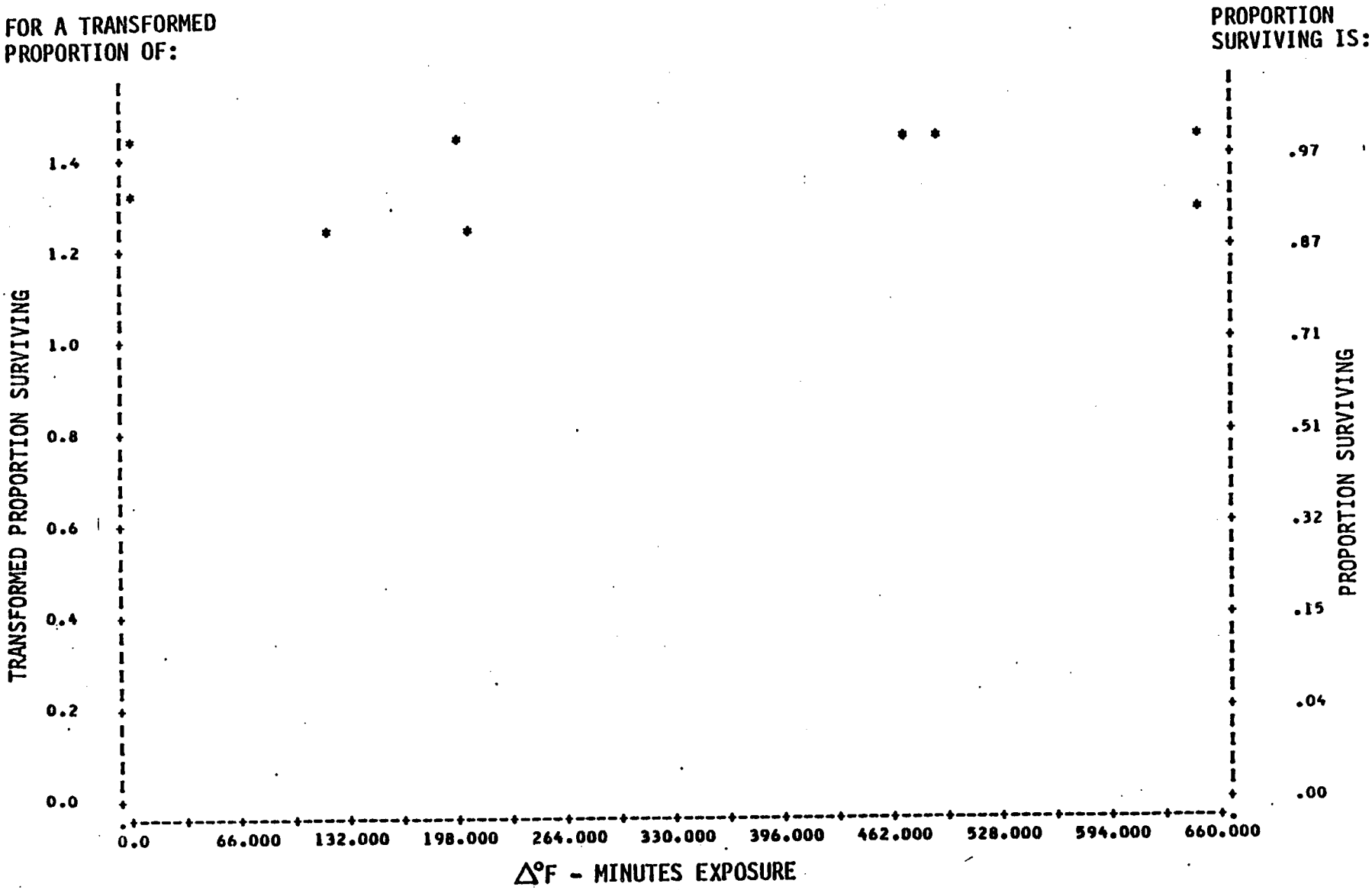
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2
2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-3f

Figure D-4 Batch 7 egg survivorship vs. thermal exposure

a) PA8 vs. calculated dose (Δ°F-min)
b) PA24 " " " "
c) PA43 " " " "
d) PA8 vs. maximum exposure temperature (°F)
e) PA 24 " " " " "
f) PA 48 " " " " "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PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
66.000
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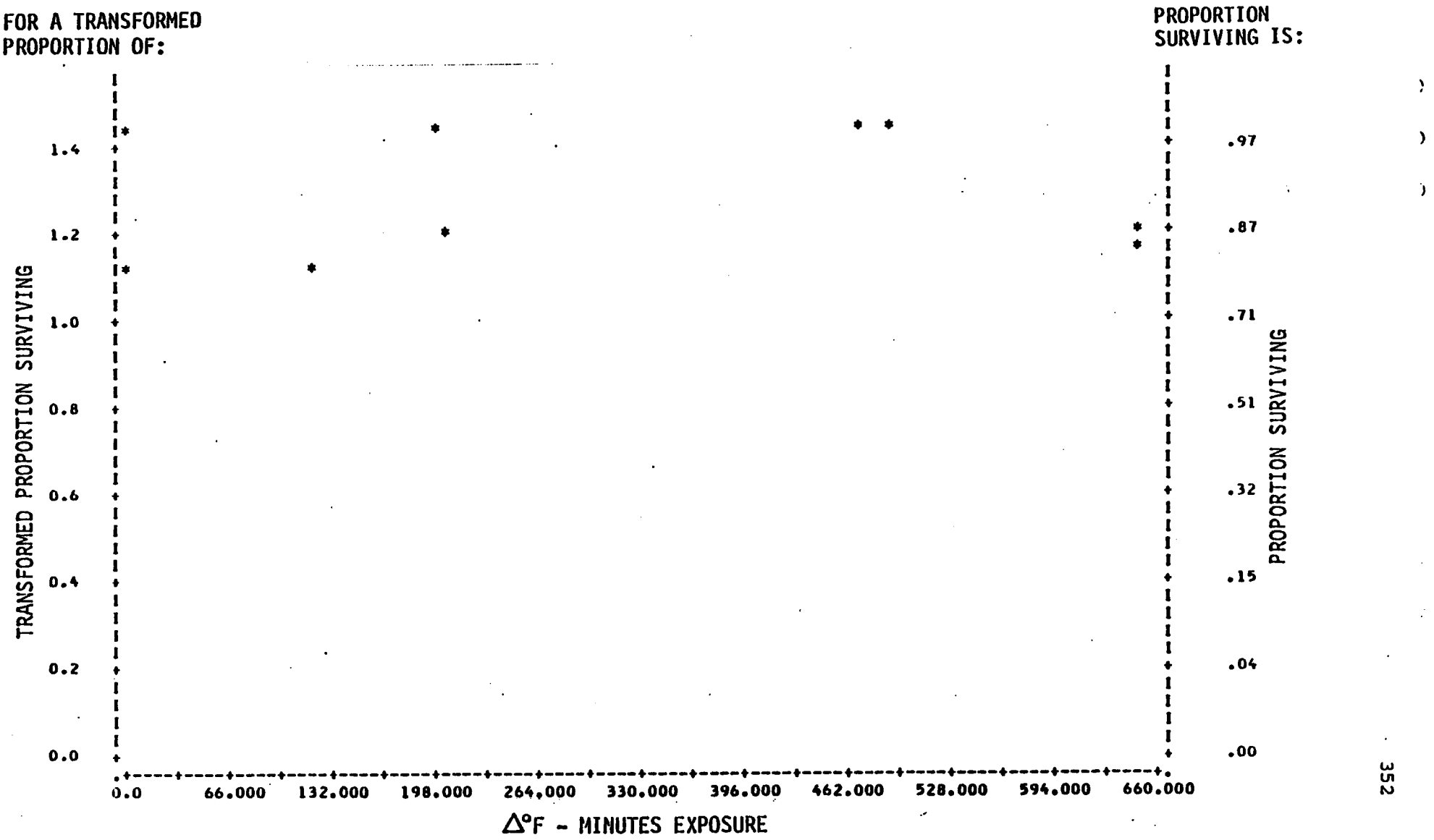
264.000
330.000
396.000
462.000
528.000
594.000
660.000
ΔºF - MINUTES EXPOSURE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0.4
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.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
66.000
132.000
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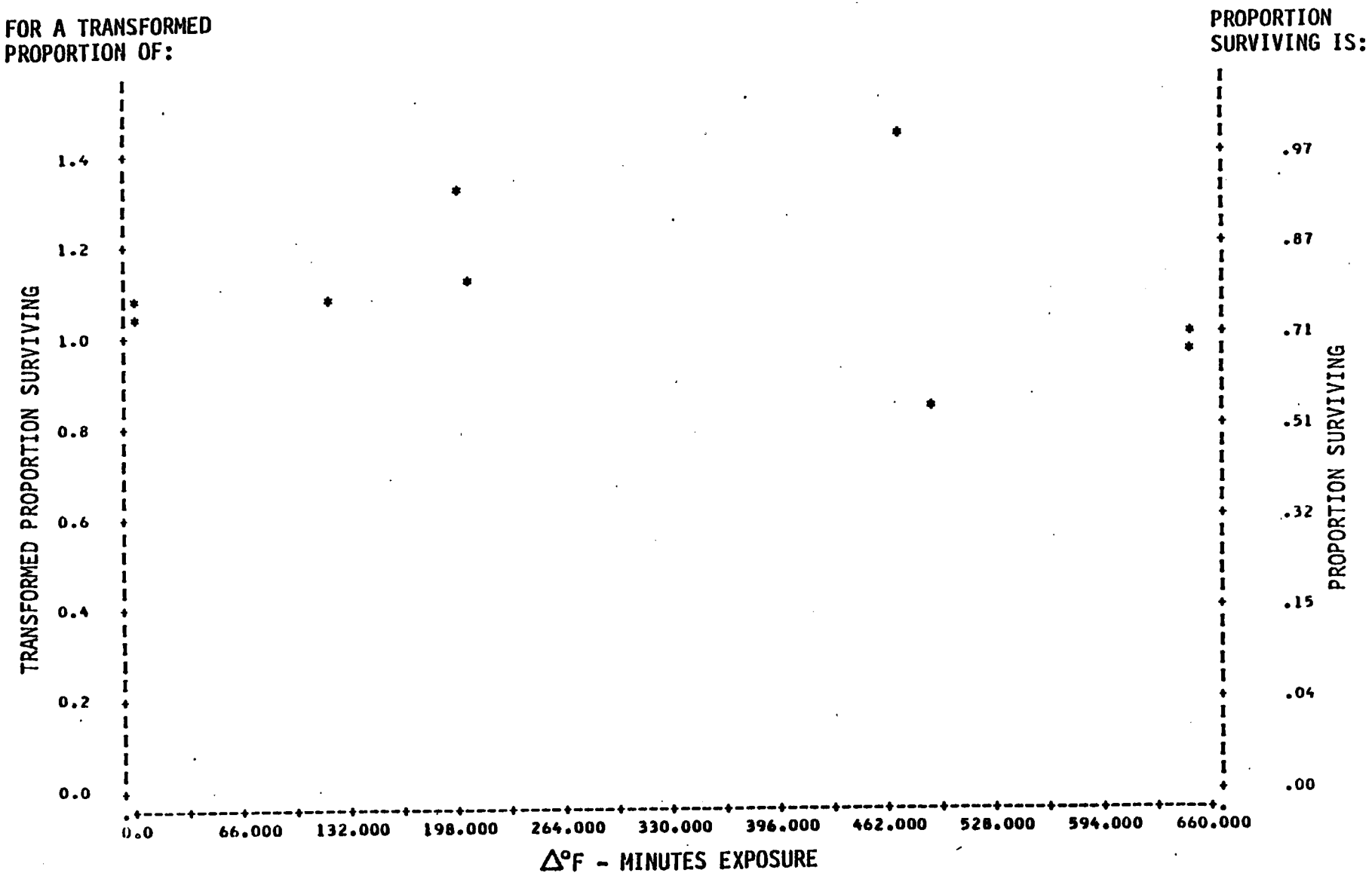
264.000
330.000
396.000
462.000
528.000
594.000
660.000
ΔºF - MINUTES EXPOSURE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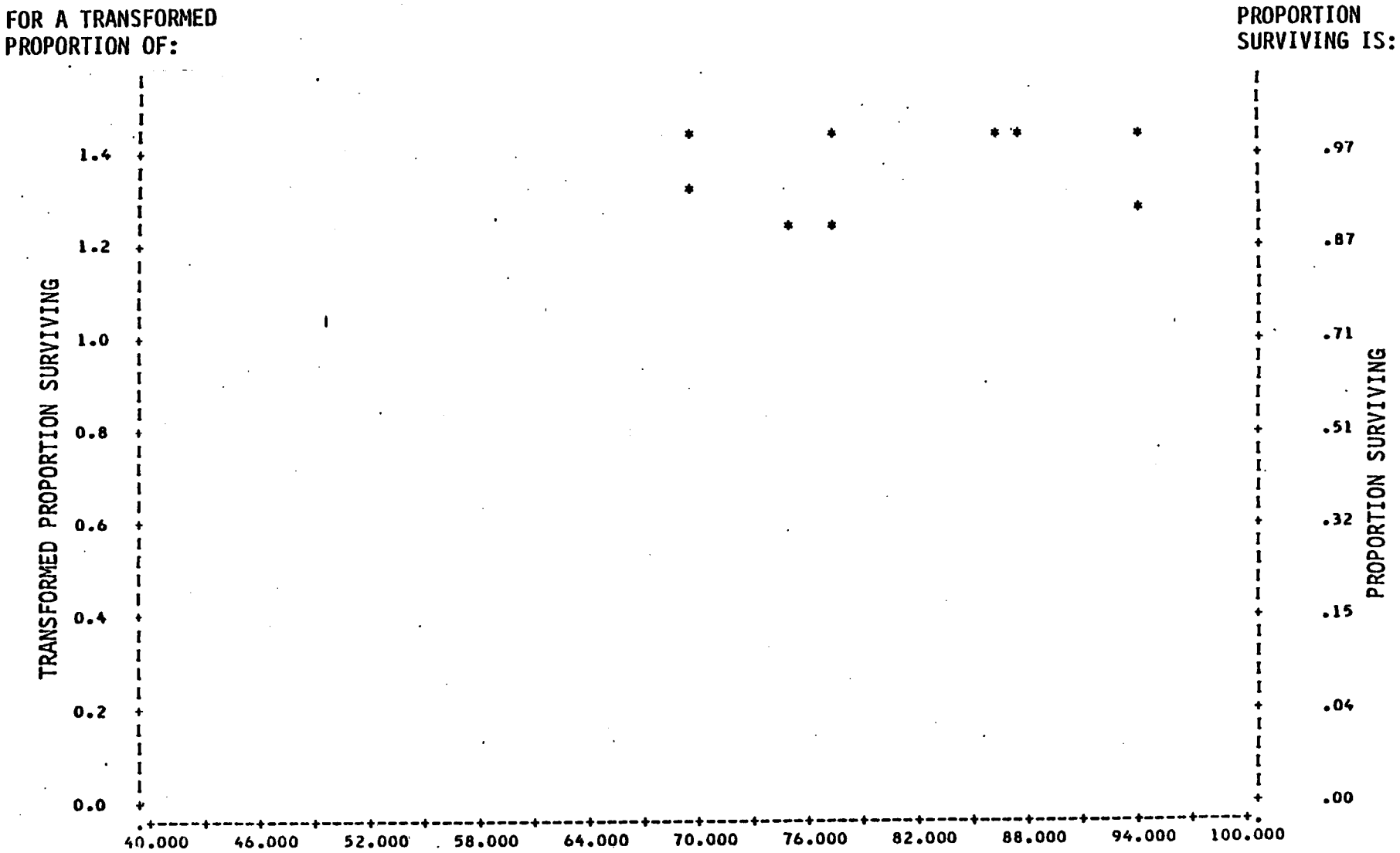
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
66.000
132.000
198.000
264.000
330.000
396.000
462.000
528.000
594.000
660.000
Δ°F - MINUTES EXPOSURE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TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
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1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
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58.000
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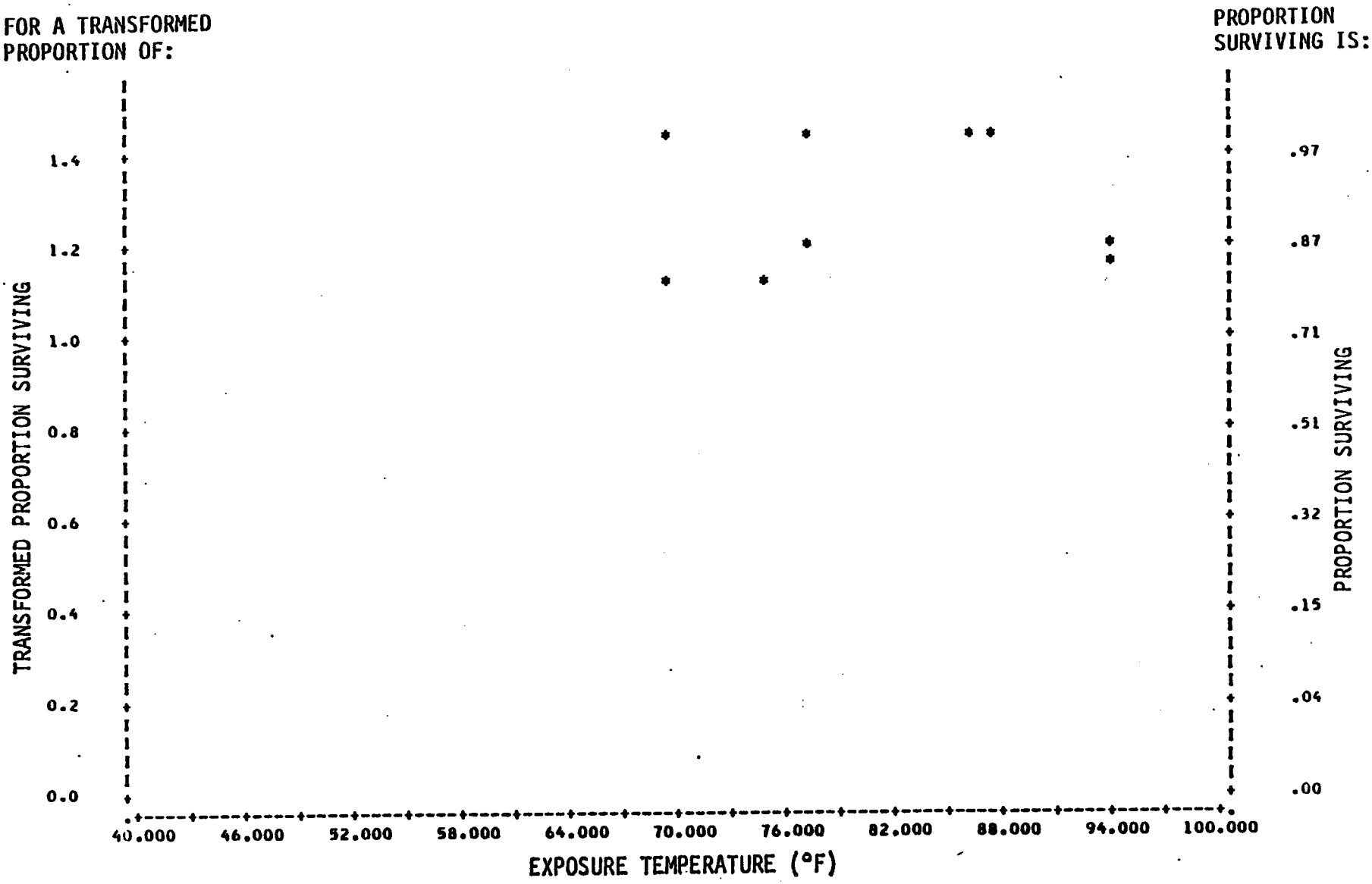
70.000
76.000
82.000
88.000
94.000
100.000

Figure D-4d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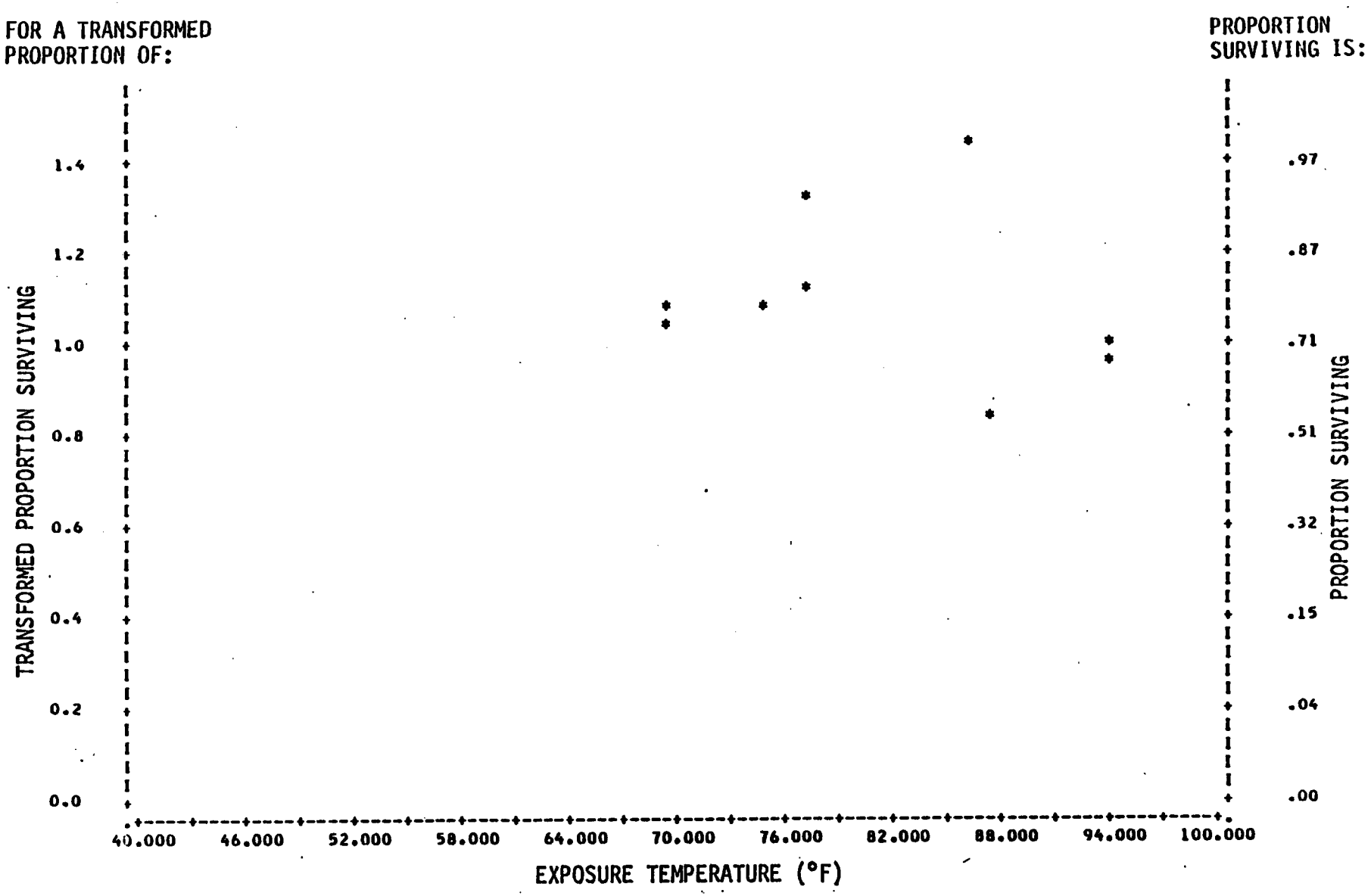
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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1.0
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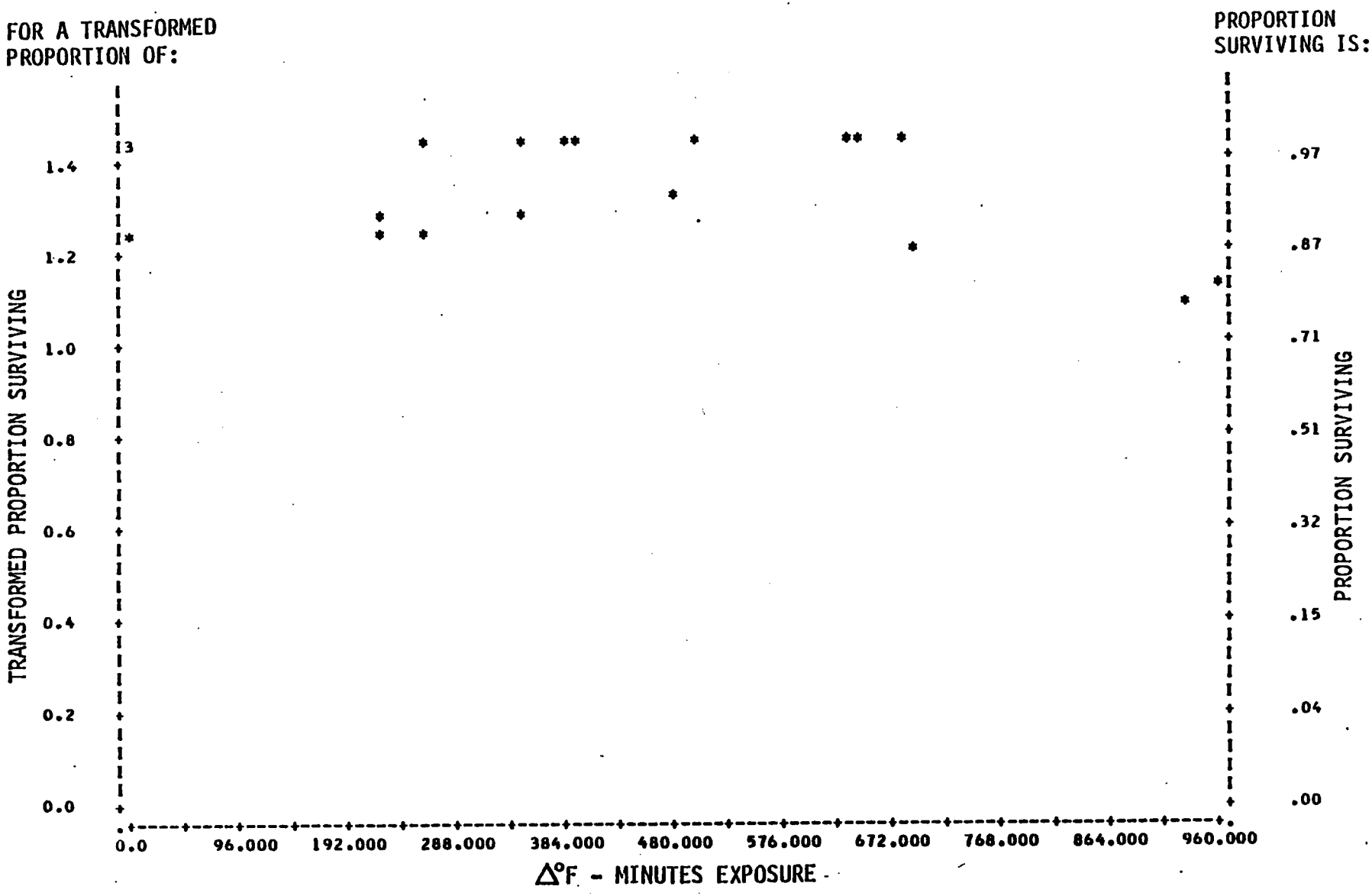
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-5 Batch 8 egg survivorshop vs. thermal exposure

a) PA8 vs. calculated dose (Δ°F-min)
b) PA24 " " " "
c) PA43 " " " "
d) PA8 vs. maximum exposure temperature (°F)
e) PA 24 " " " " "
f) PA 48 " " " " "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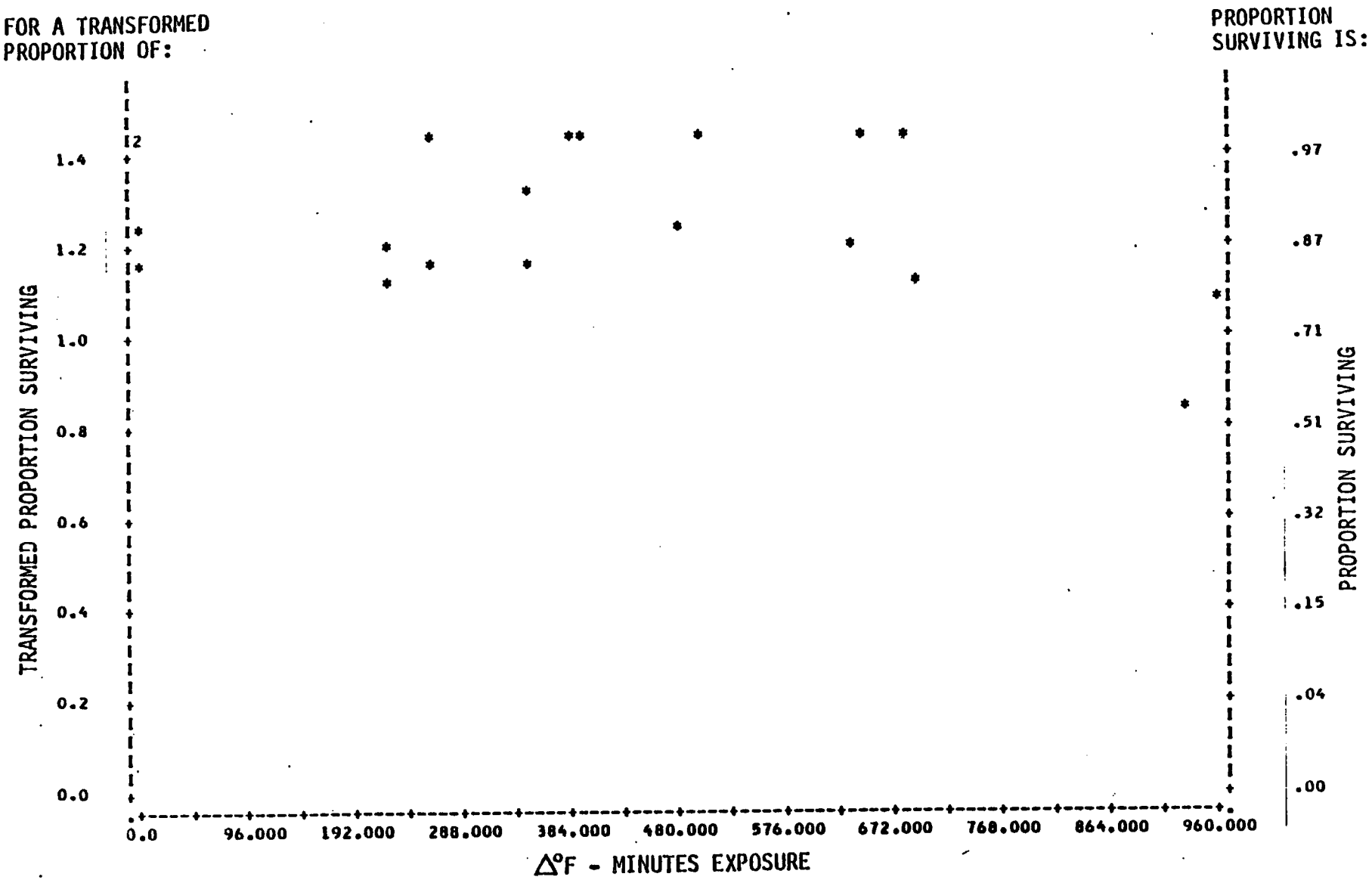
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
96.000
192.000
288.000
384.000
480.000
576.000
672.000
768.000
864.000
960.000
ΔºF - MINUTES EXPOSURE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1.4
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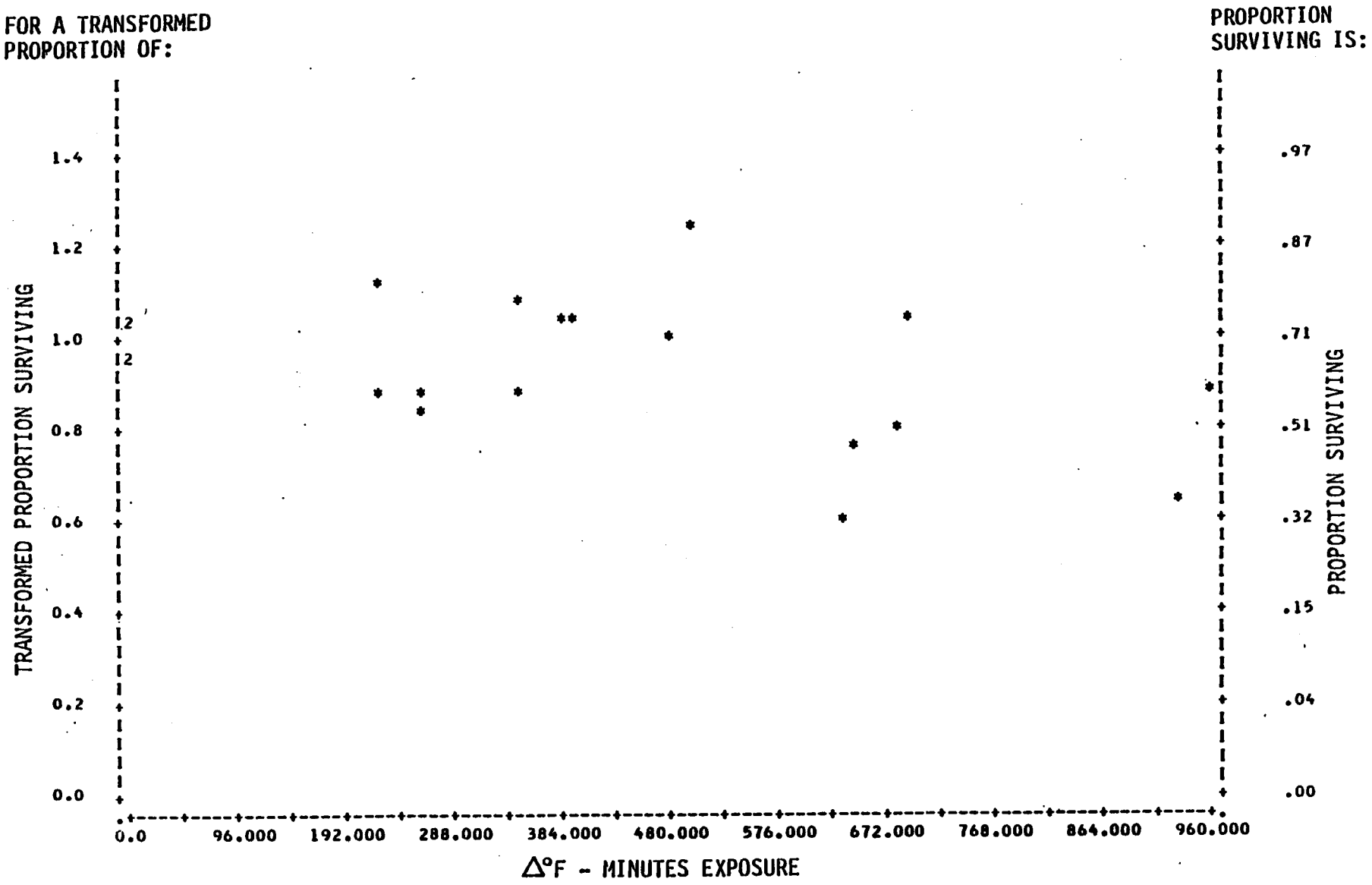
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
96.000
192.000
288.000
384.000
480.000
576.000
672.000
768.000
864.000
960.000
ΔºF - MINUTES EXPOSURE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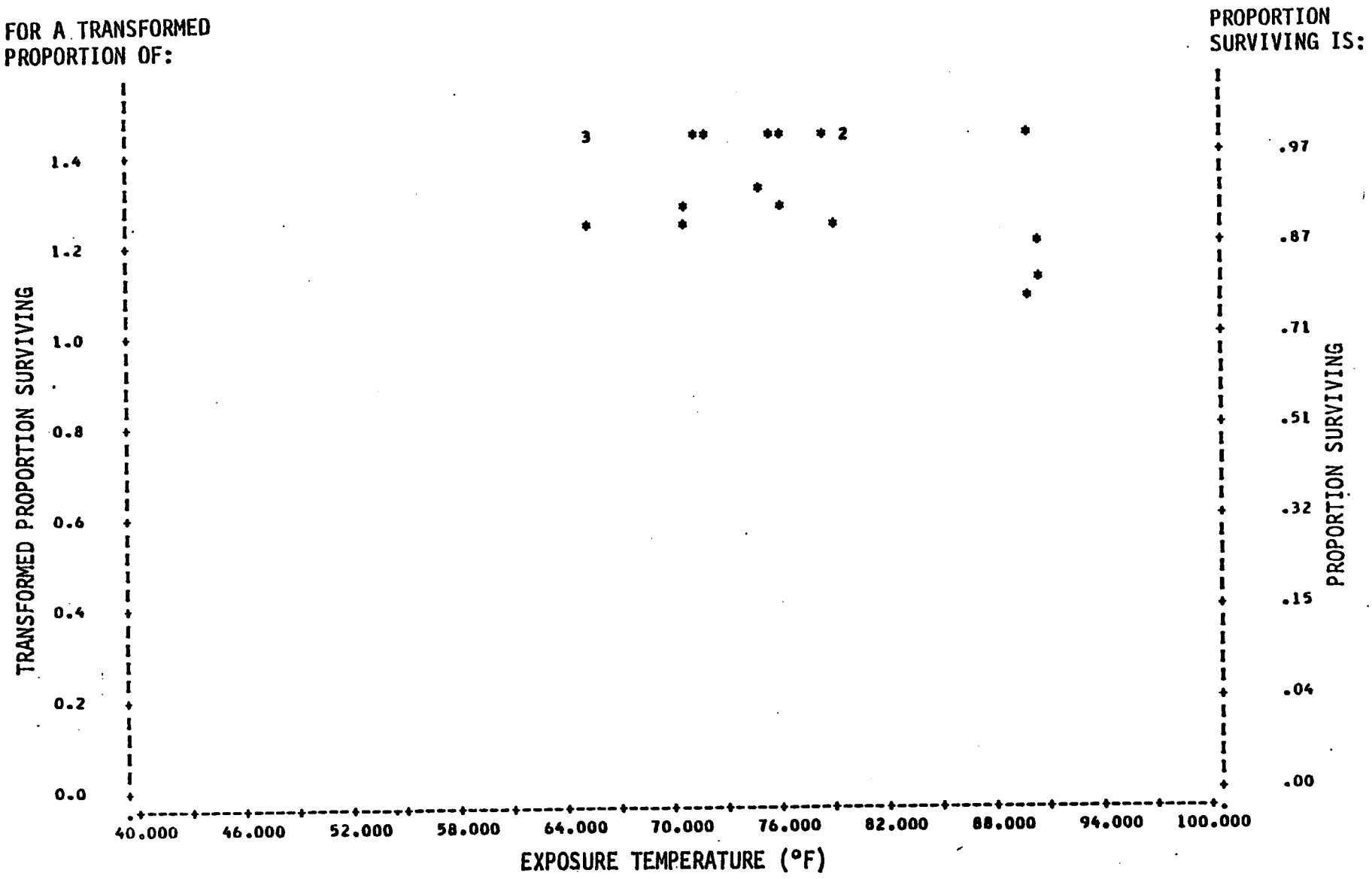
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
96.000
192.000
288.000
384.000
480.000
576.000
672.000
768.000
864.000
960.000
ΔºF - MINUTES EXPOSURE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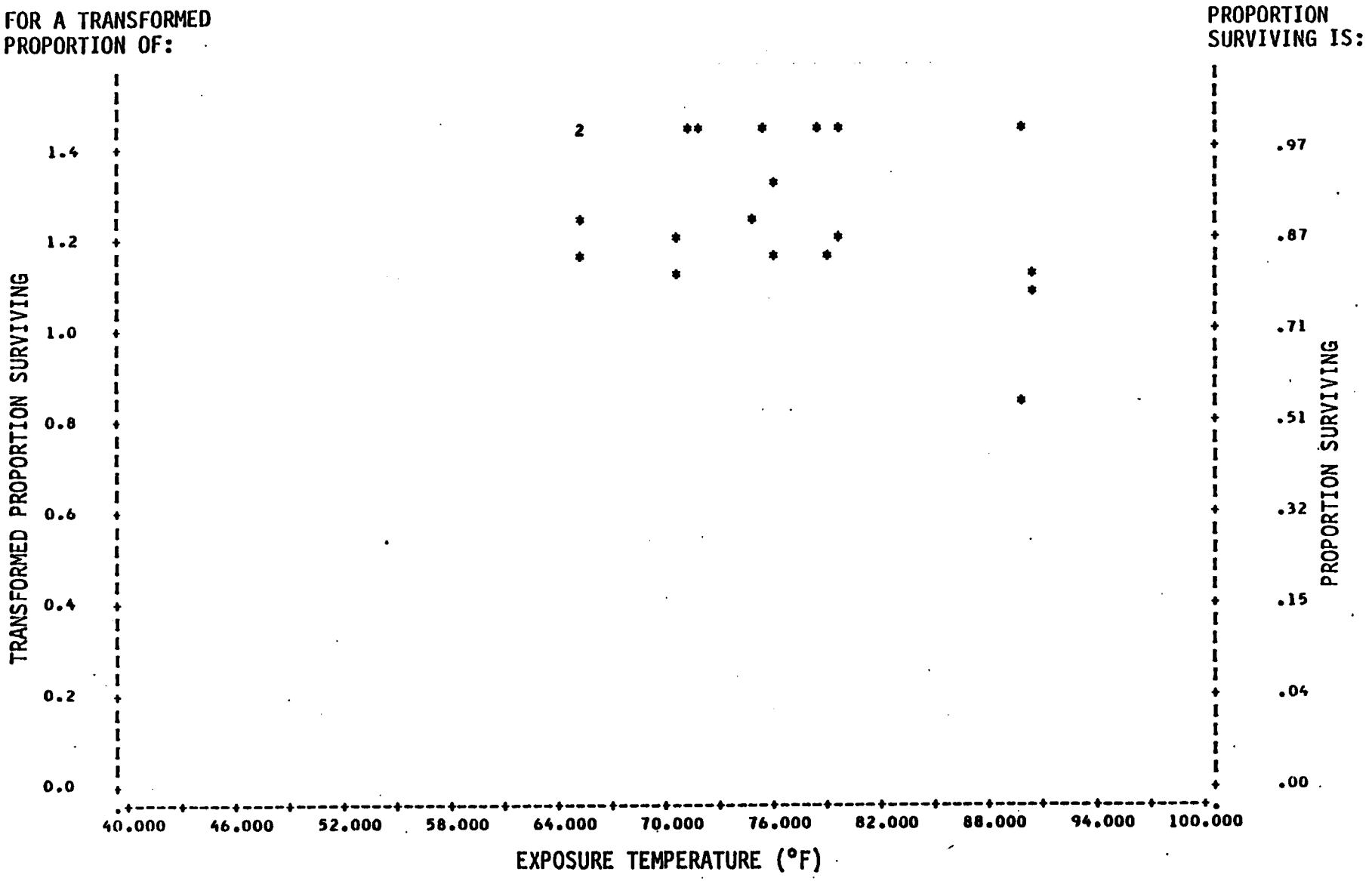
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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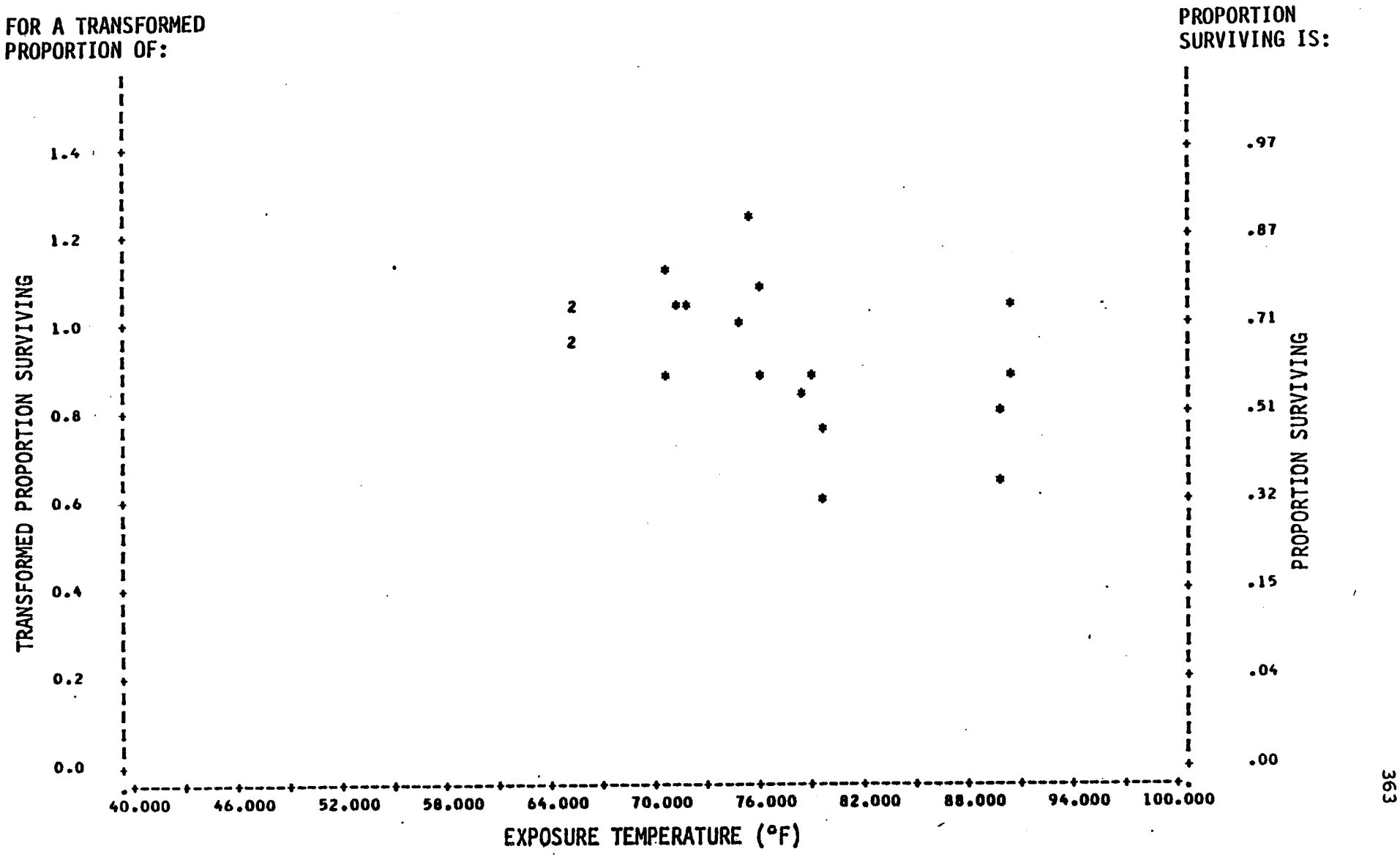
1.0
0.8
0.6
0.4
0.2
0.0
2
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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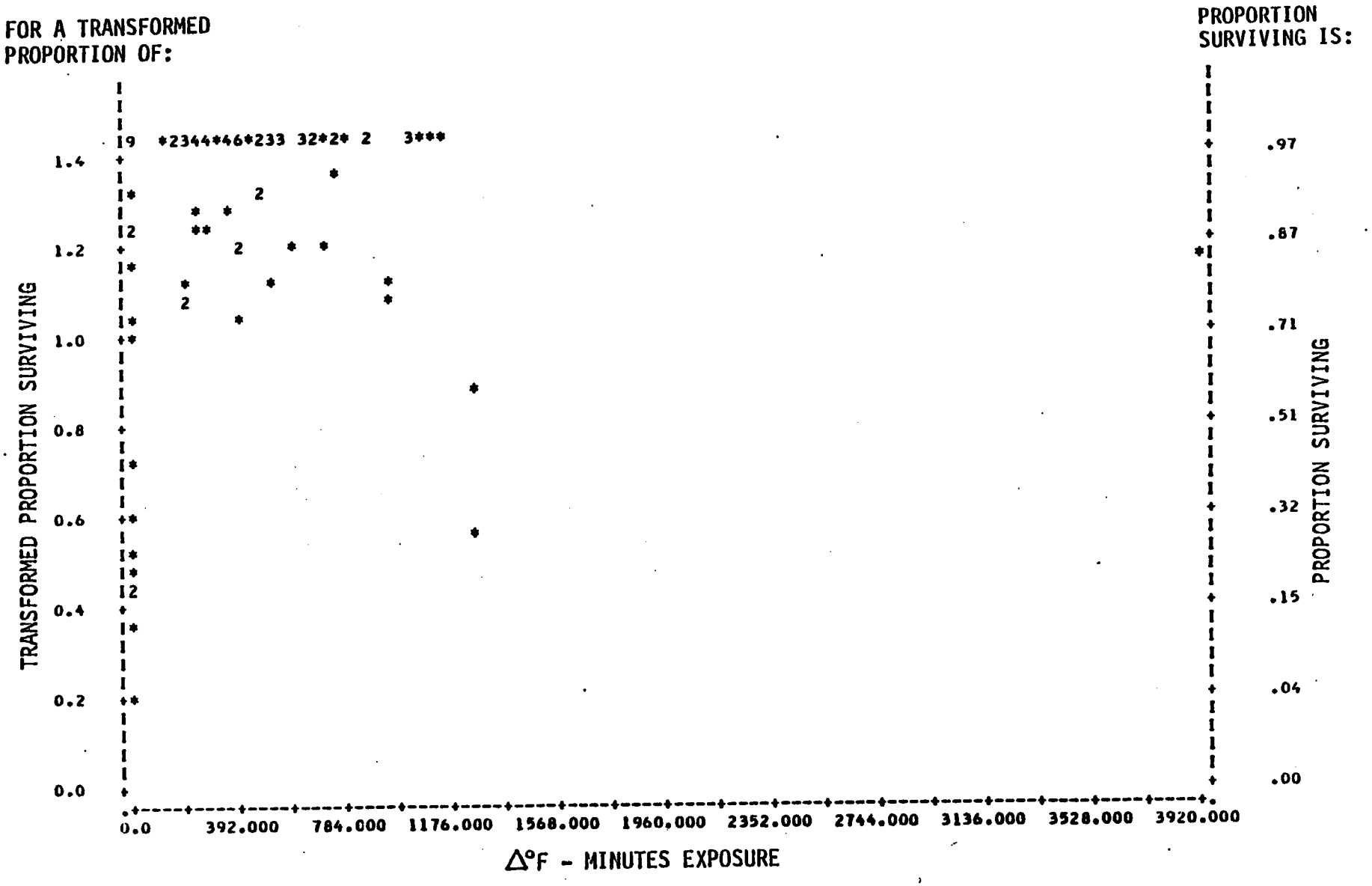
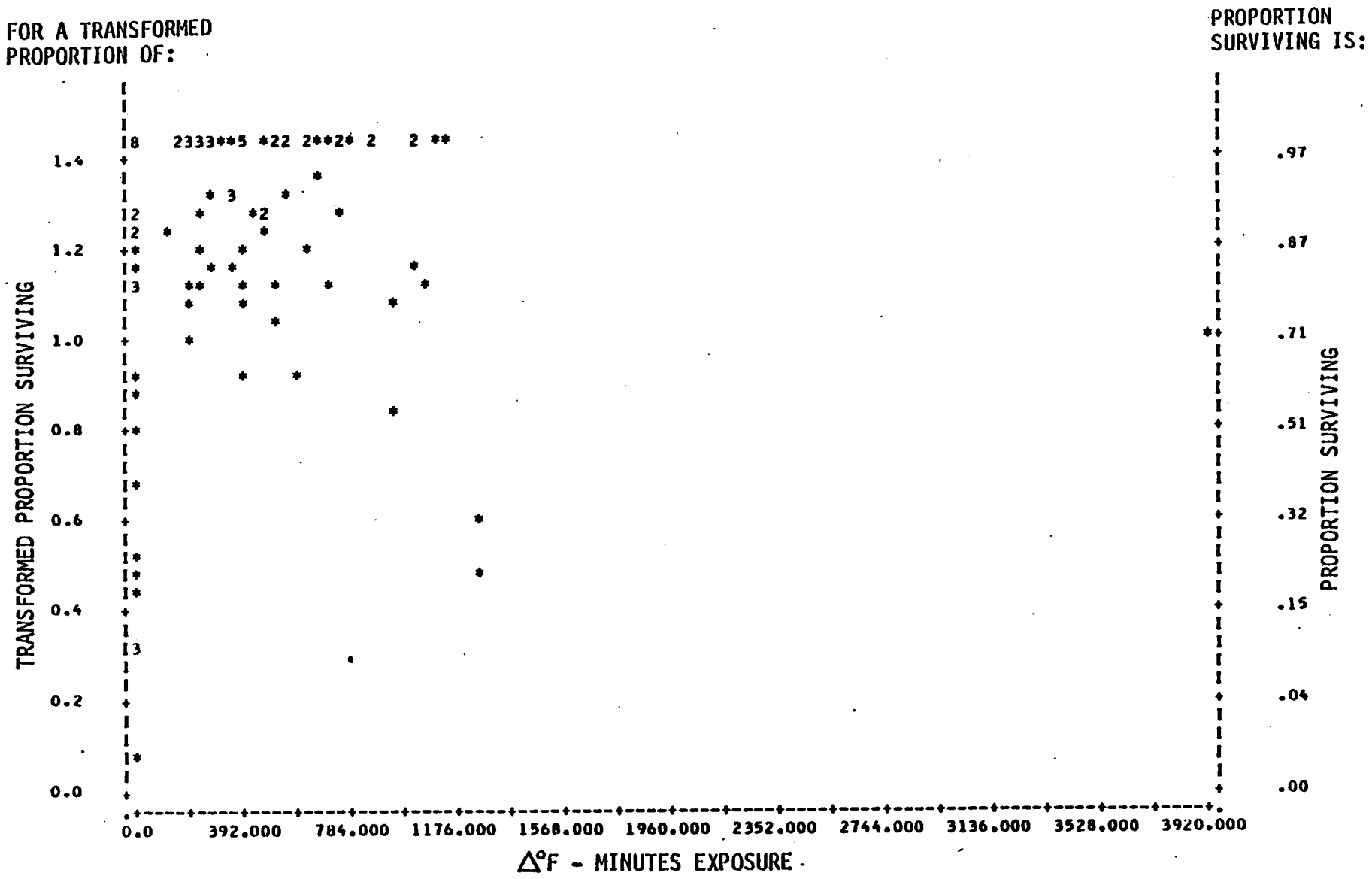
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-6 Egg survivorship (all batches) vs. thermal exposure

a) PA8 vs. calculated dose (Δ°F-min)
b) PA24 " " " "
c) PA43 " " " "
d) PA8 vs. maximum exposure temperature (°F)
e) PA 24 " " " " "
f) PA 48 " " " " "


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
0.0
392.000
784.000
1176.000
1568.000
1960.000
2352.000
2744.000
3136.000
3528.000
3920.000
Δ°F - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
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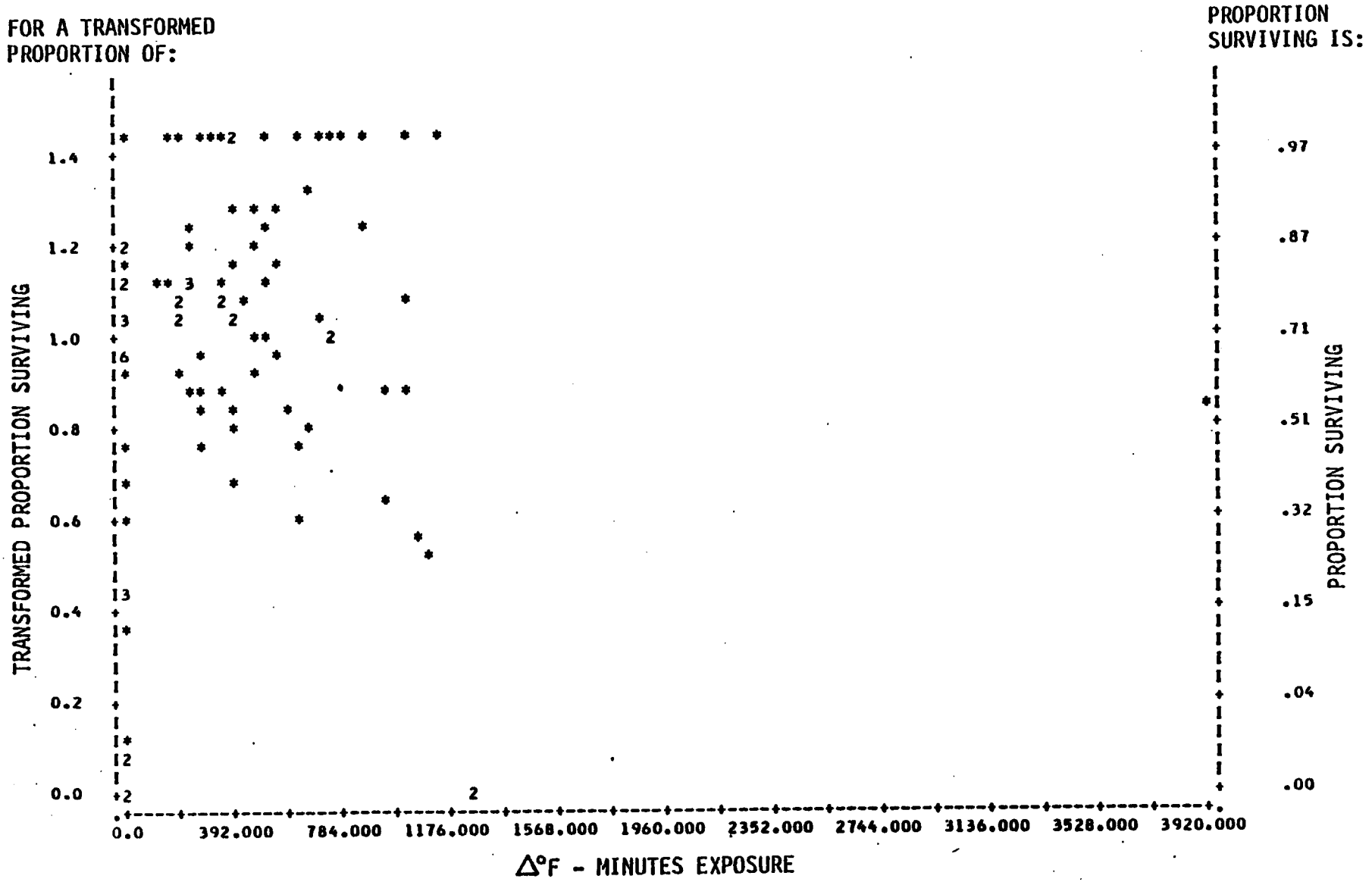
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
0.0
392.000
784.000
1176.000
1568.000
1960.000
2352.000
2744.000
3136.000
3528.000
3920.000
ΔºF - MINUTES EXPOSURE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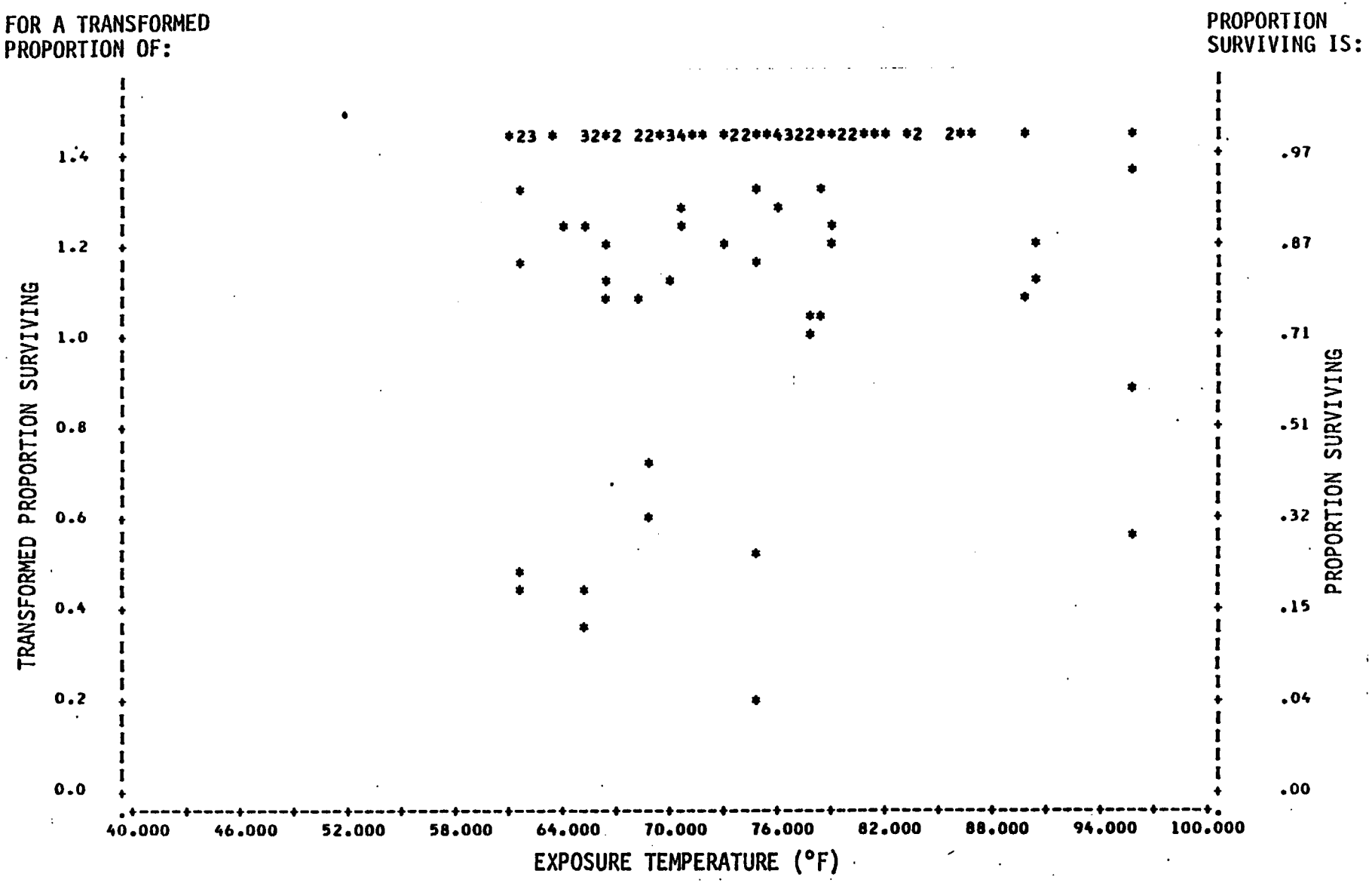
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
392.000
784.000
1176.000
1568.000
1960.000
2352.000
2744.000
3136.000
3528.000
3920.000
ΔºF - MINUTES EXPOSURE

Figure D-6c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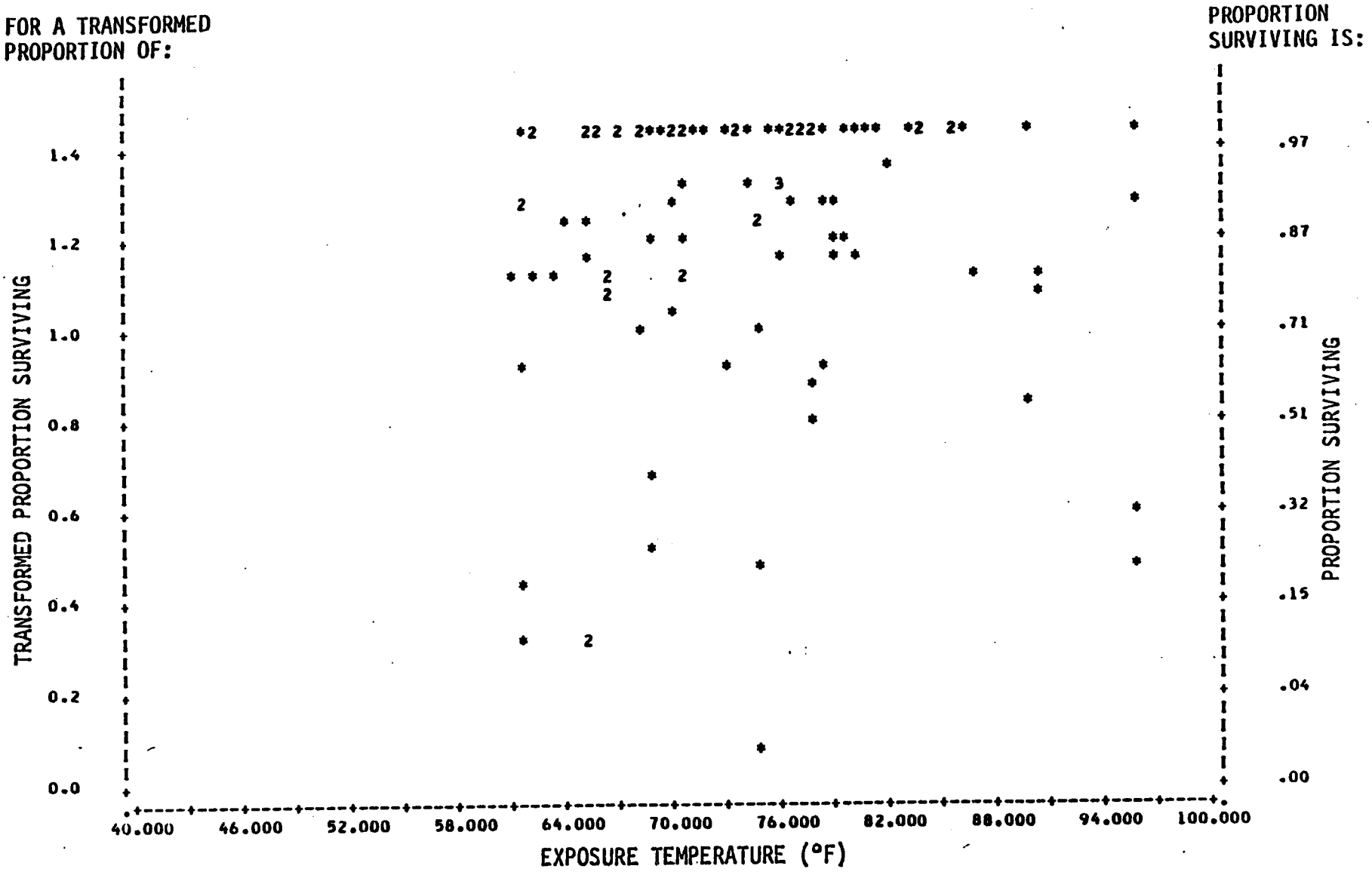
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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PROPORTION SURVIVING IS:
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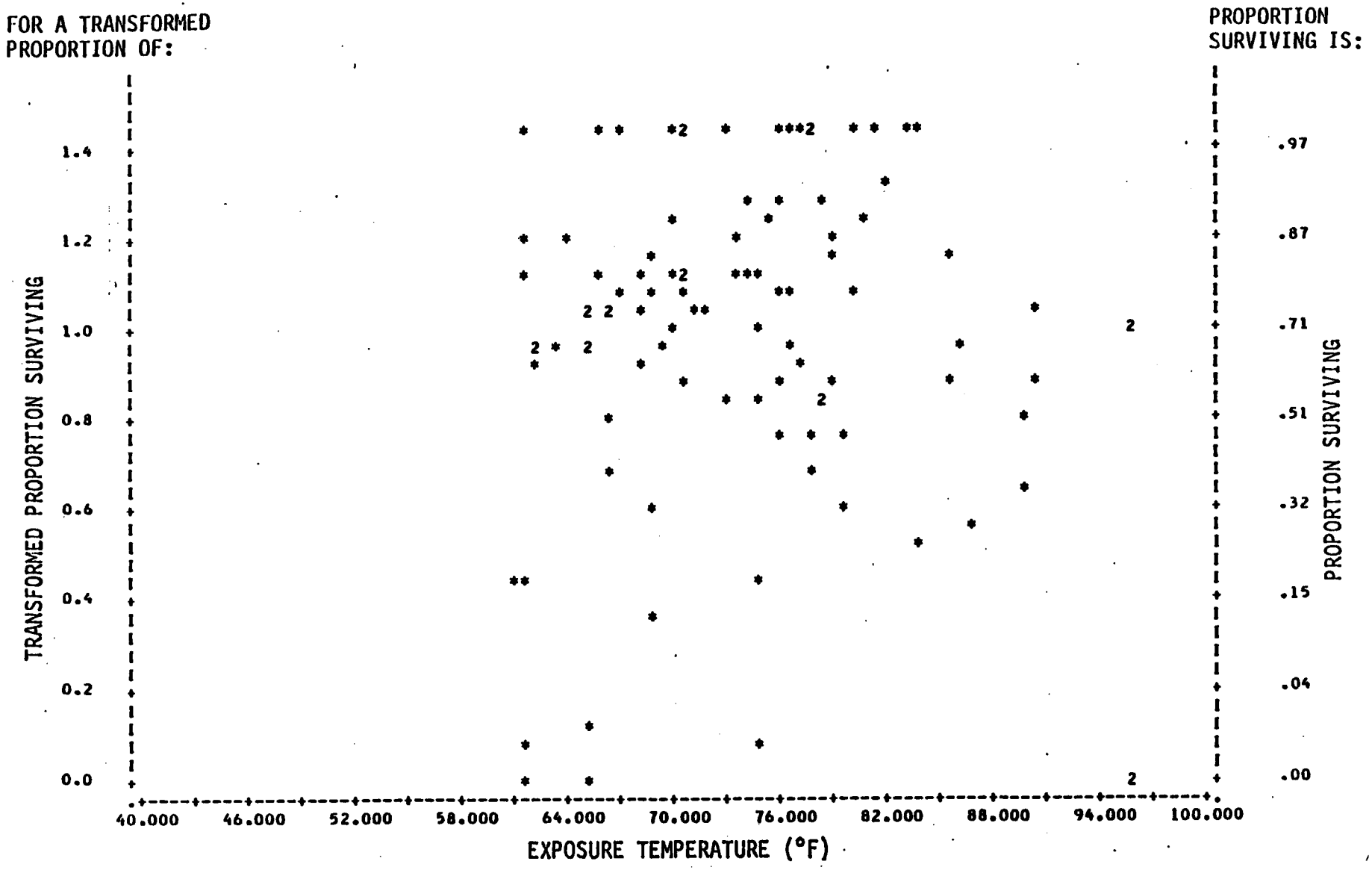
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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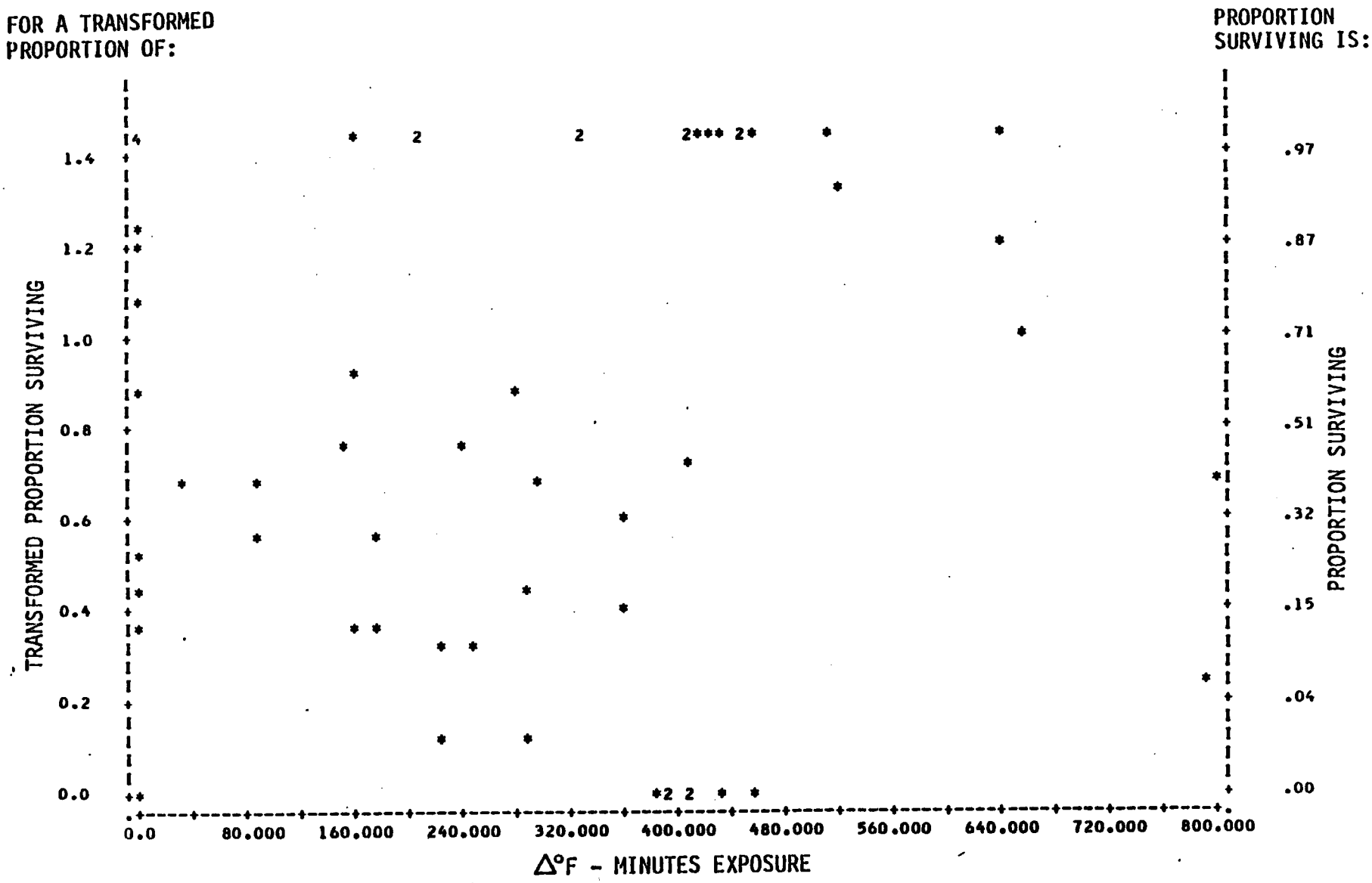
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-7. Batch 3 larvae survivorshp vs. thermal exposure

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " " "
c) PA 8 " " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " " "
f) PA 8 " " " " "


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
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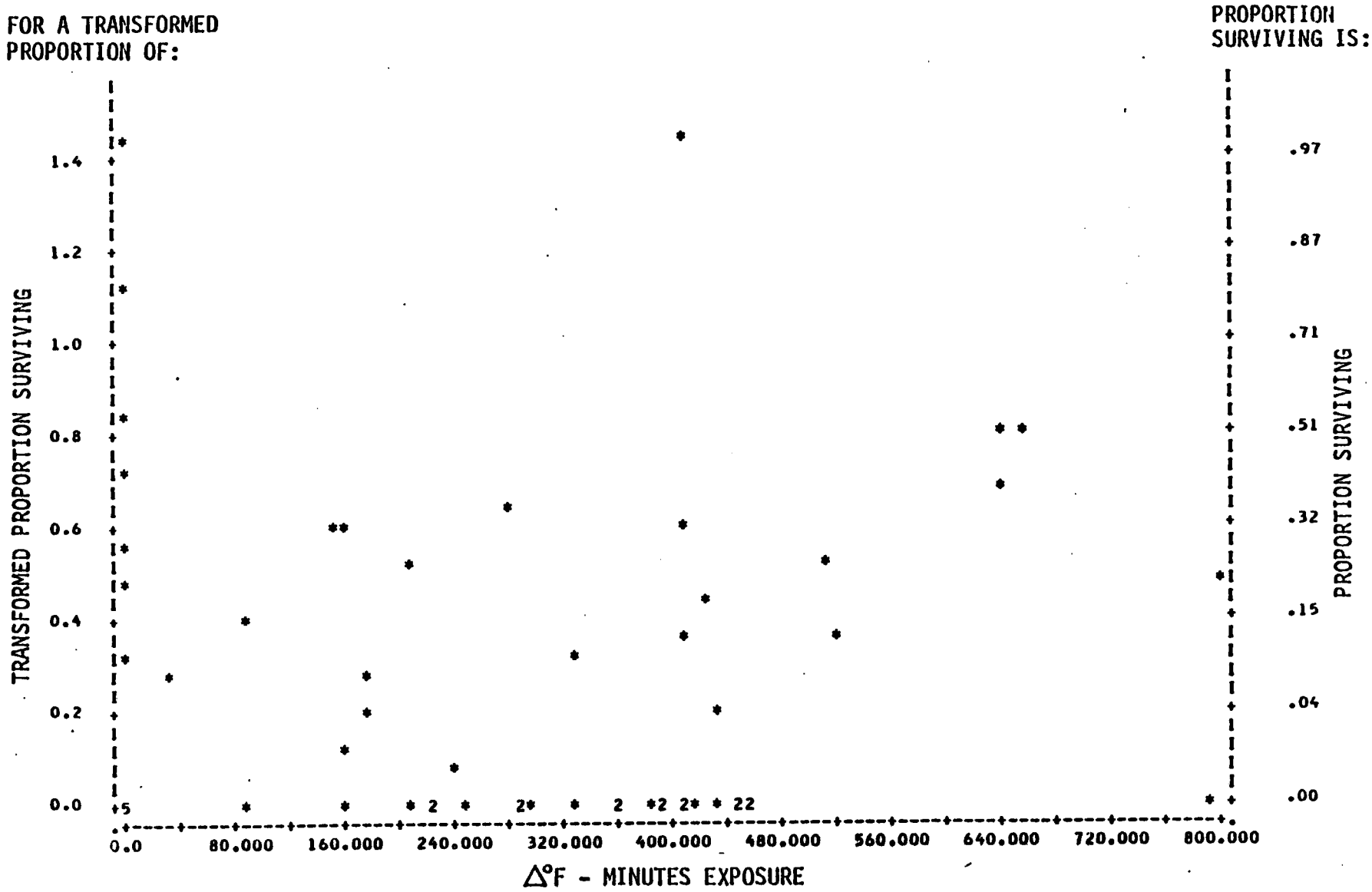
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
80.000
160.000
240.000
320.000
400.000
480.000
560.000
640.000
720.000
800.000
ΔºF - MINUTES EXPOSURE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PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
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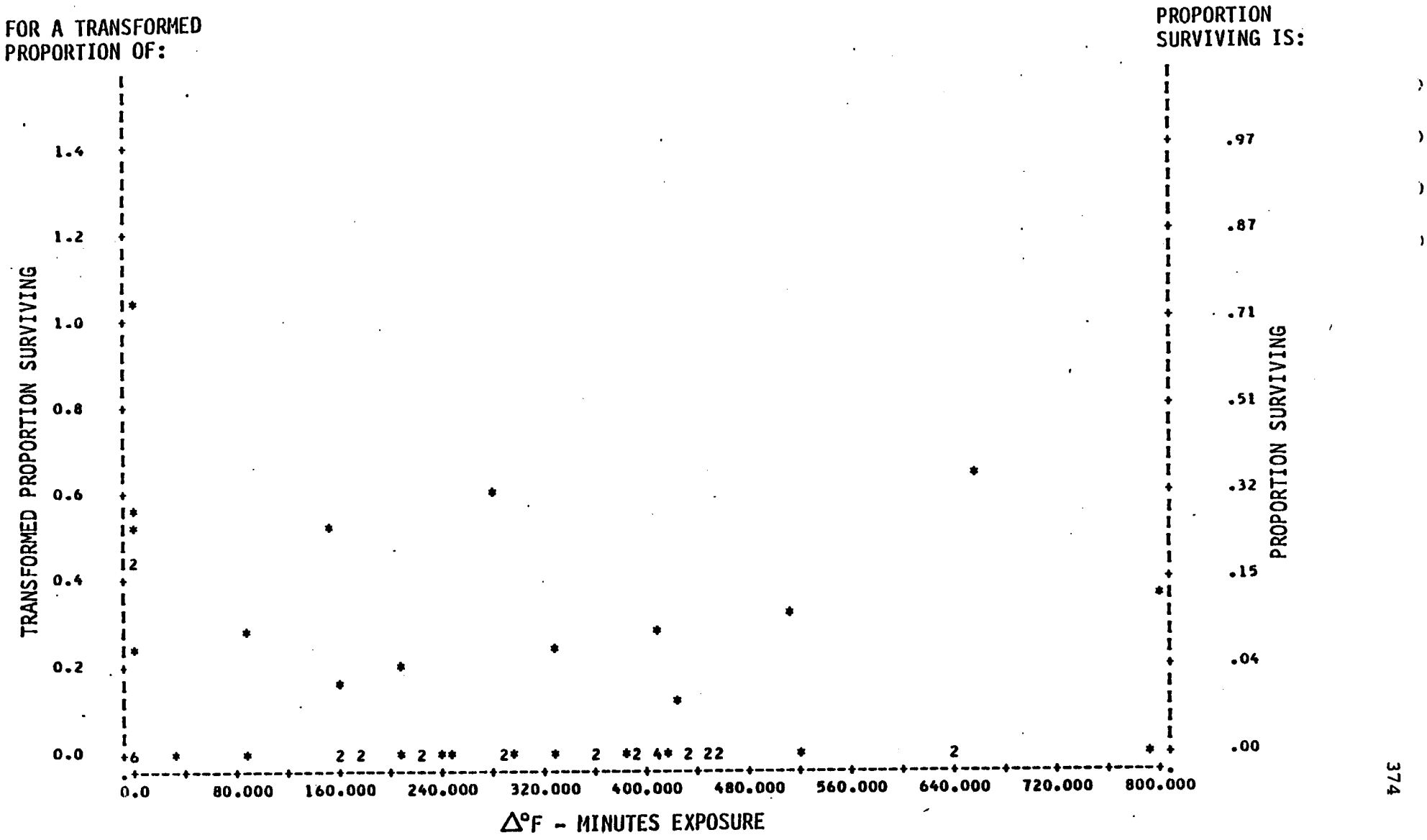
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
80.000
160.000
240.000
320.000
400.000
480.000
560.000
640.000
720.000
800.000
ΔºF - MINUTES EXPOSURE

Figure D-7b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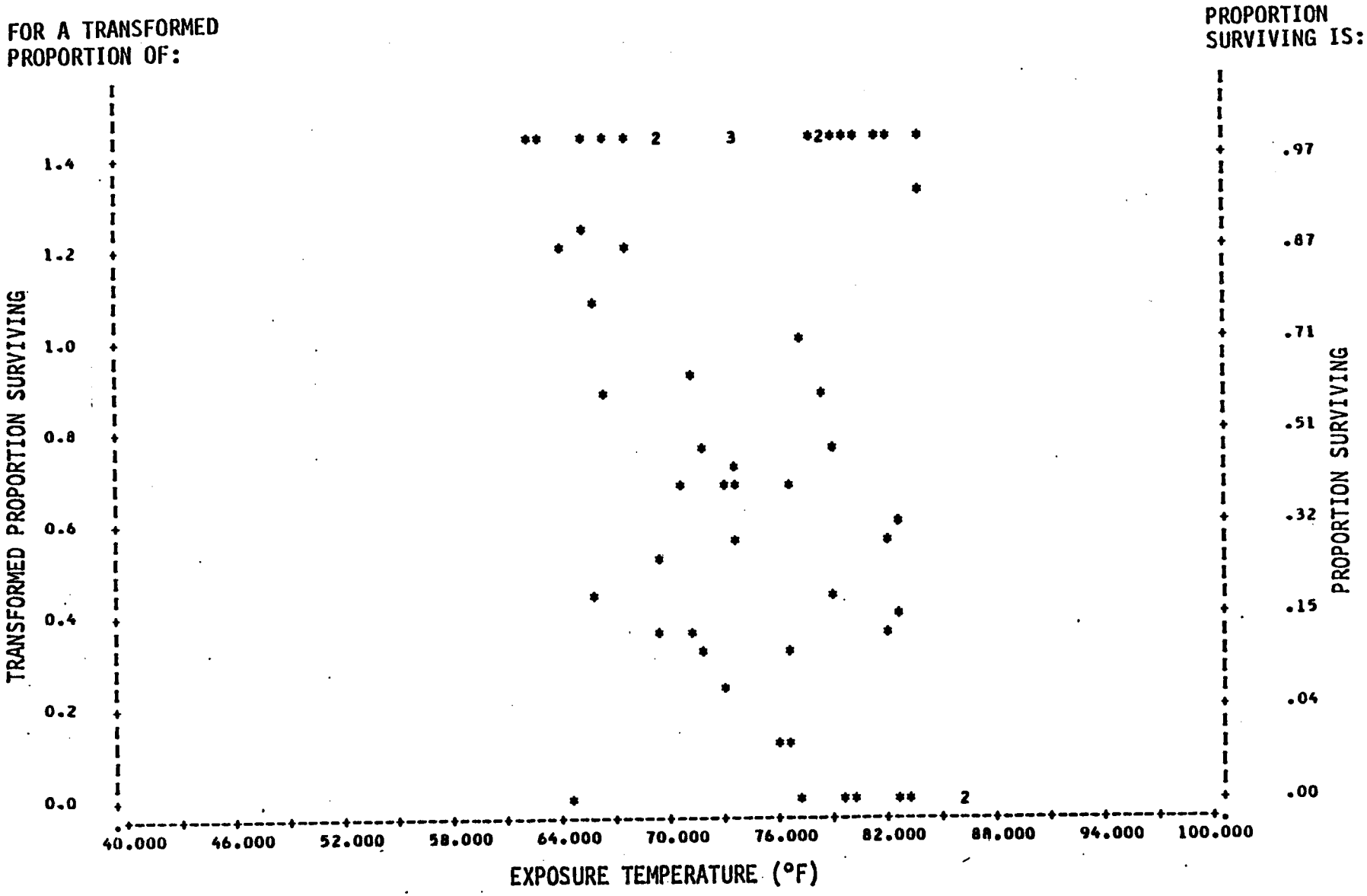
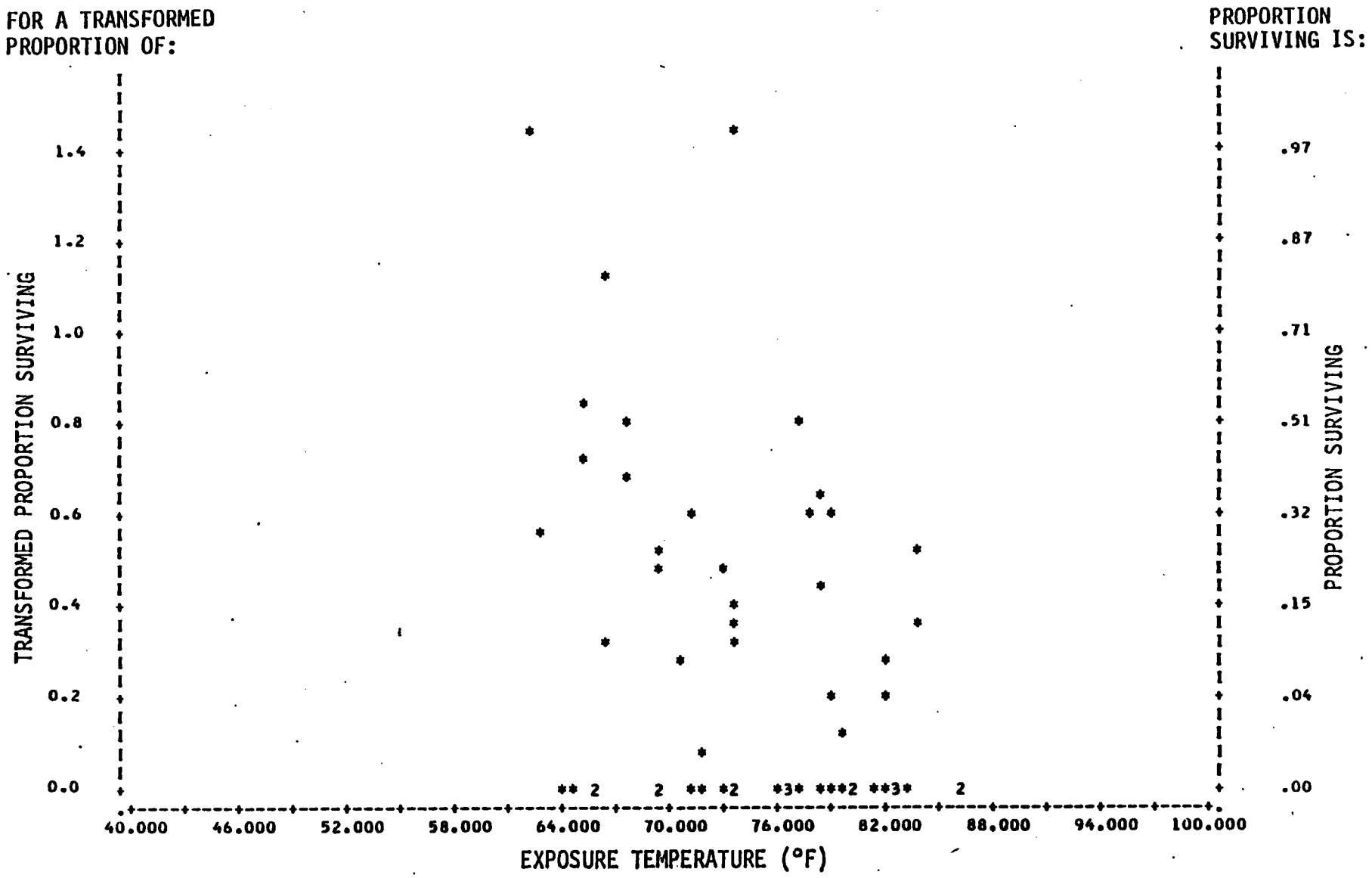
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
80.000
160.000
240.000
320.000
400.000
480.000
560.000
640.000
720.000
800.000
Δ°F - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
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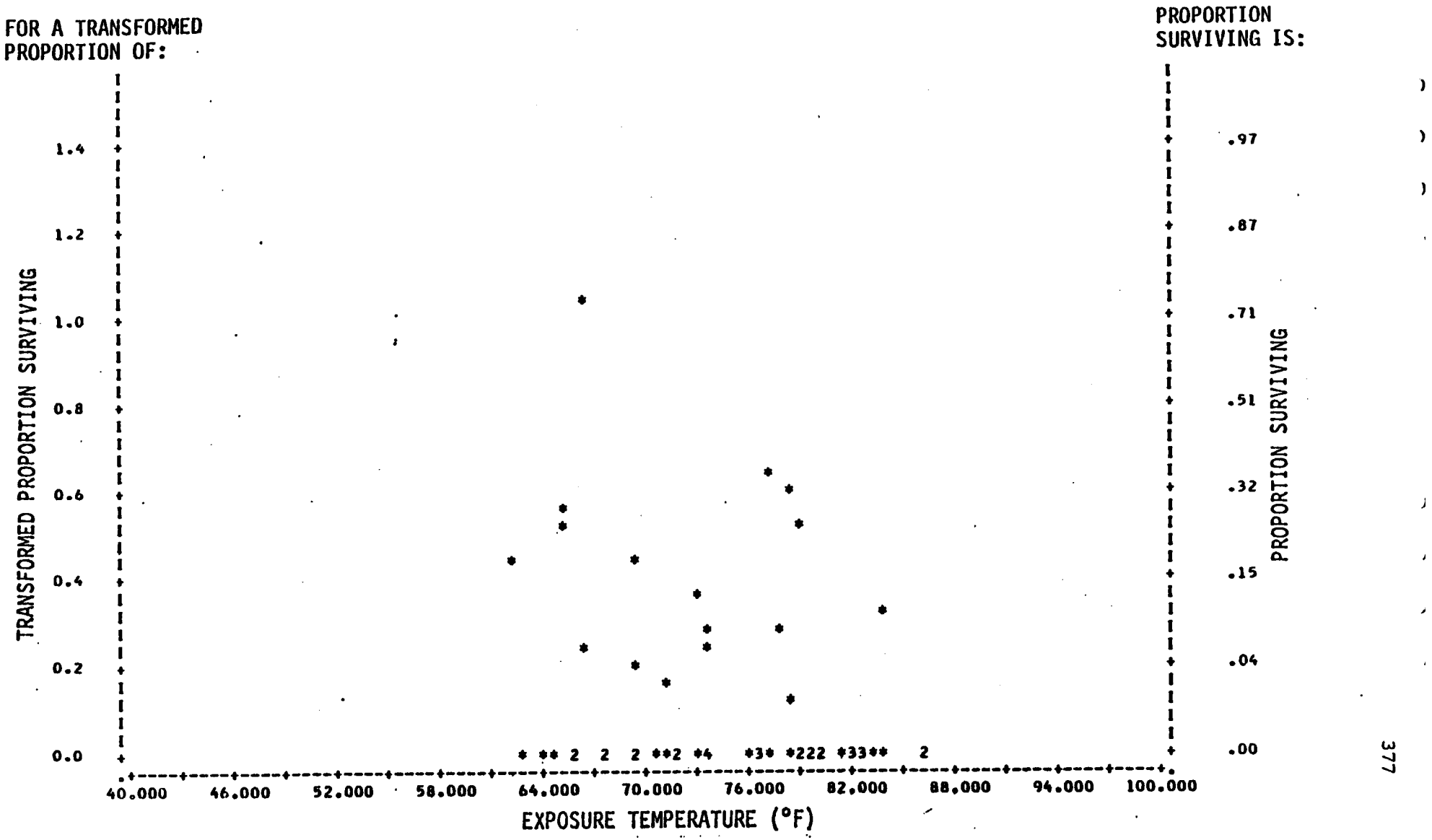
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
** 2 2 ** *2 *3* ***2 **3* 2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
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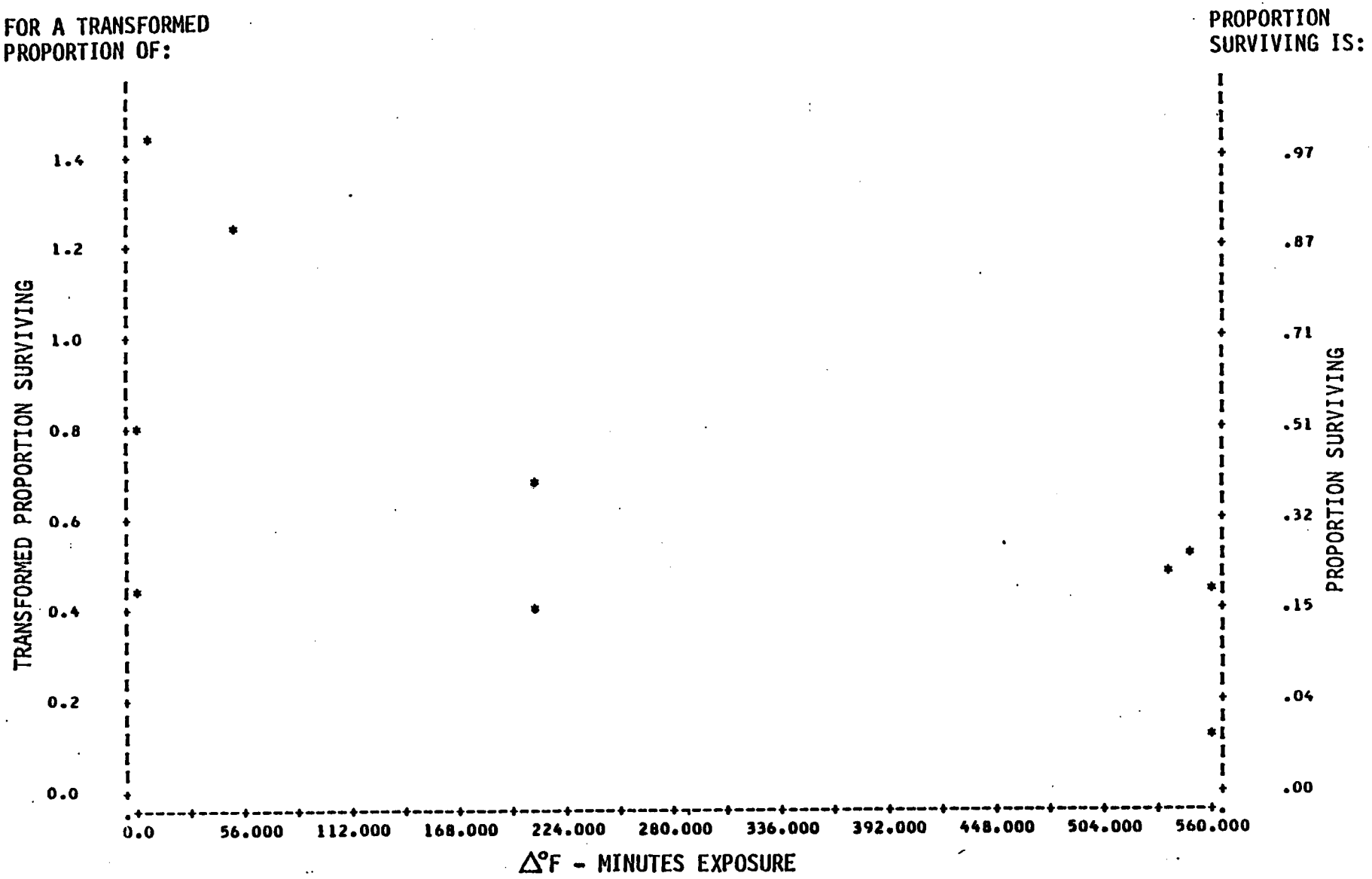
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
* ** 2 2 2 **2 *4 *3* *222 *33** 2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-8. Batch 5 larvae survivorship vs. thermal exposure

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " " "
c) PA 8 " " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " " "
f) PA 8 " " " " "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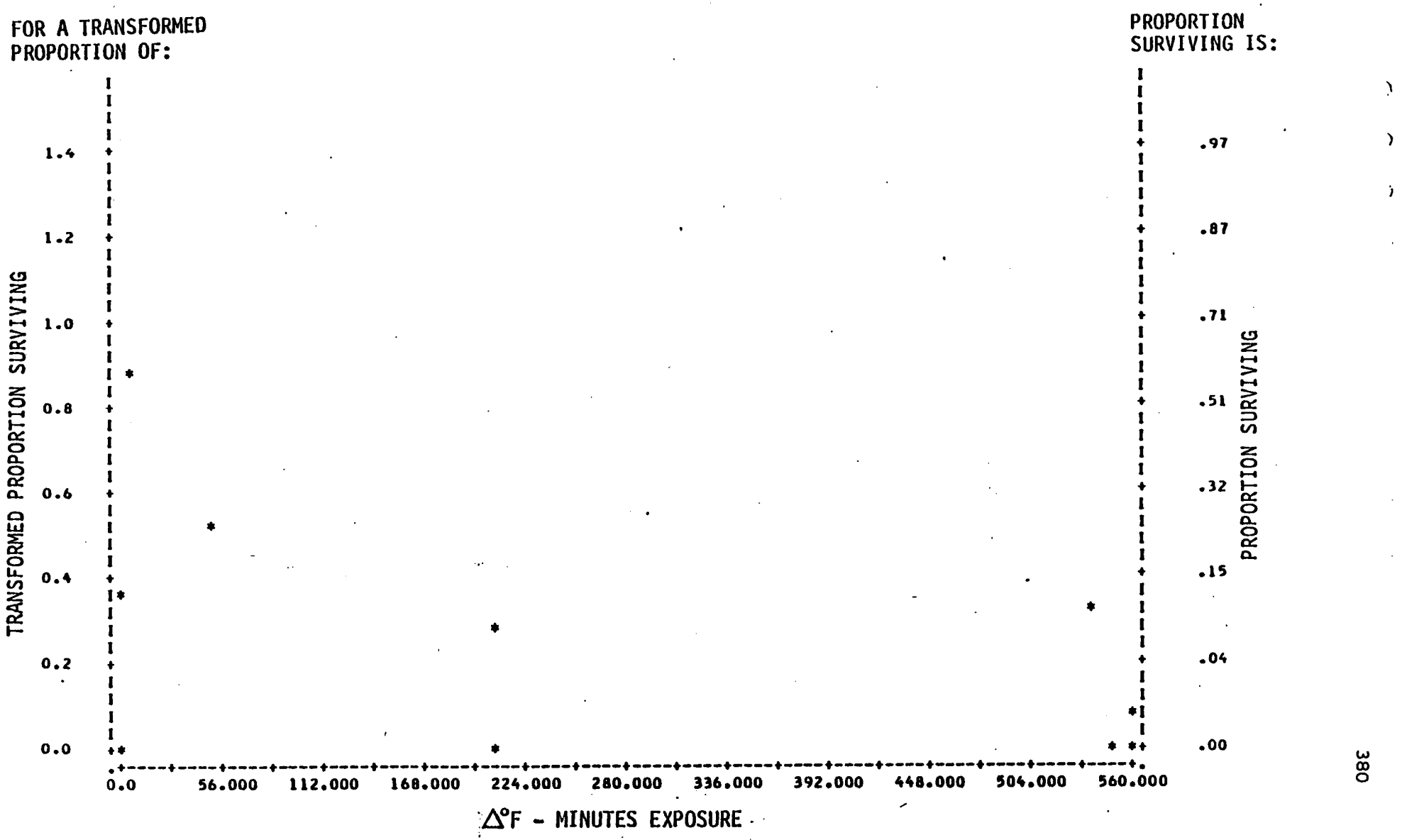
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
56.000
112.000
168.000
224.000
280.000
336.000
392.000
448.000
504.000
560.000
ΔºF - MINUTES EXPOSURE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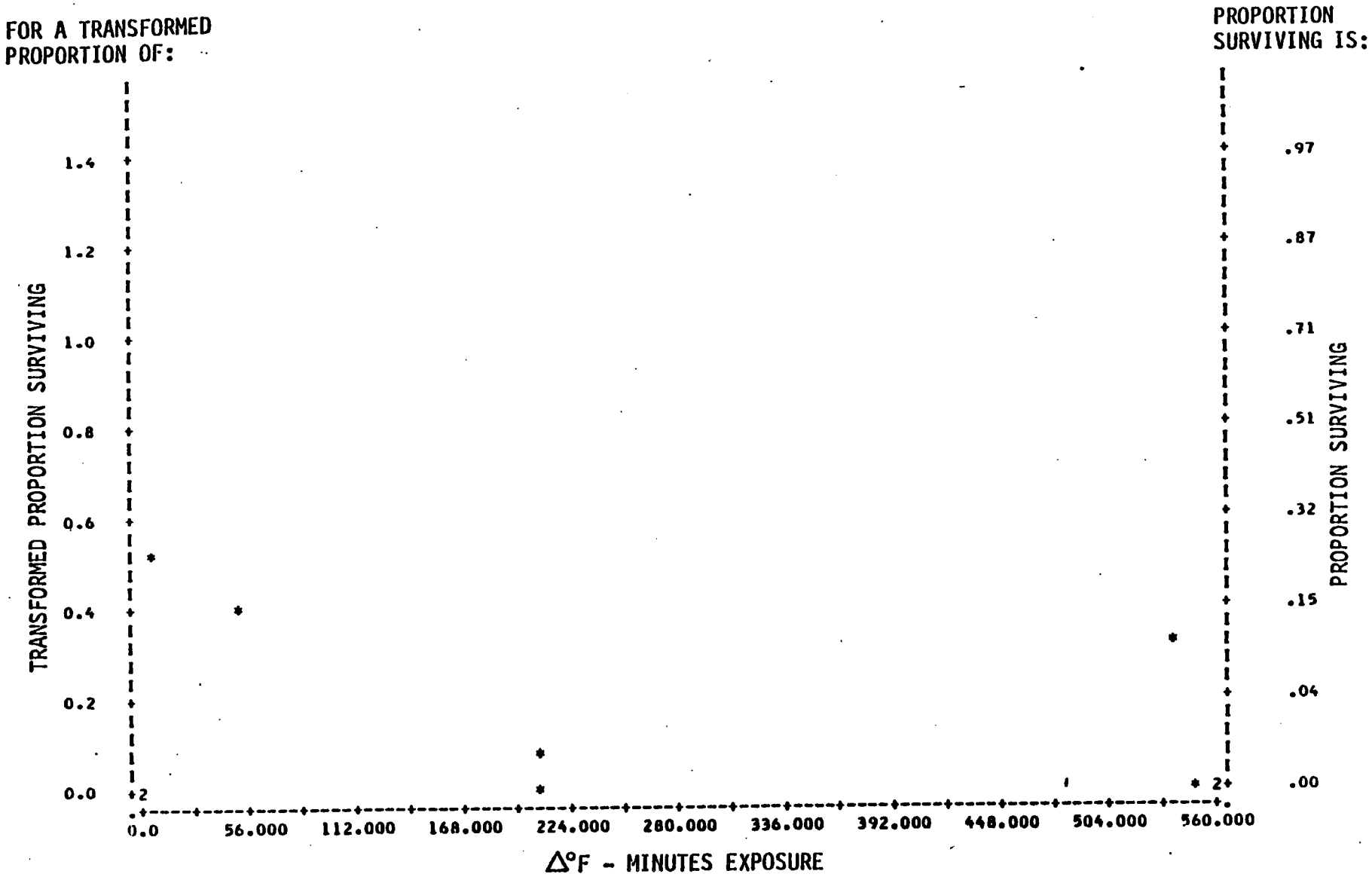
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
56.000
112.000
168.000
224.000
280.000
336.000
392.000
448.000
504.000
560.000
ΔºF - MINUTES EXPOSURE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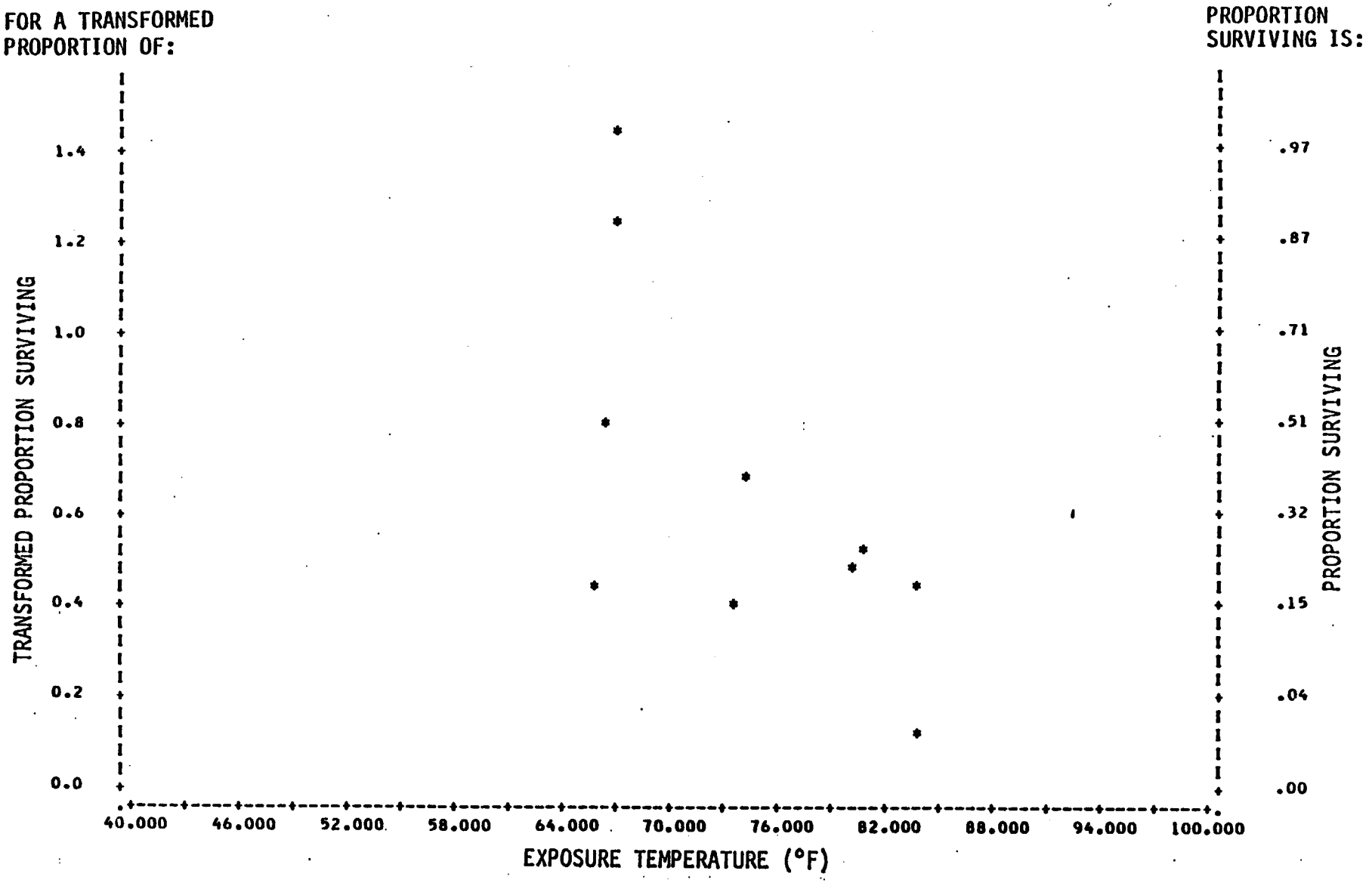
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
56.000
112.000
168.000
224.000
280.000
336.000
392.000
448.000
504.000
560.000
ΔºF - MINUTES EXPOSURE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PROPORTION SURVIVING IS:
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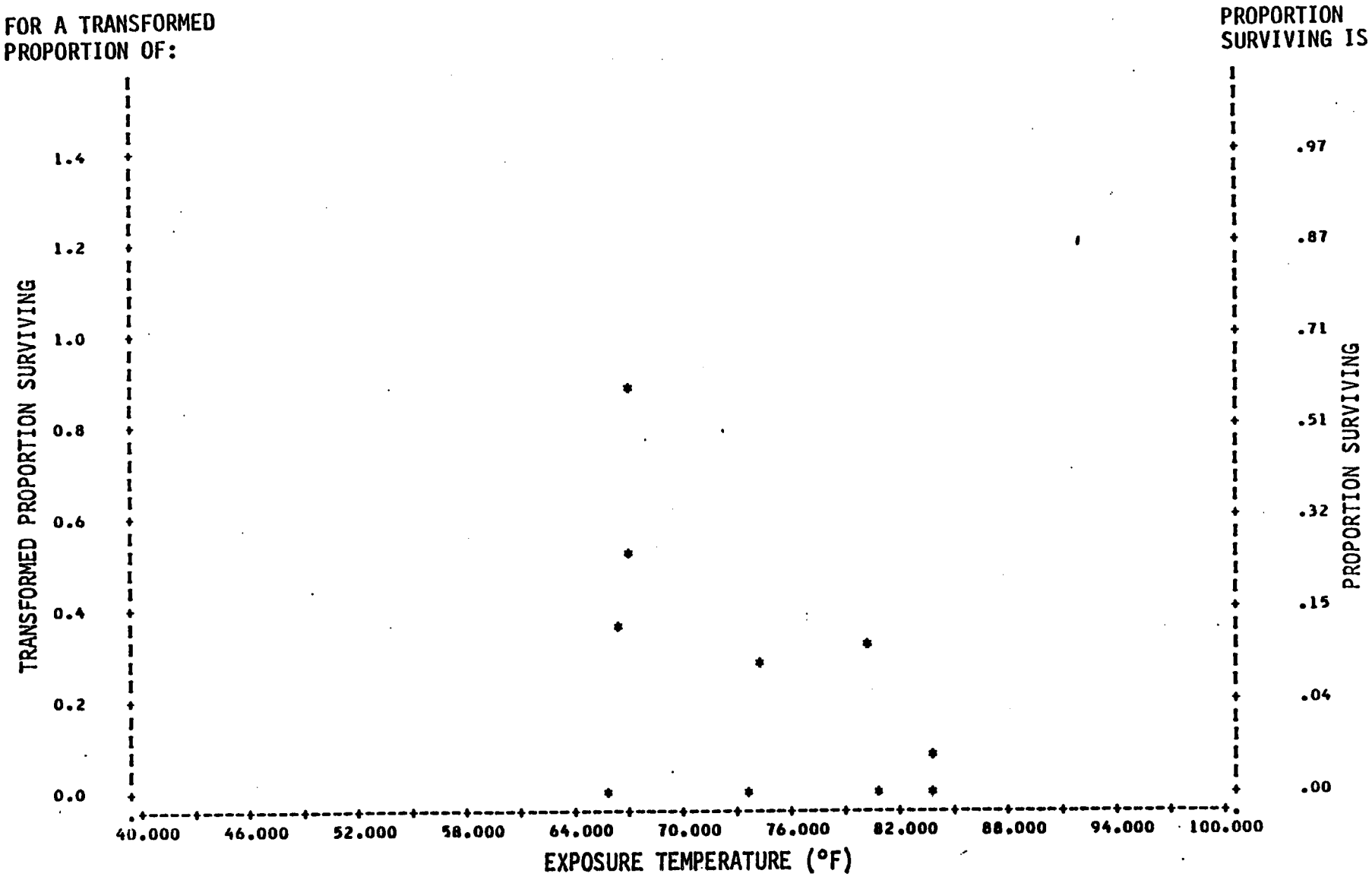
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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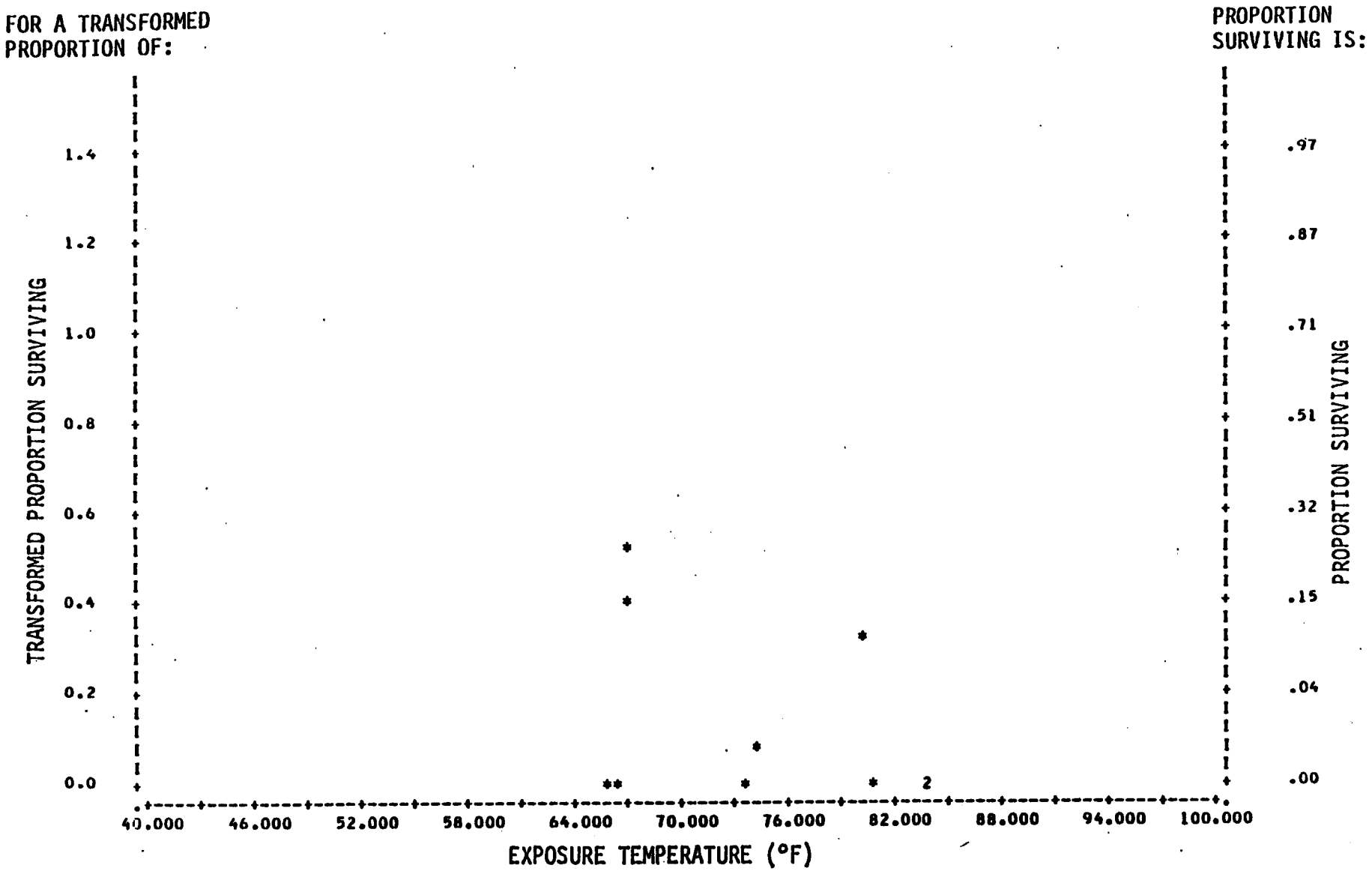
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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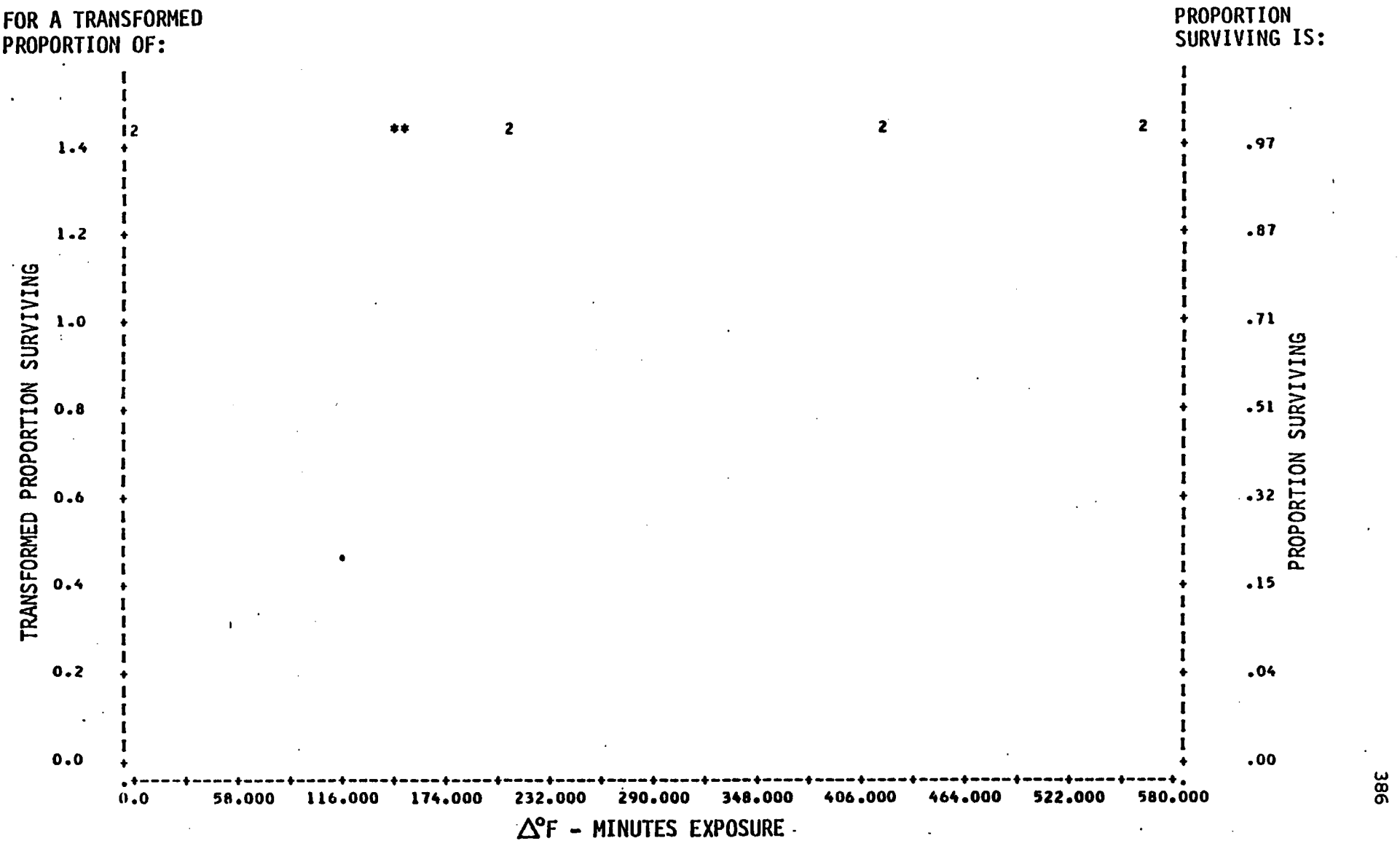
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-9. Batch 6 larvae survivorship vs. thermal exposure.

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " "
c) PA 8 " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " "
f) PA 8 " " " "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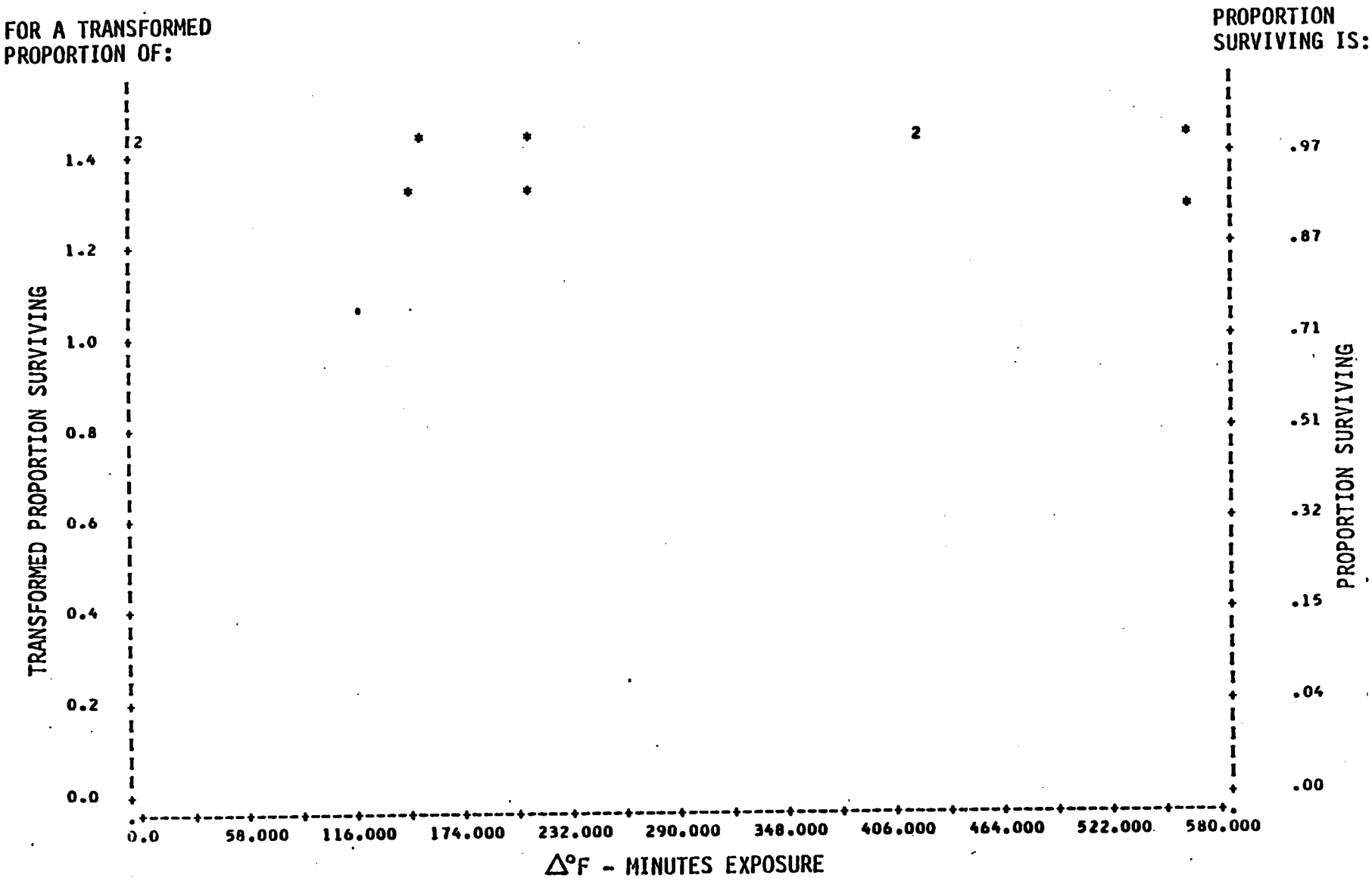
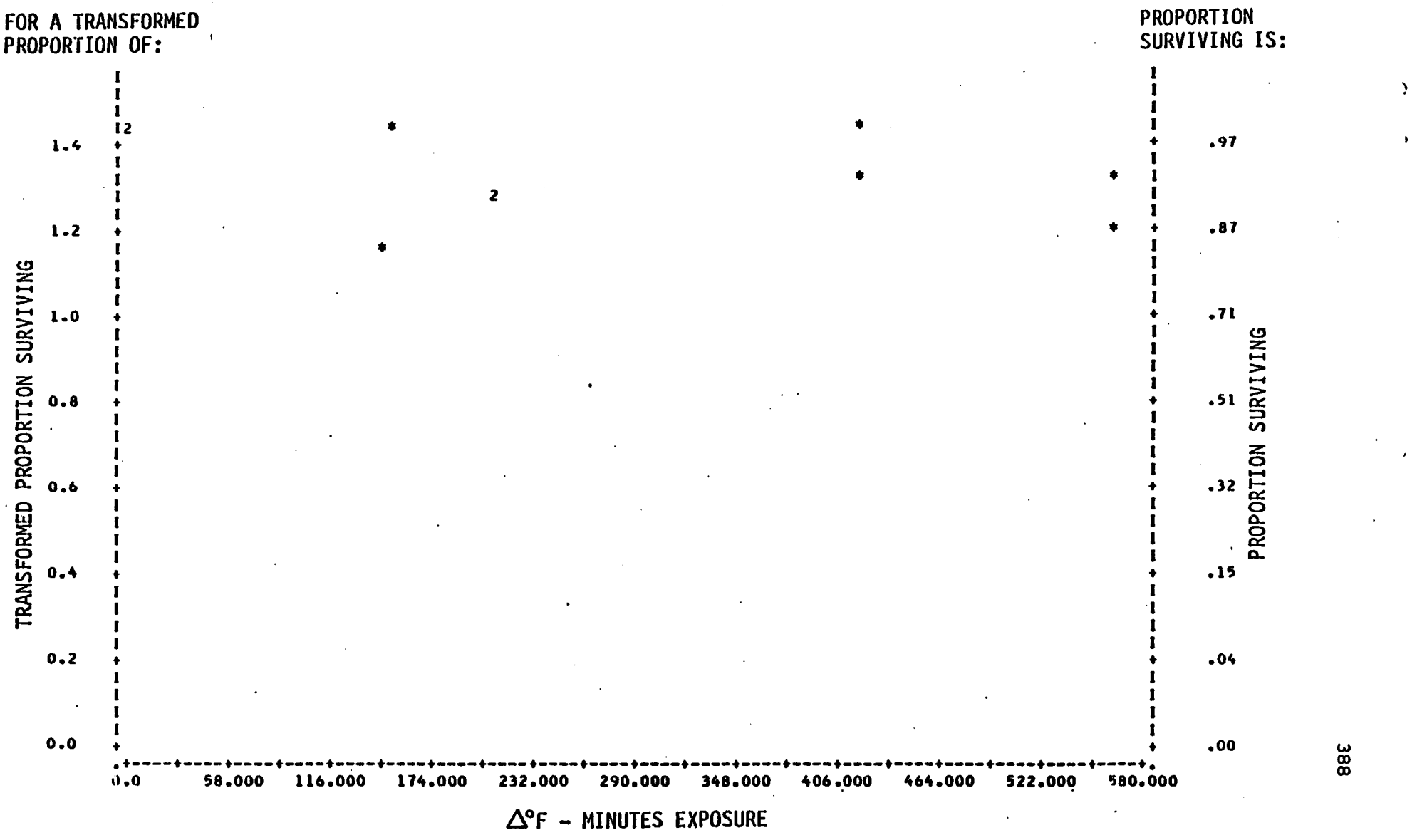
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
ΔºF - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
ΔºF - MINUTES EXPOSURE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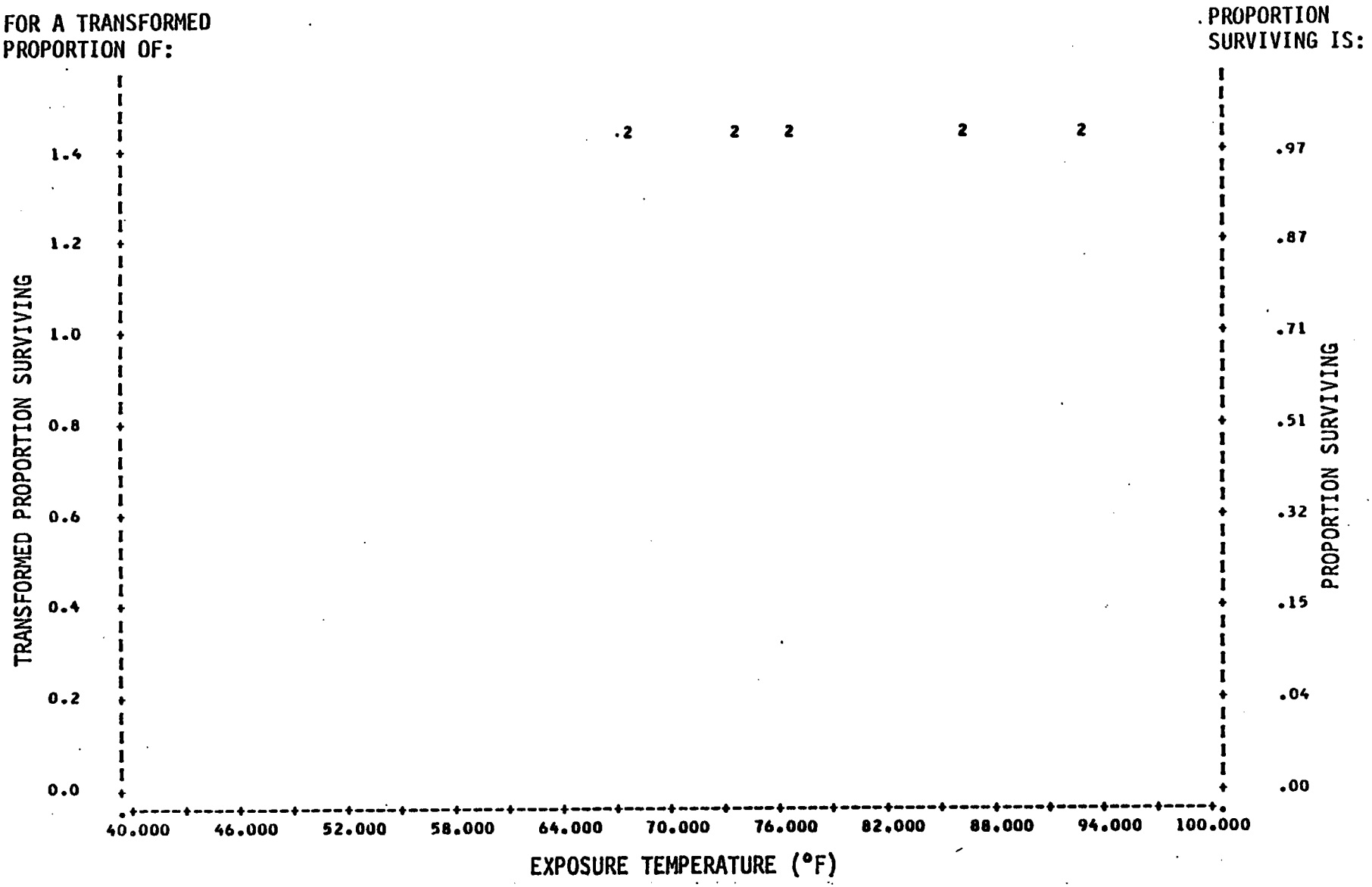
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
Δ°F - MINUTES EXPOSURE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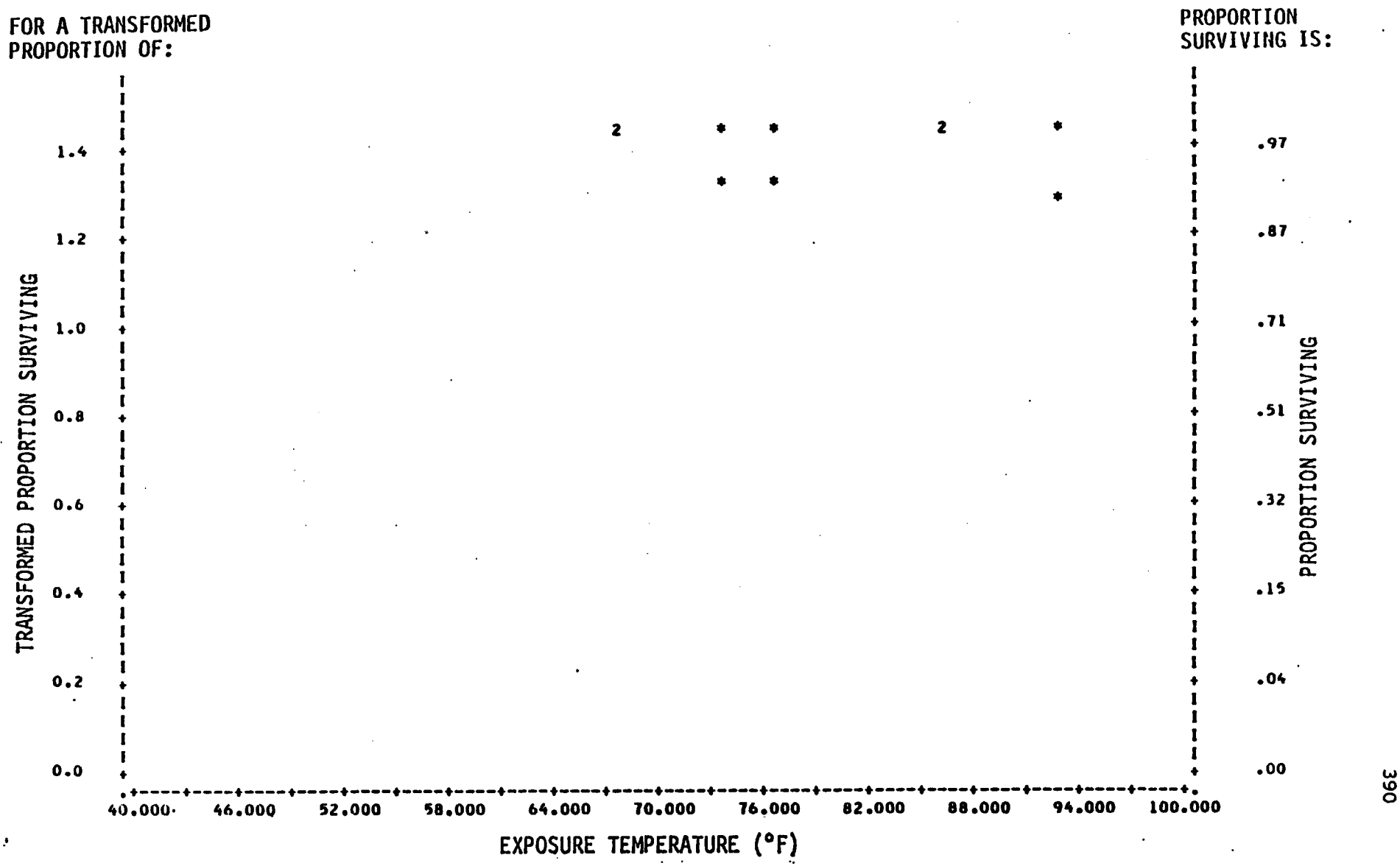
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.2 2 2 2 2
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000 46.000 52.000 58.000 64.000 70.000 76.000 82.000 88.000 94.000 100.000
EXPOSURE TEMPERATURE (°F)


FOR A TRANSFORMED PROPORTION OF:
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TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2
2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

FOR A TRANSFORMED
PROPORTION OF:

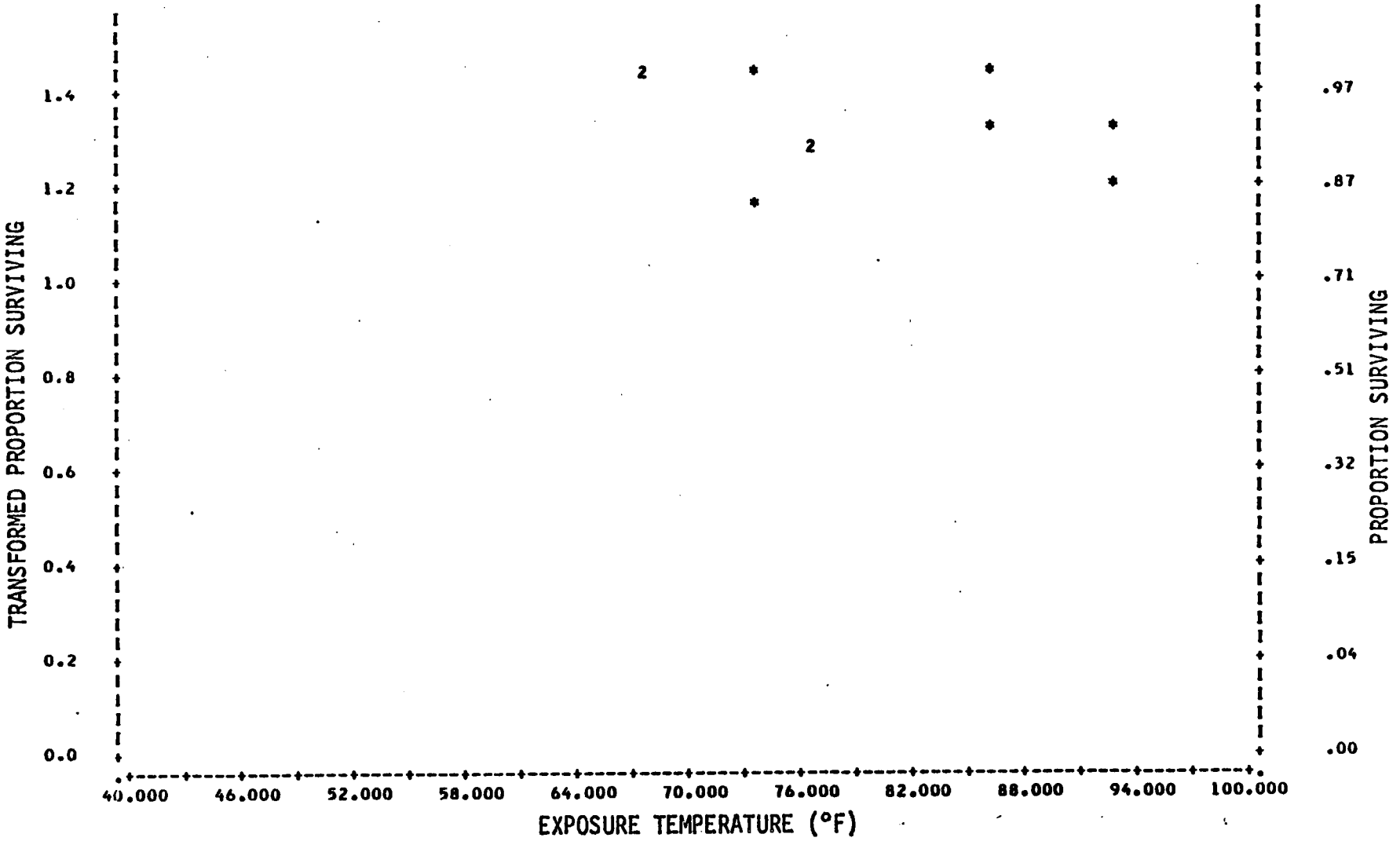
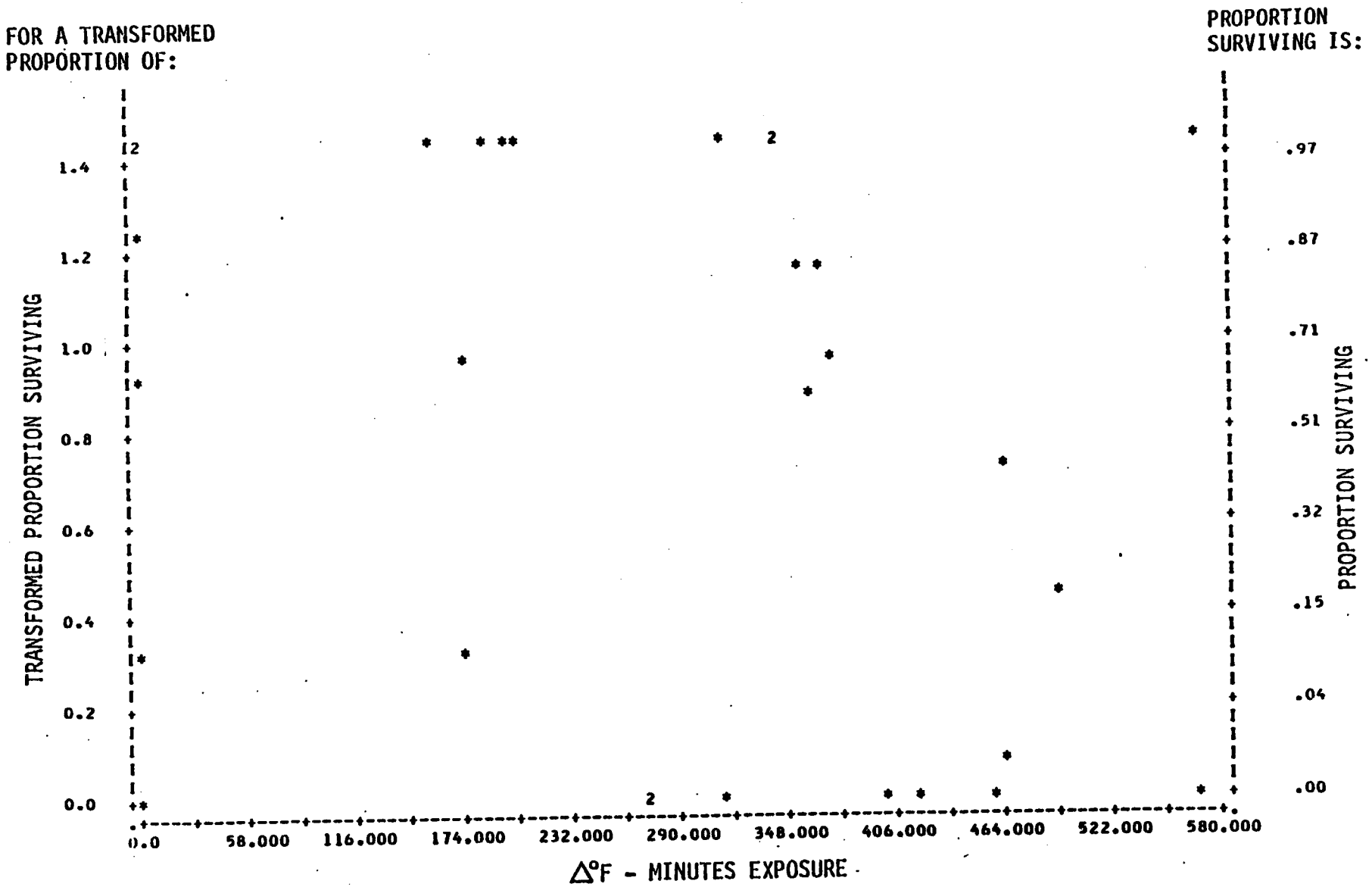
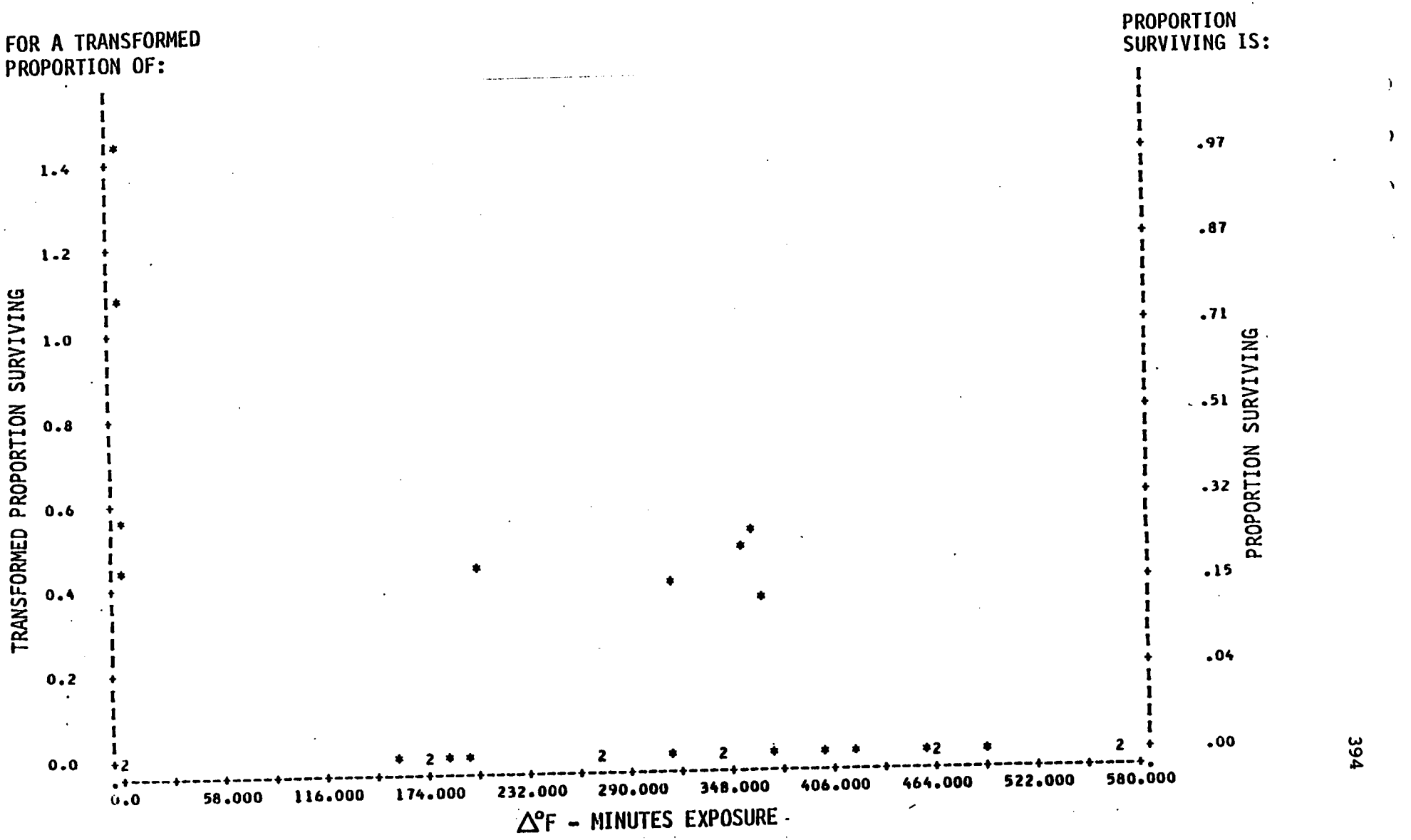


Figure D-10. Batch 7 larvae survivorship vs. thermal exposure.

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " " "
c) PA 8 " " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " " "
f) PA 8 " " " " "


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
ΔºF - MINUTES EXPOSURE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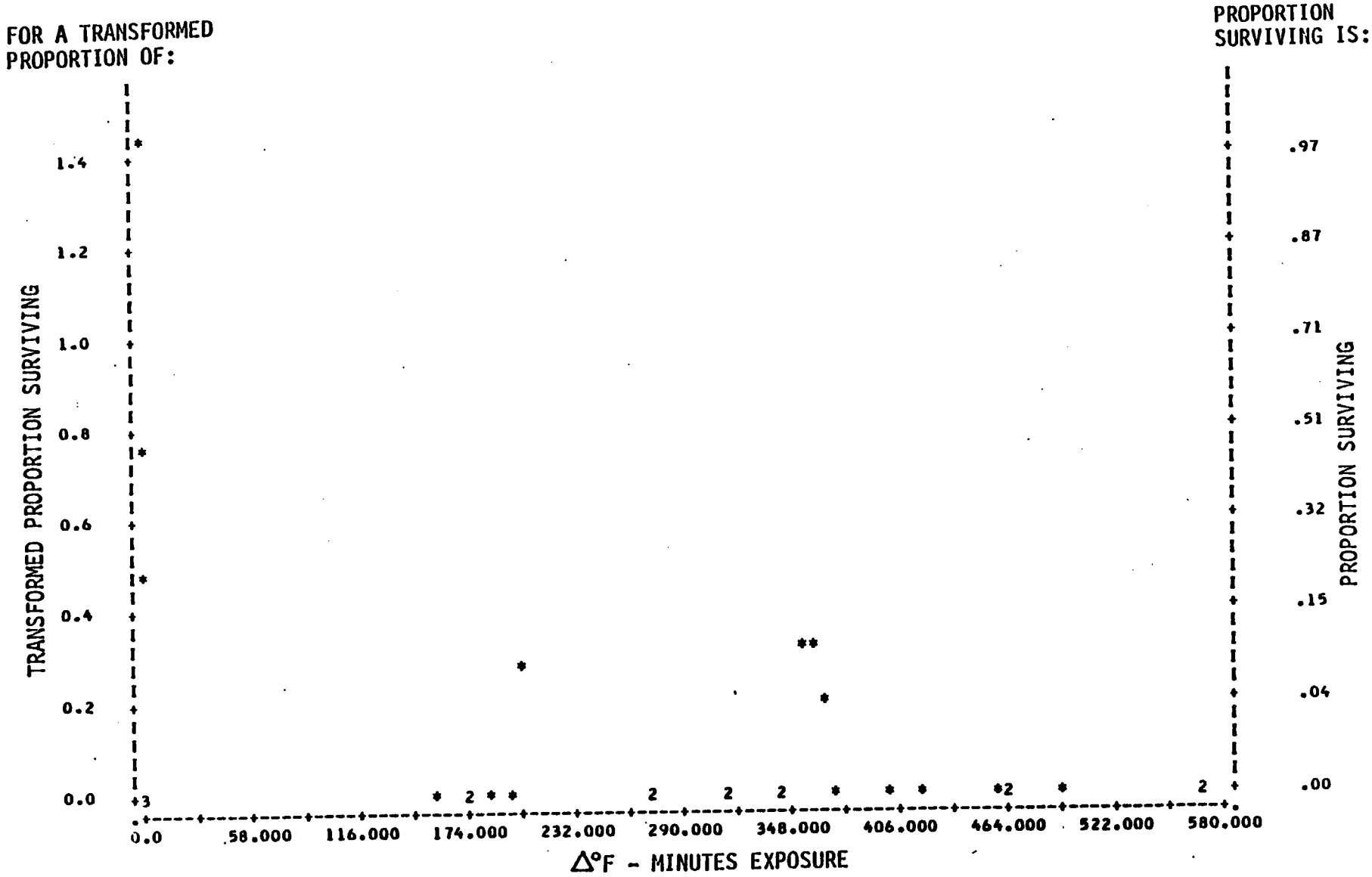
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
ΔºF - MINUTES EXPOSURE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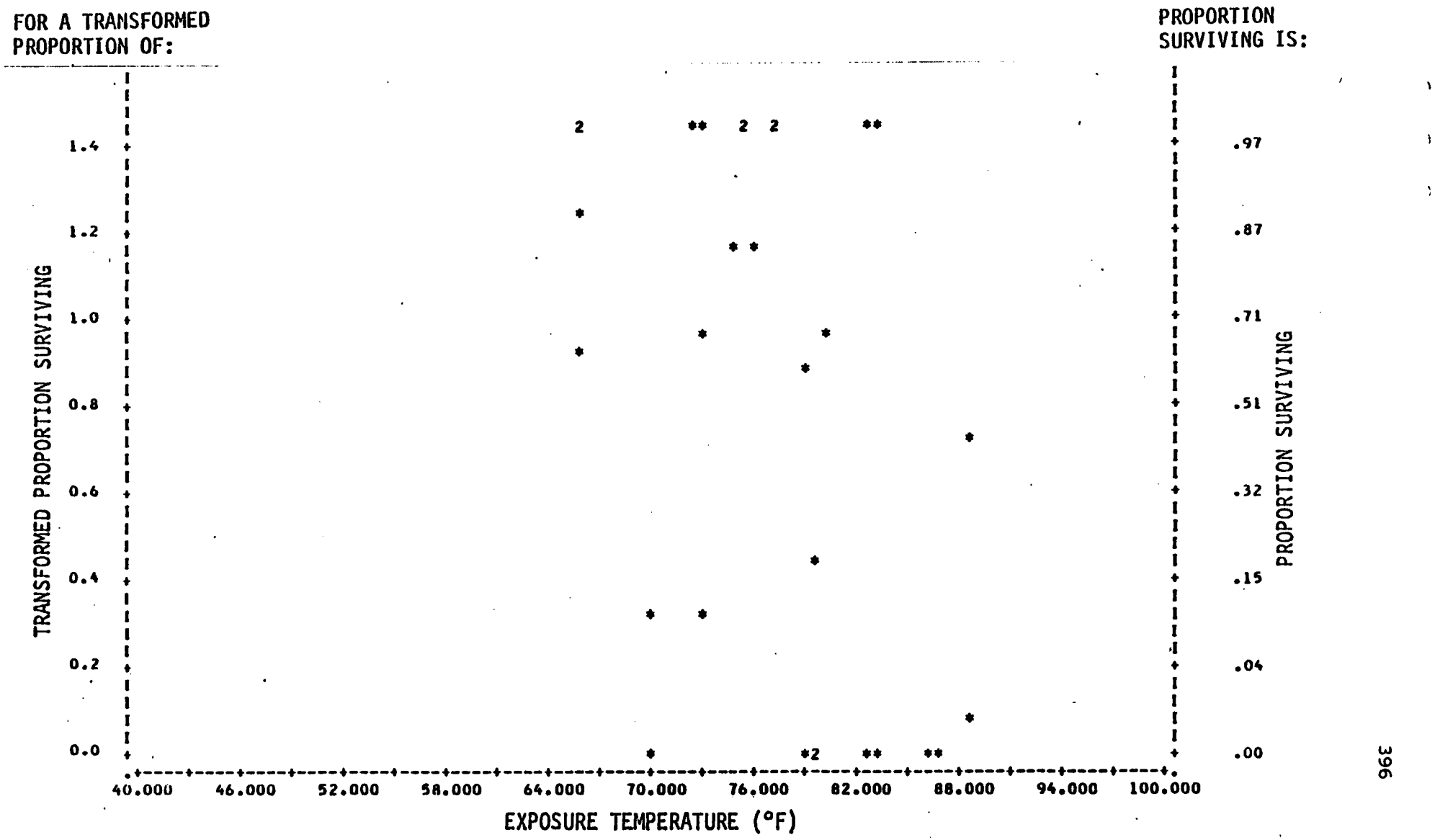
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
58.000
116.000
174.000
232.000
290.000
348.000
406.000
464.000
522.000
580.000
Δ°F - MINUTES EXPOSURE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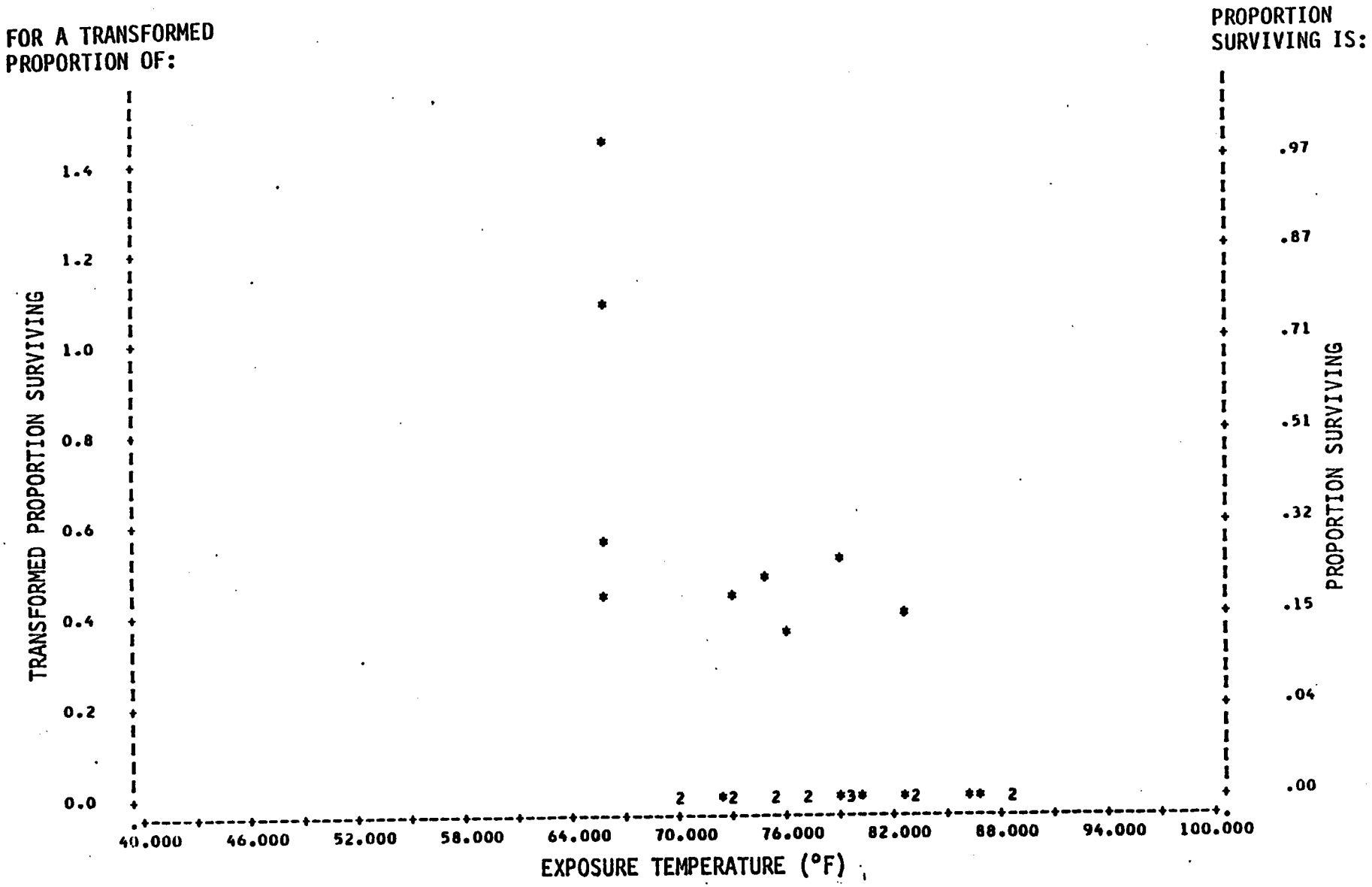
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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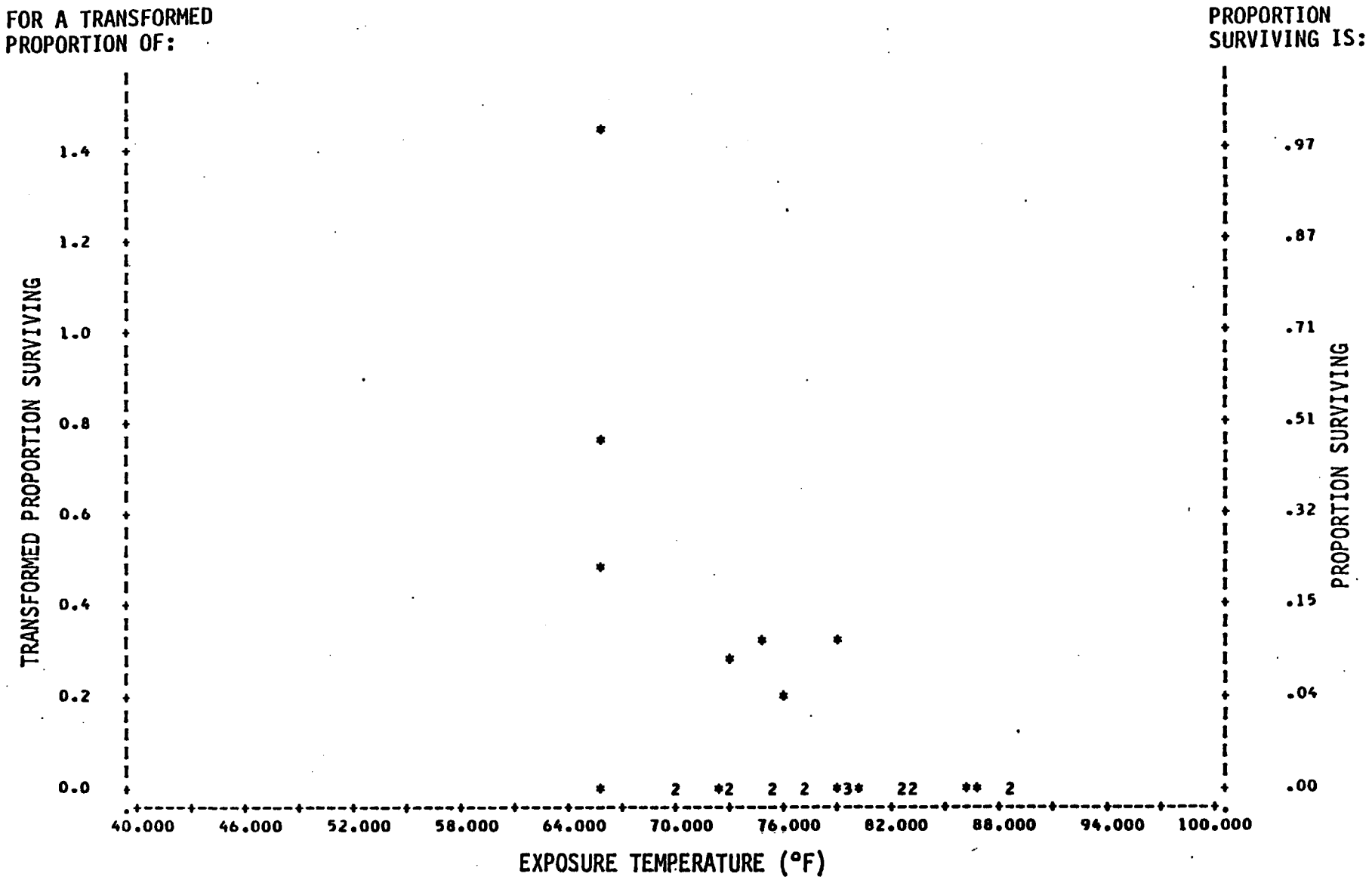
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2 *2 2 2 *3* *2 ** 2
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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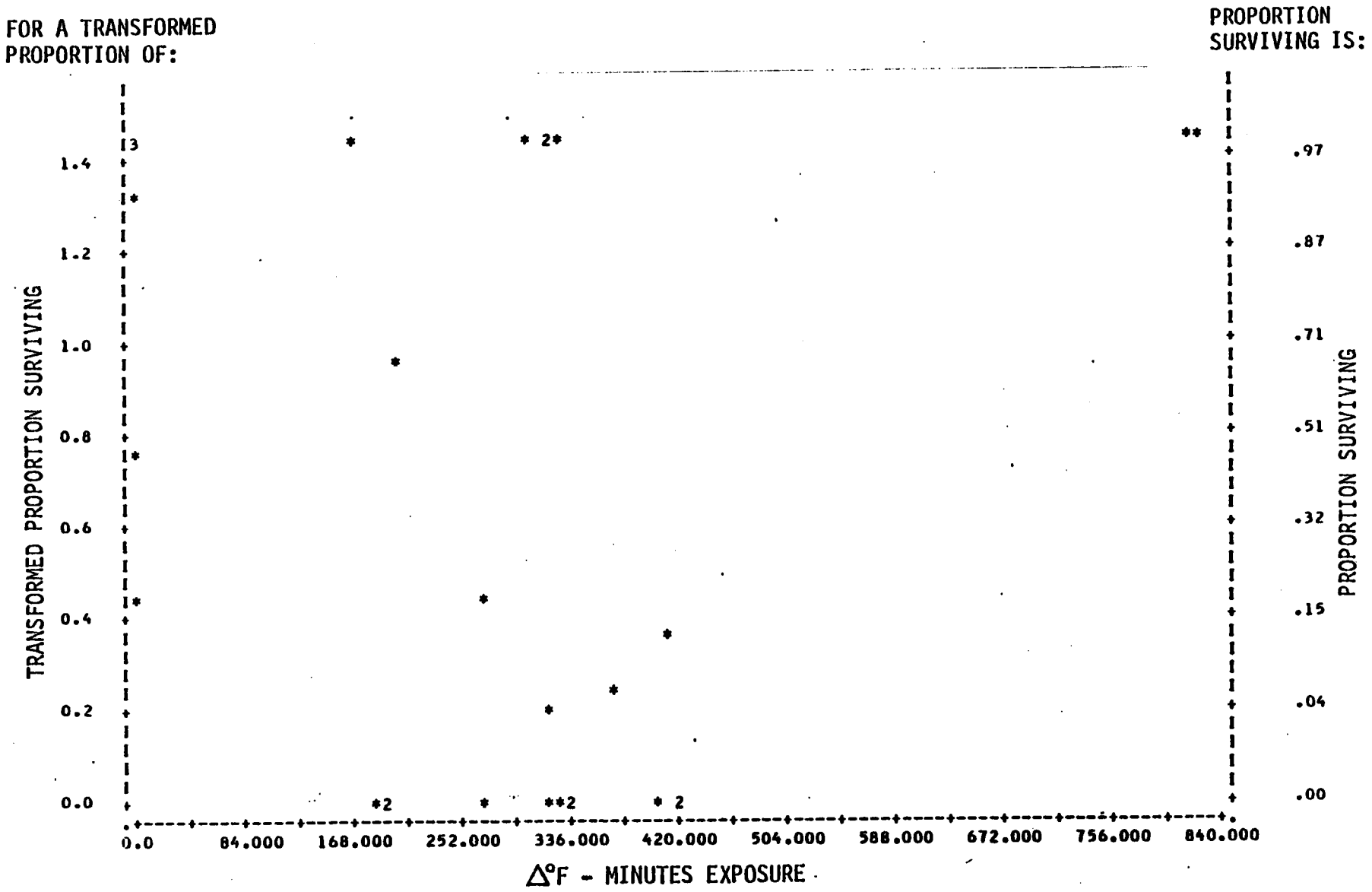
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2 *2 2 2 *3* 22 ** 2
40.000 46.000 52.000 58.000 64.000 70.000 76.000 82.000 88.000 94.000 100.000
EXPOSURE TEMPERATURE (°F)

Figure D-11. Batch 8 larvae survivorship vs. thermal exposure

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " "
c) PA 8 " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " "
f) PA 8 " " " "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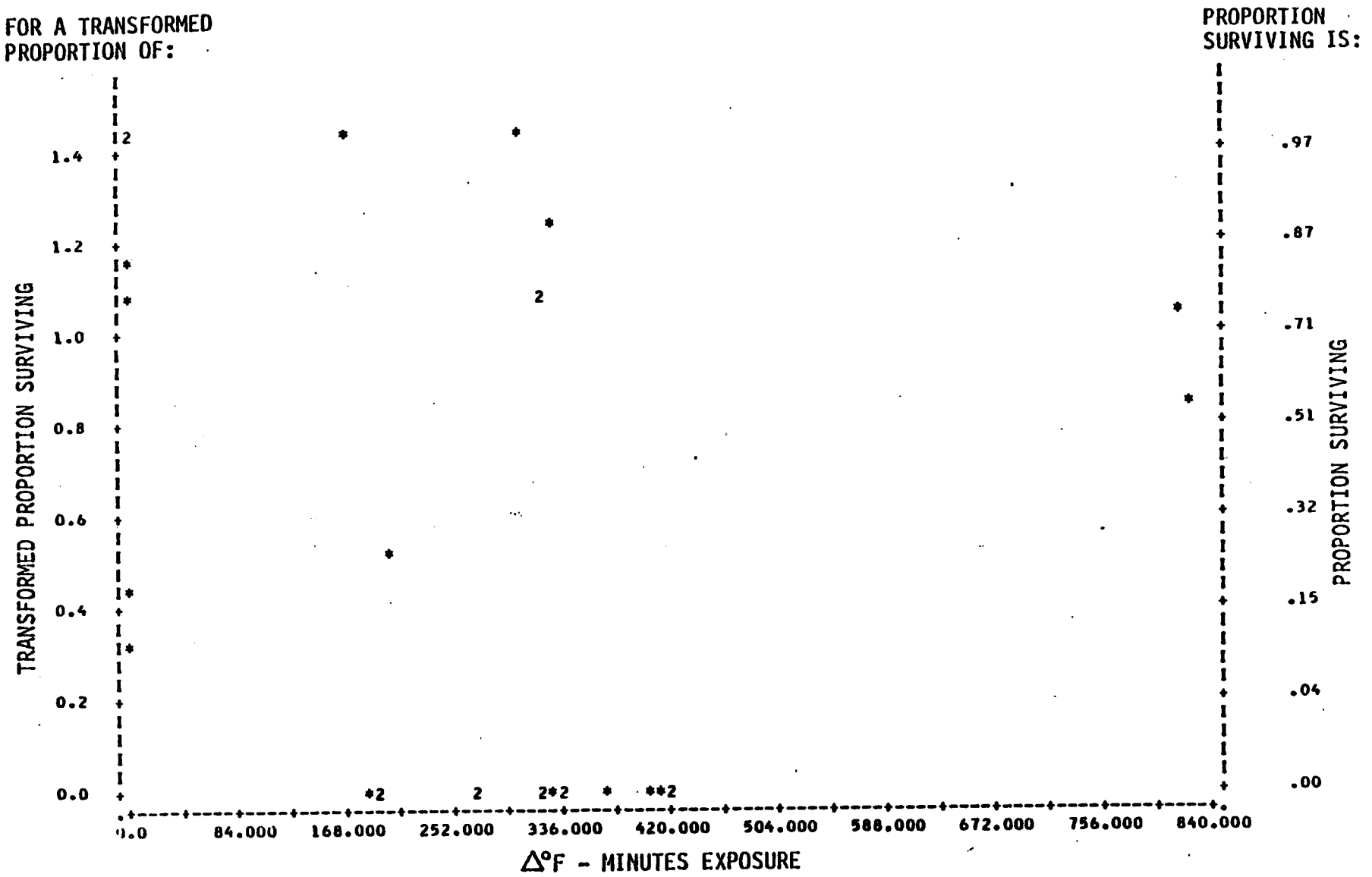
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
84.000
168.000
252.000
336.000
420.000
504.000
588.000
672.000
756.000
840.000
ΔºF - MINUTES EXPOSURE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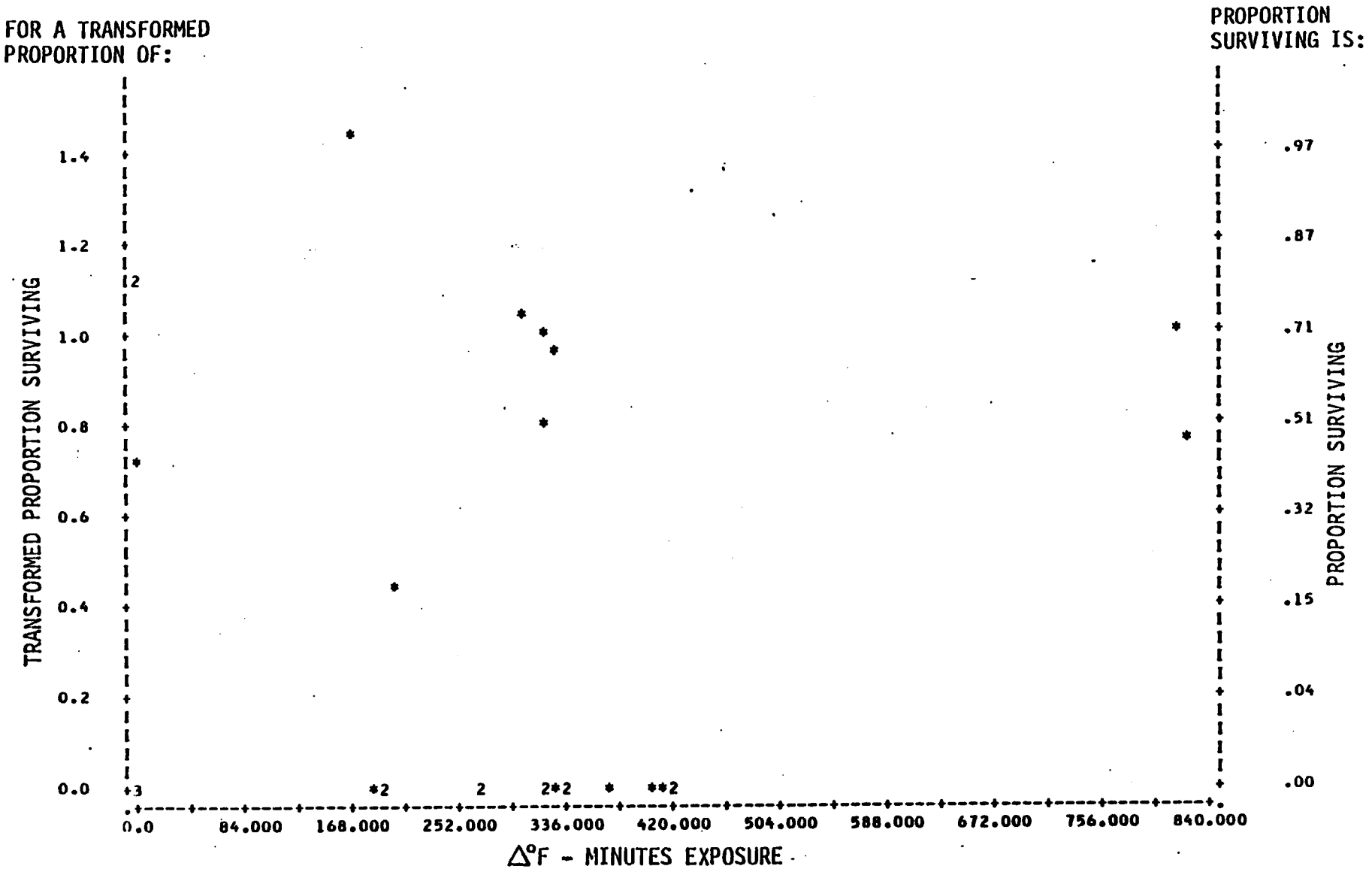
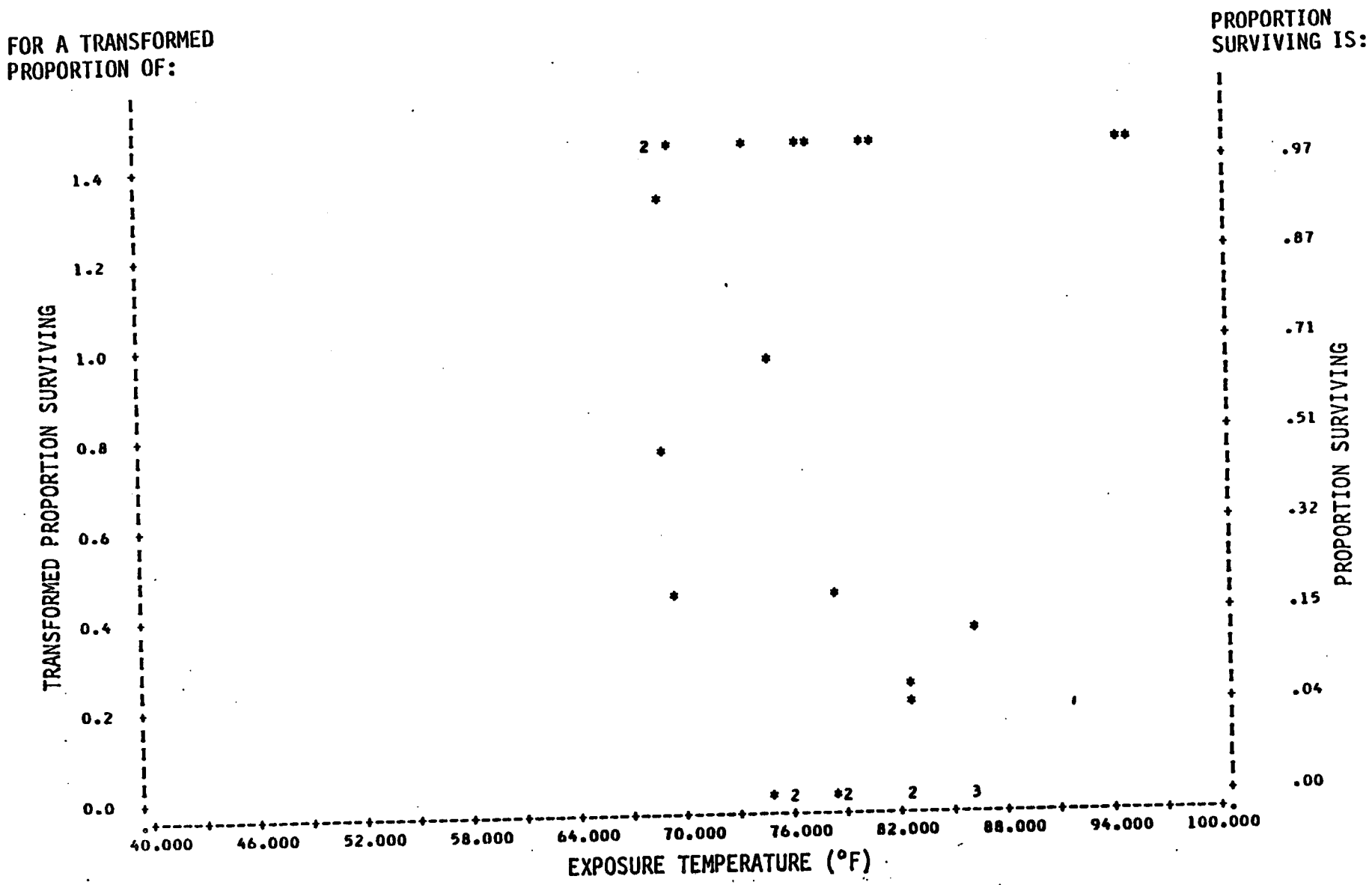
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
84.000
168.000
252.000
336.000
420.000
504.000
588.000
672.000
756.000
840.000
Δ°F - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
84.000
168.000
252.000
336.000
420.000
504.000
588.000
672.000
756.000
840.000
ΔºF - MINUTES EXPOSURE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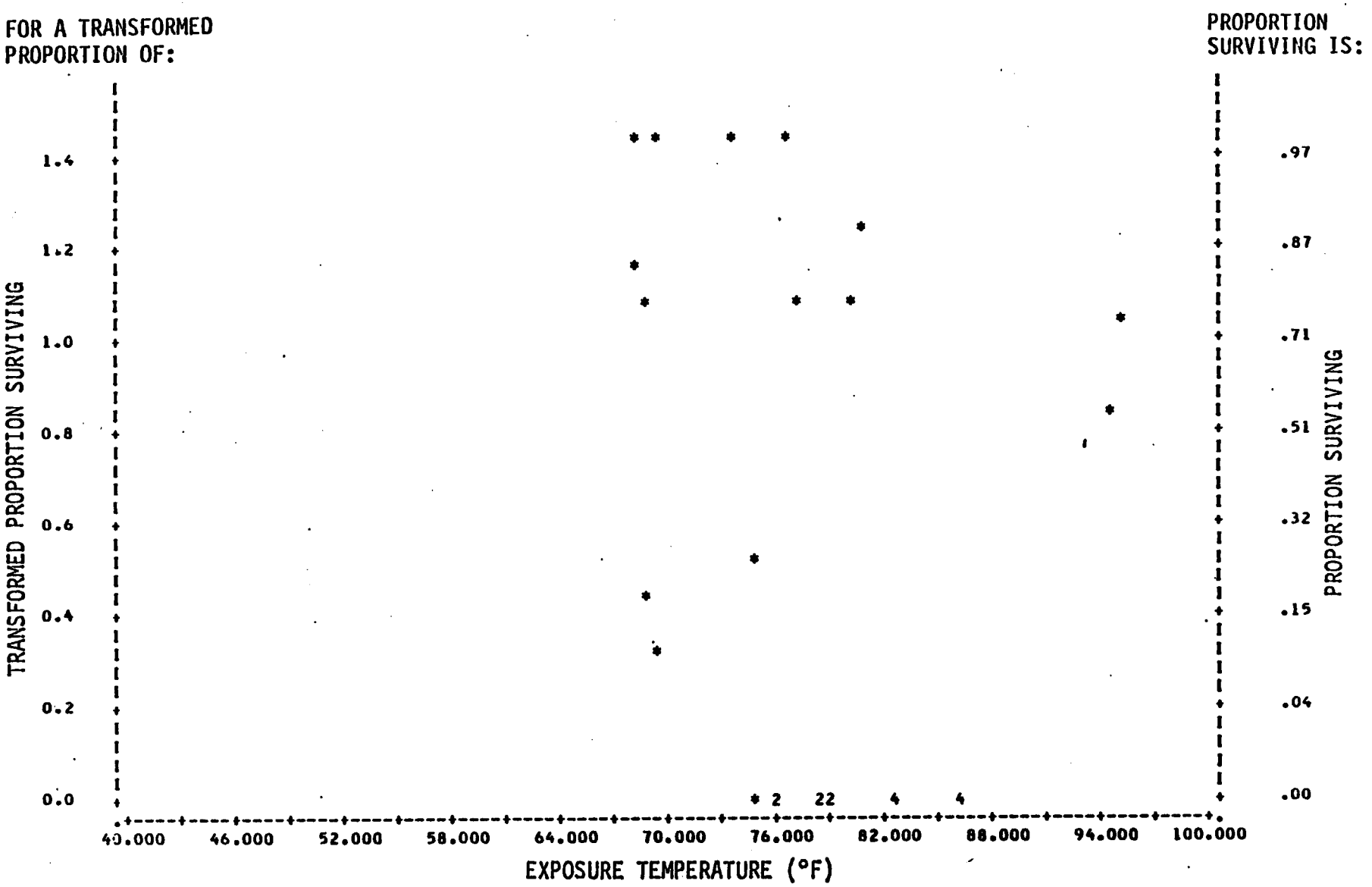
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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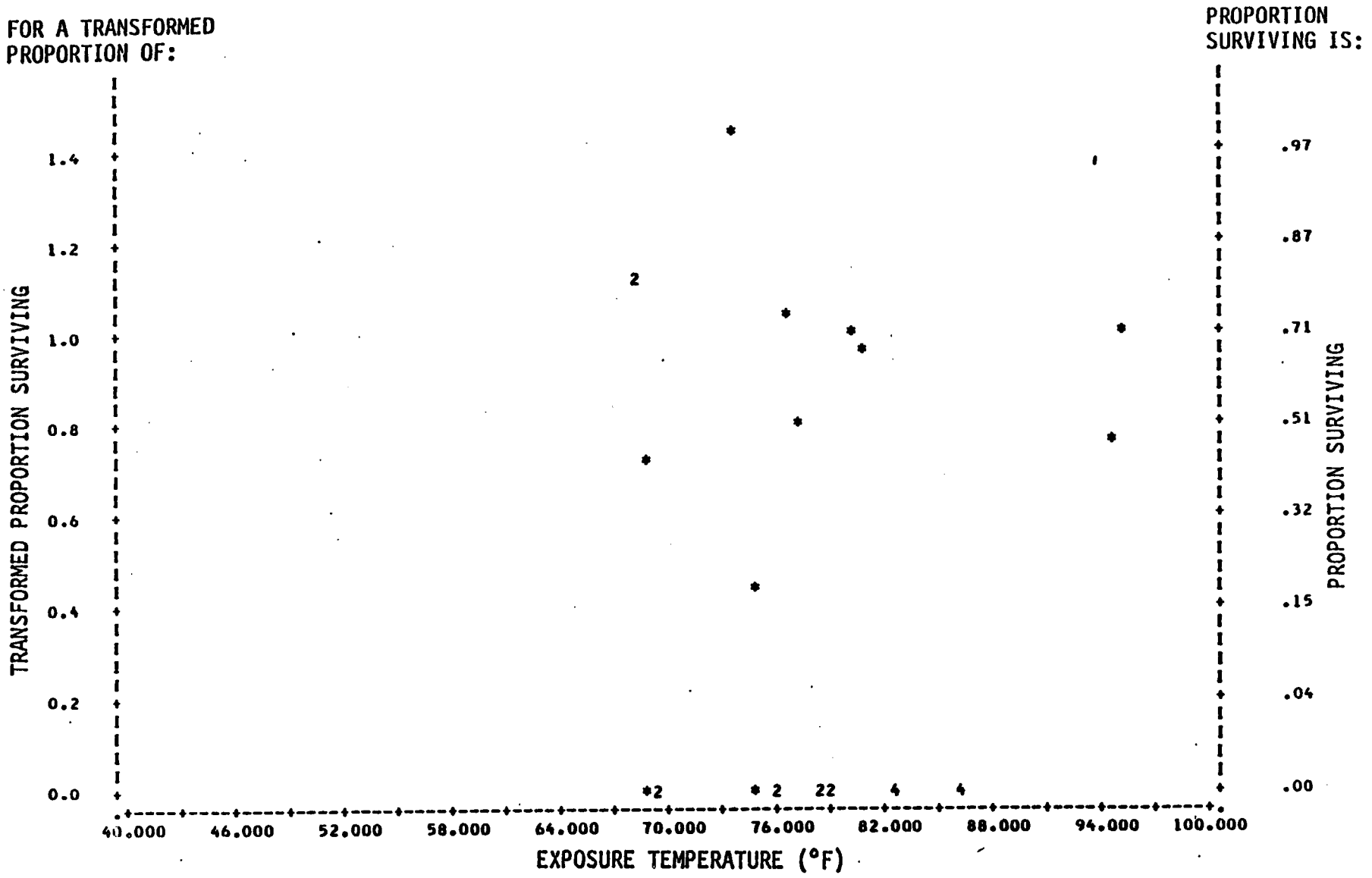
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
* 2 22 4 4
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
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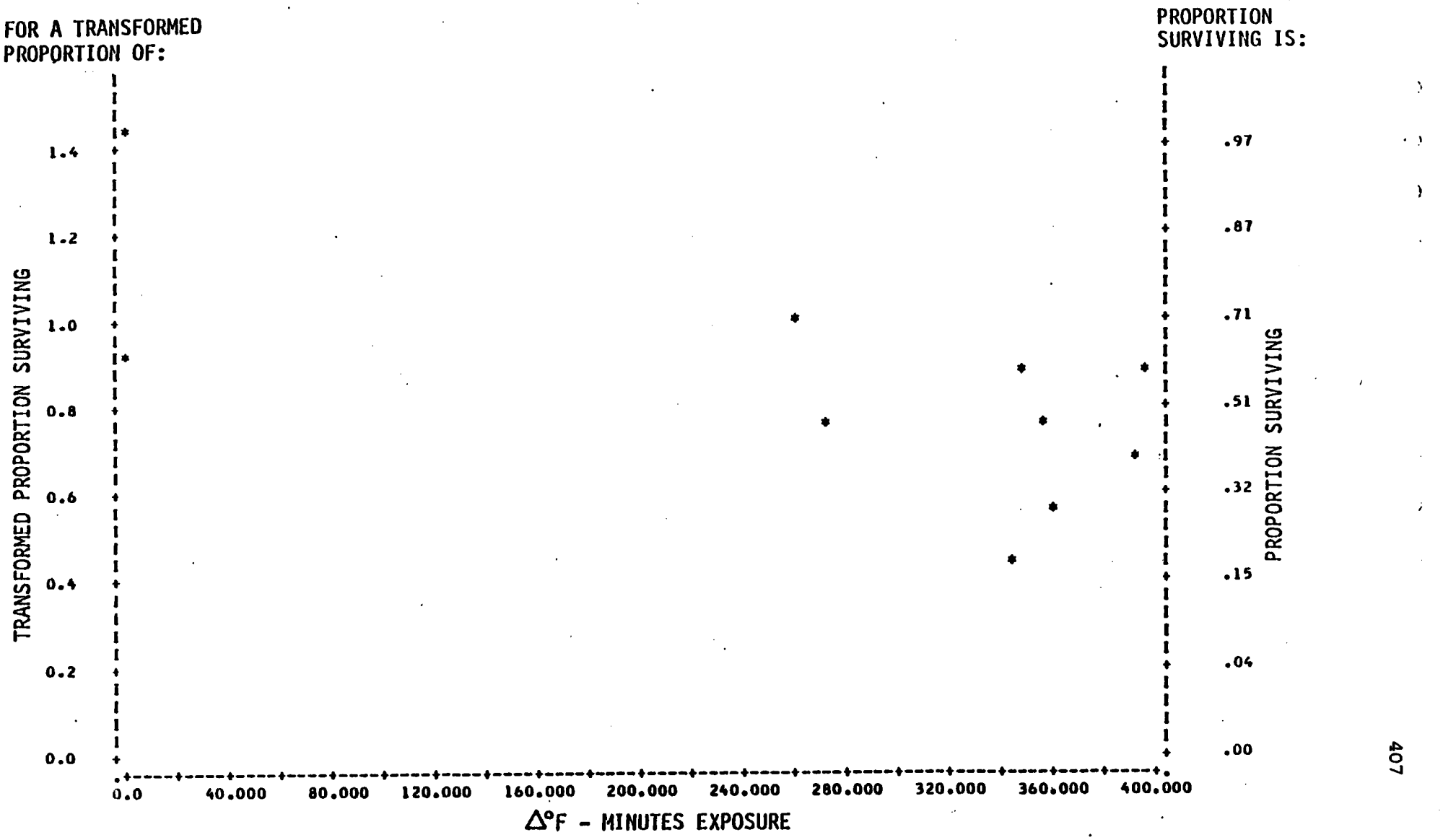
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
2
*2
* 2
22
4
4
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D.11f

Figure D-12. Batch 9 larvae survivorship vs. thermal exposure

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " " "
c) PA 8 " " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " " "
f) PA 8 " " " " "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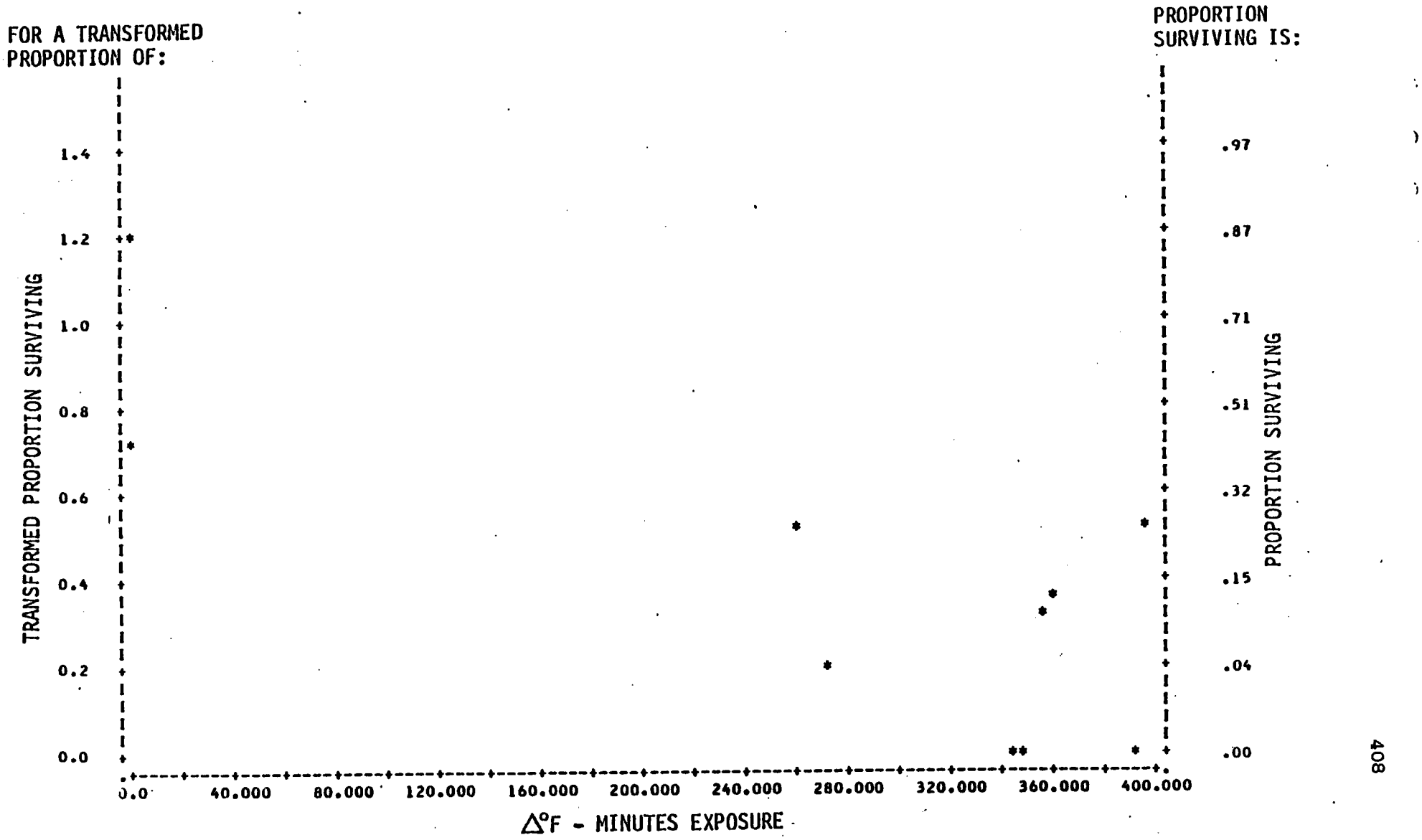
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
40.000
80.000
120.000
160.000
200.000
240.000
280.000
320.000
360.000
400.000
ΔºF - MINUTES EXPOSURE

Figure D-12a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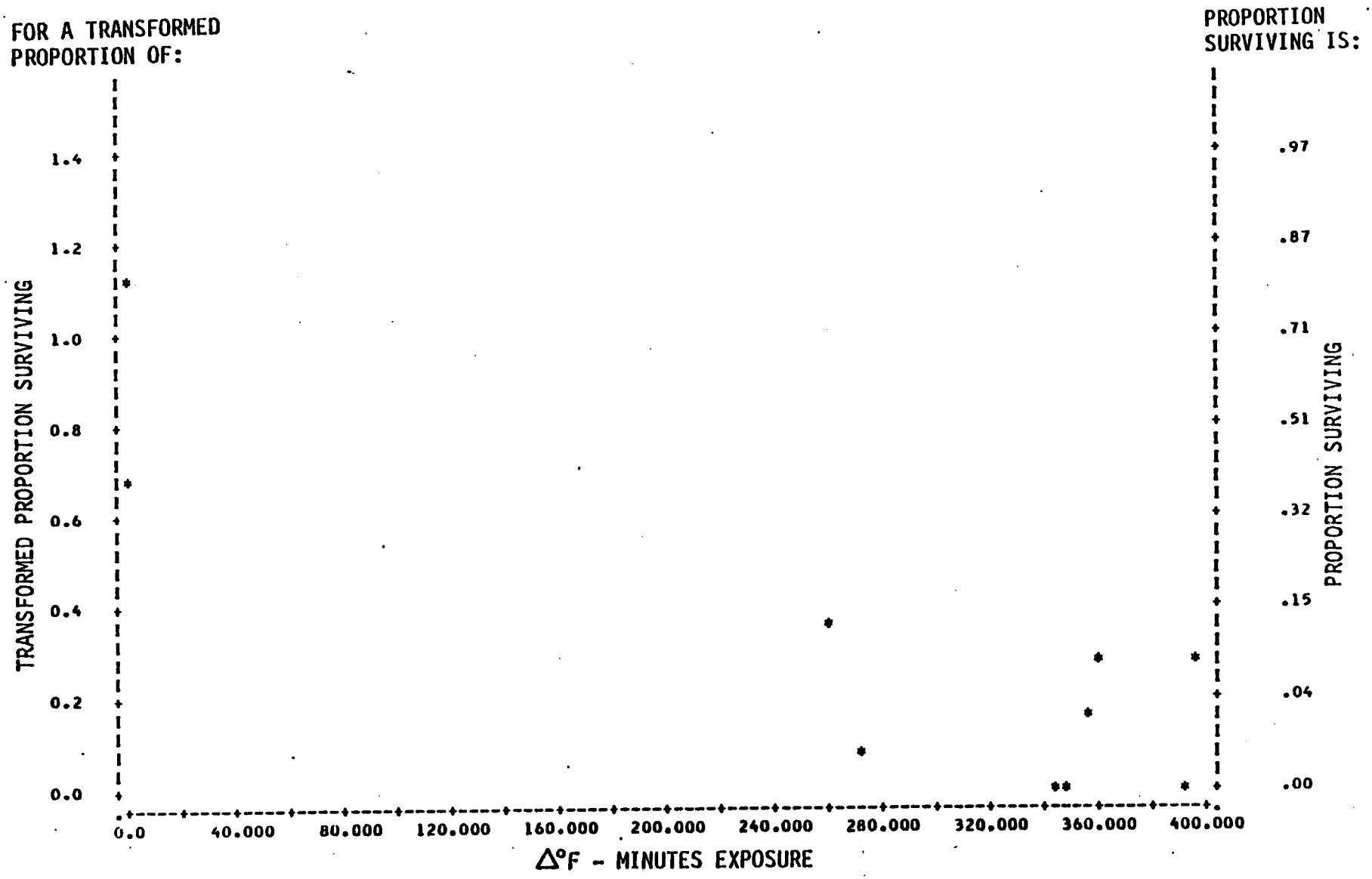
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
40.000
80.000
120.000
160.000
200.000
240.000
280.000
320.000
360.000
400.000
ΔºF - MINUTES EXPOSURE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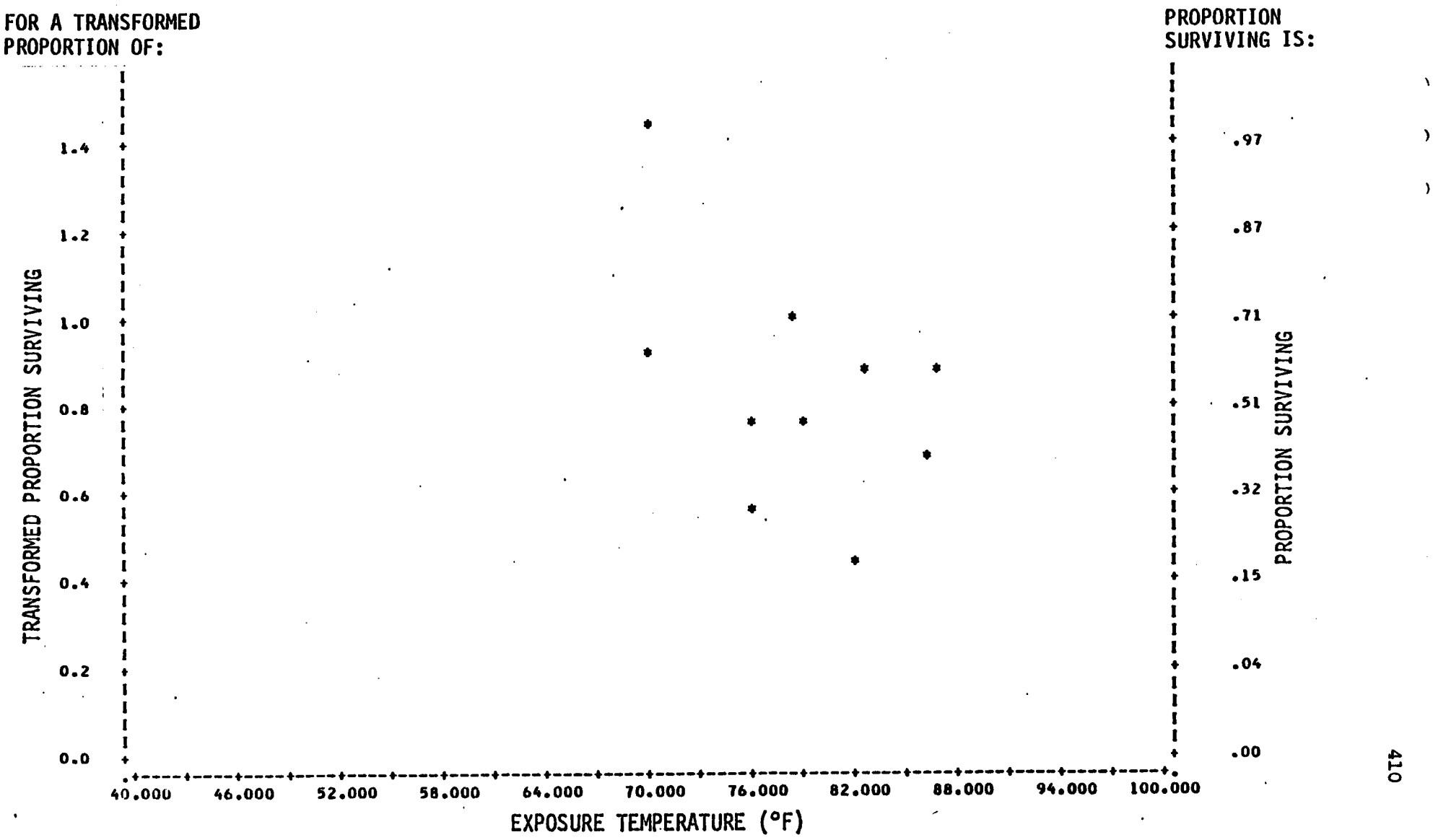
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
40.000
80.000
120.000
160.000
200.000
240.000
280.000
320.000
360.000
400.000
ΔºF - MINUTES EXPOSURE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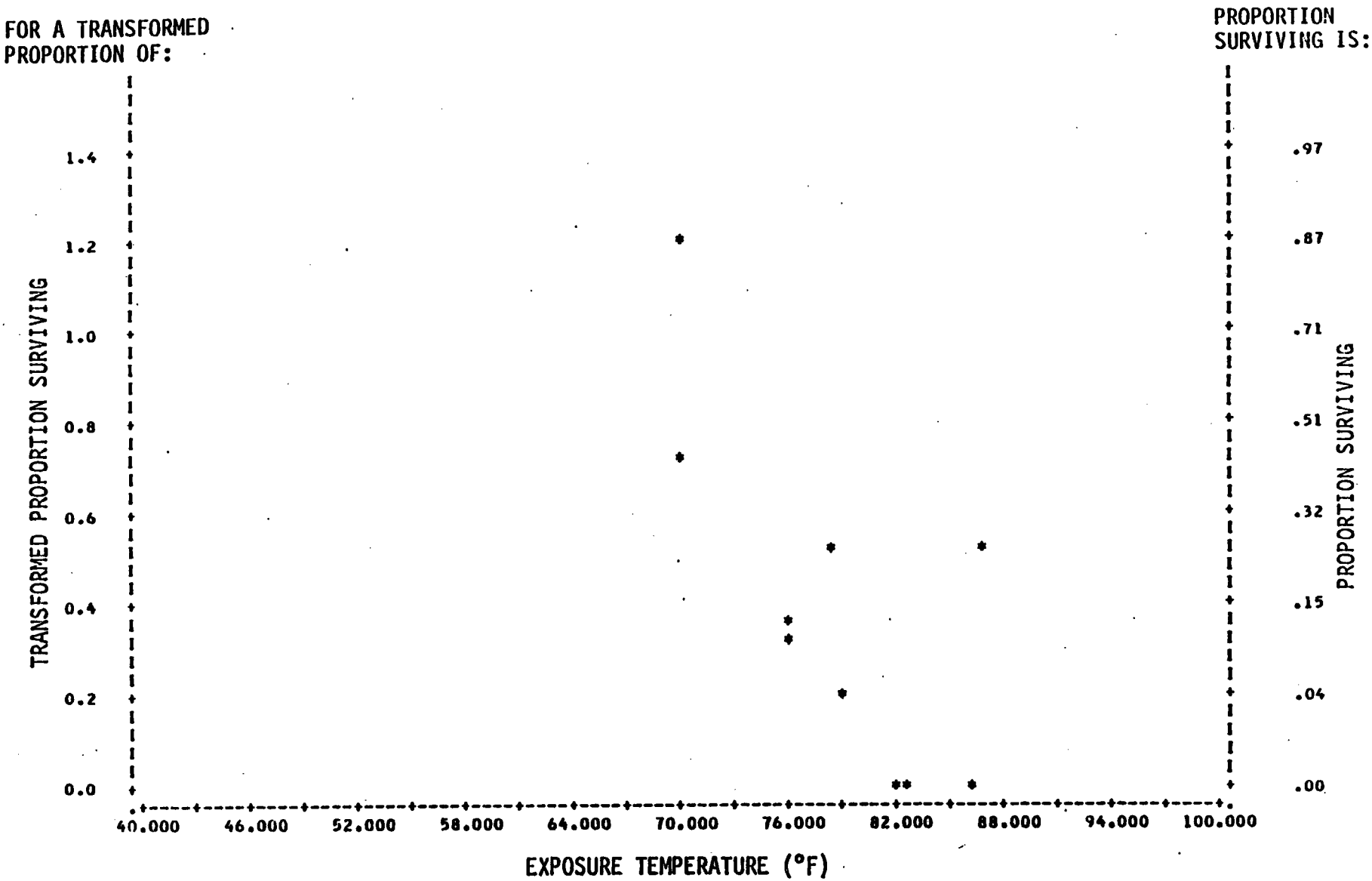
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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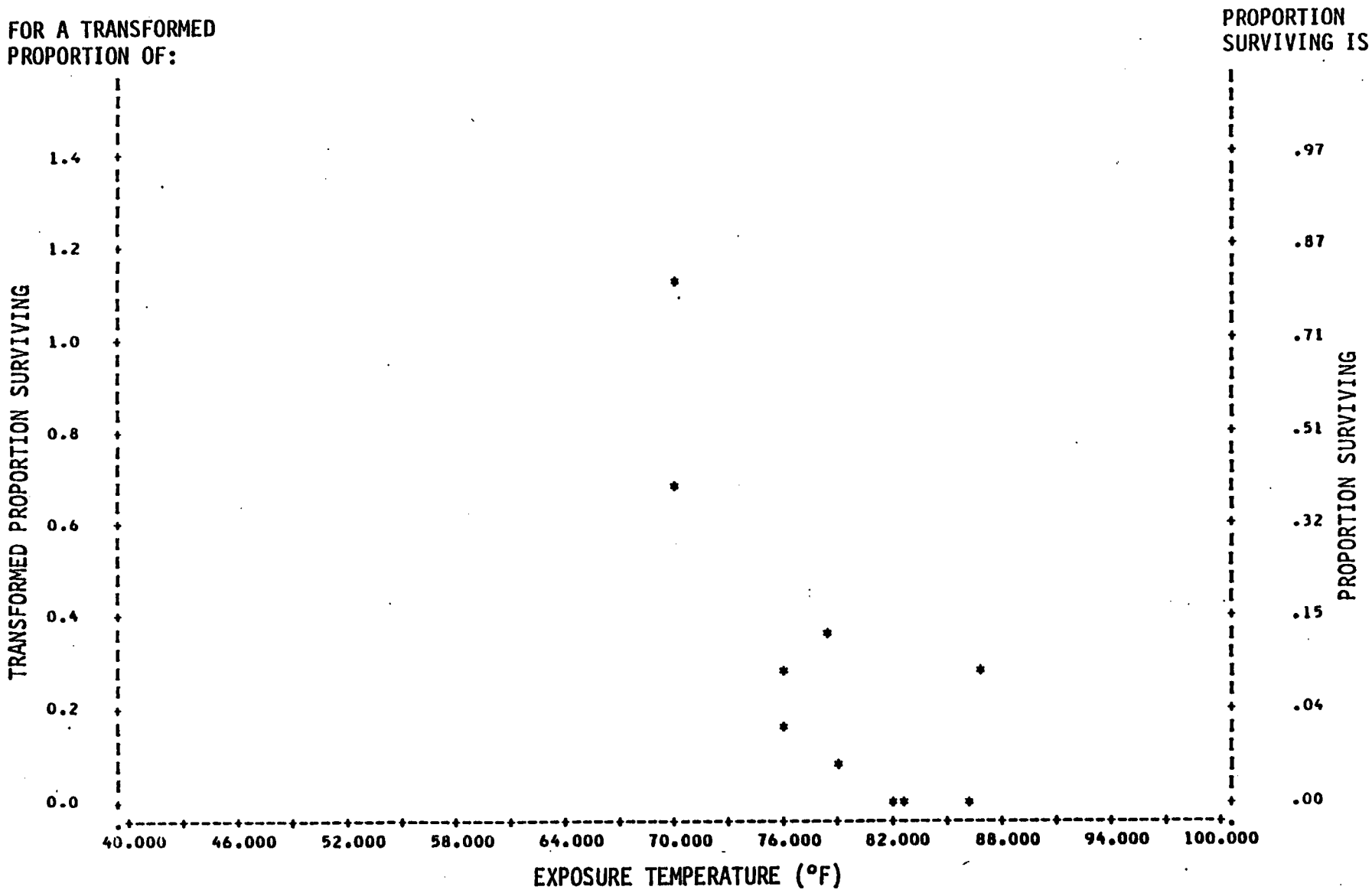
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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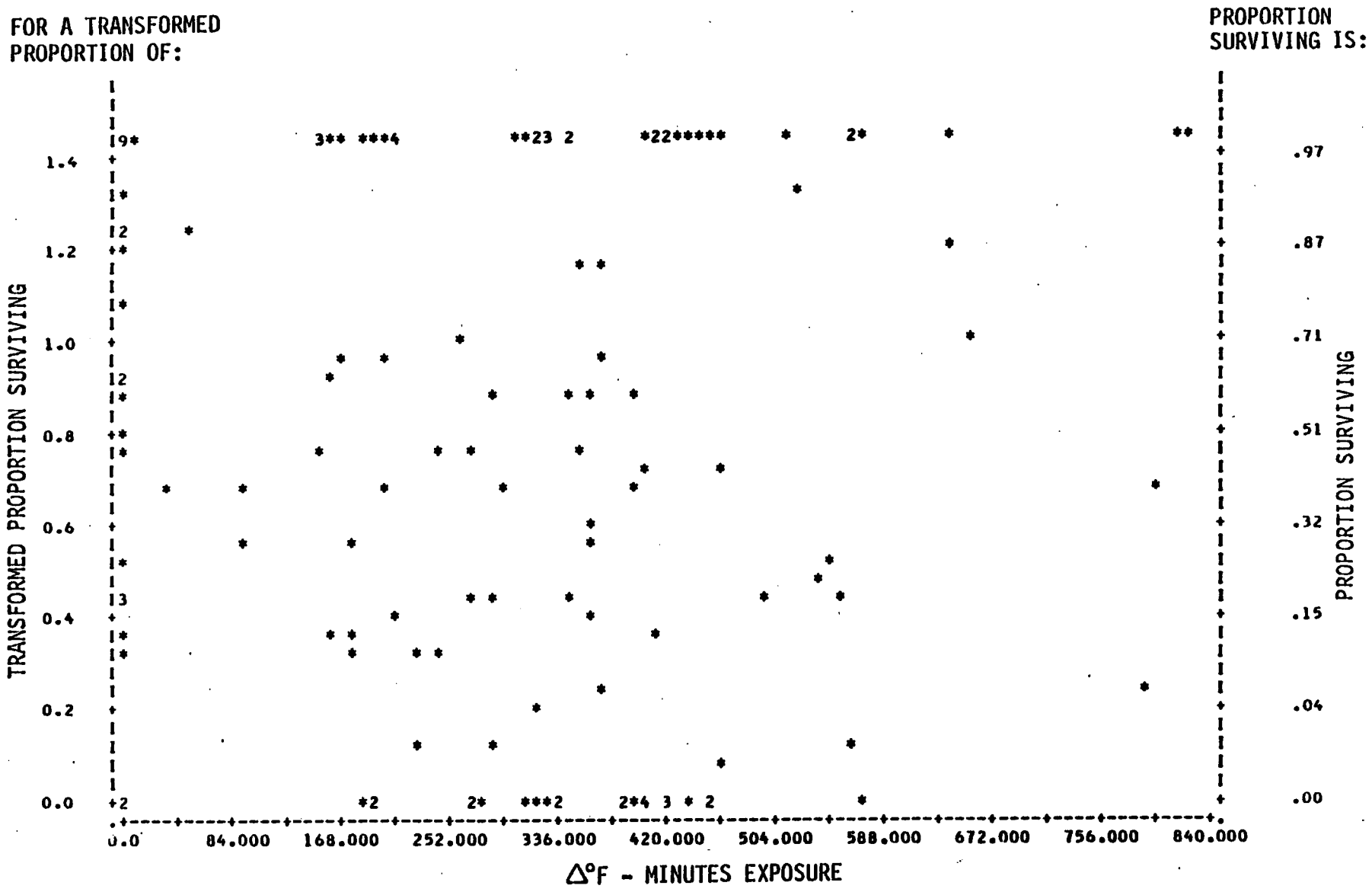
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D-13. Larvae survivorship (all batches) vs. thermal exposure

a) PA 1 vs. calculated dose (Δ°F-min)
b) PA 4 " " " "
c) PA 8 " " " "
d) PA 1 vs. maximum exposure temperature (°F)
e) PA 4 " " " " "
f) PA 8 " " " " "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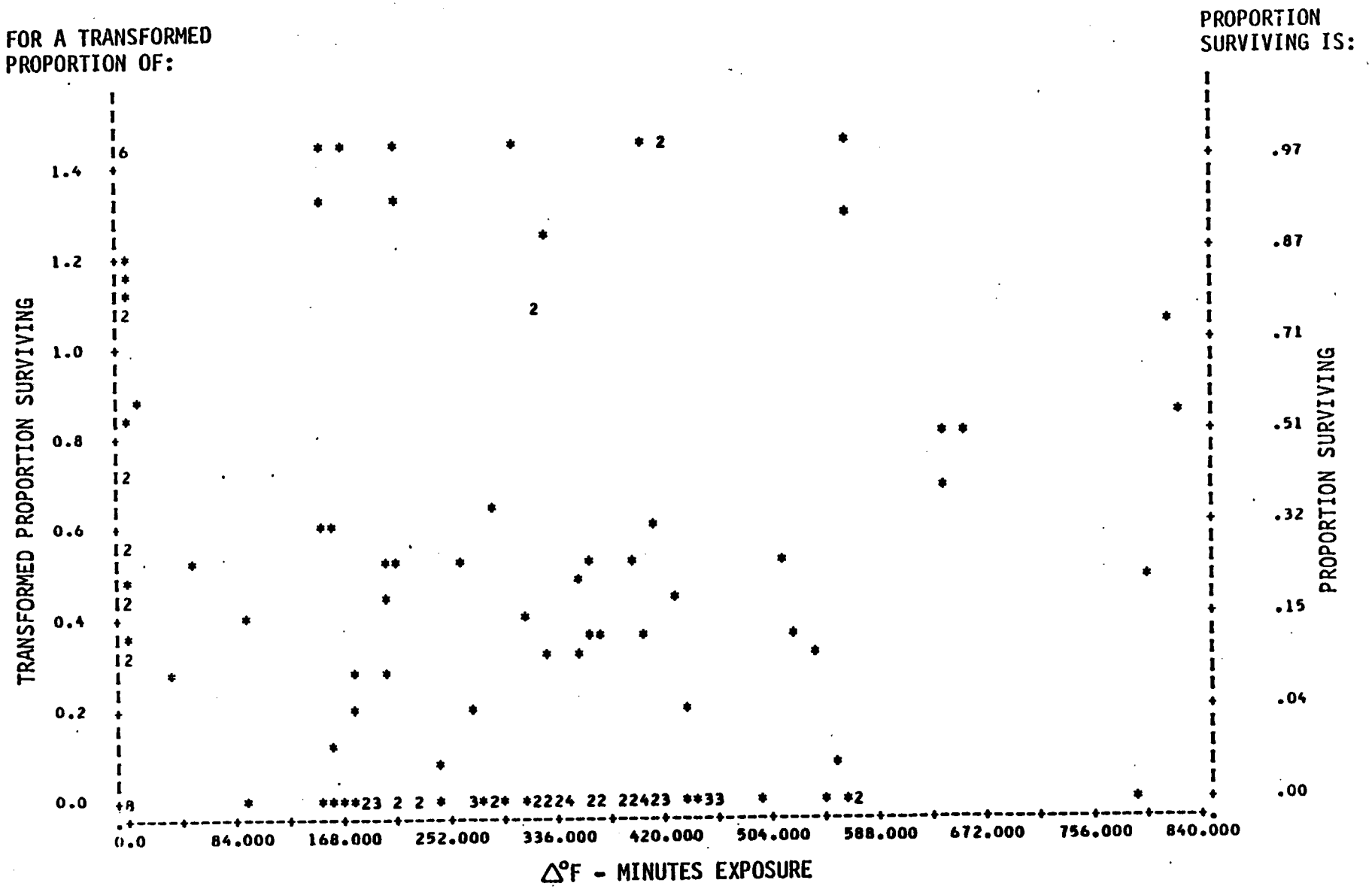
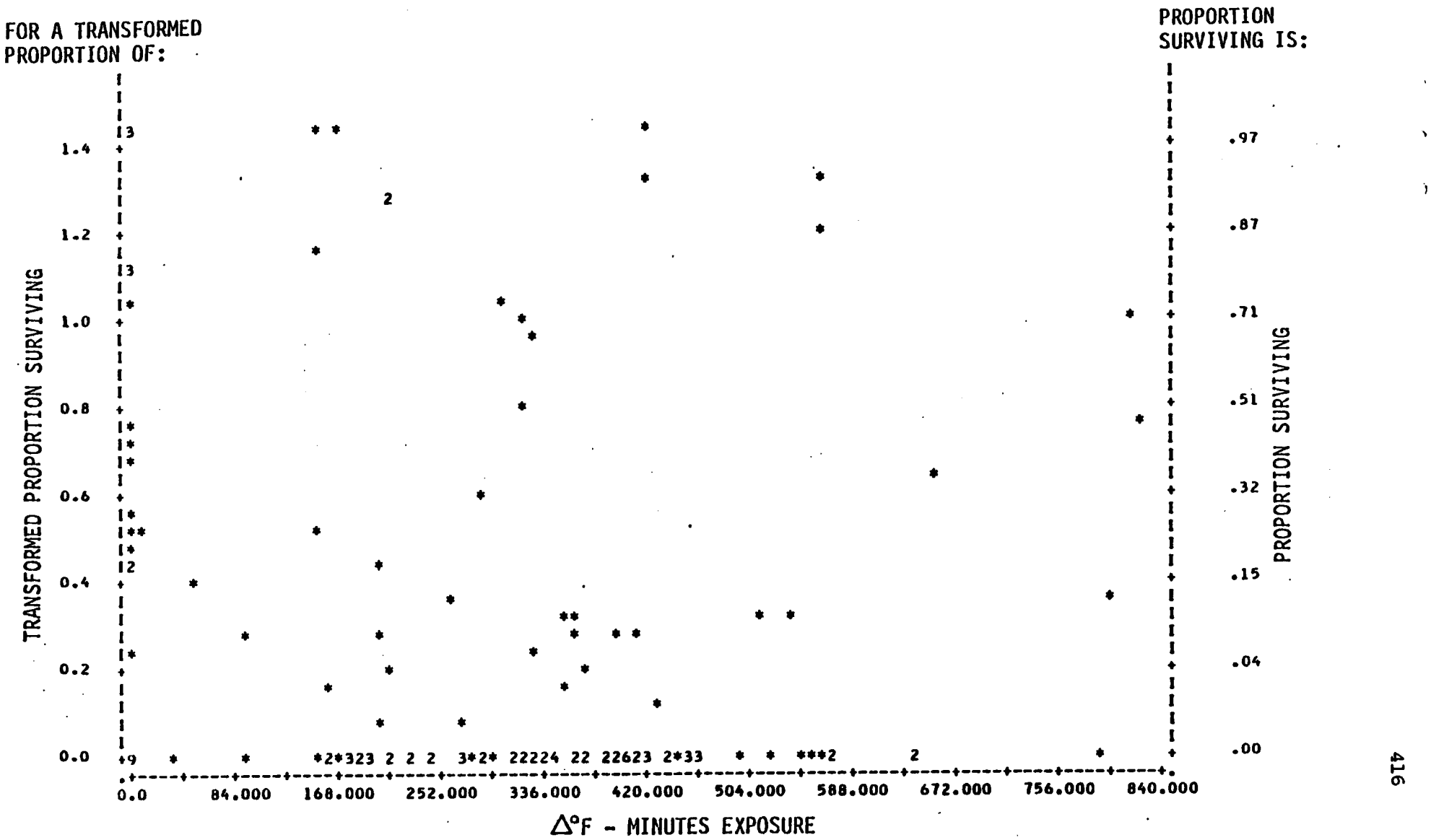
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
0.0
84.000
168.000
252.000
336.000
420.000
504.000
588.000
672.000
756.000
840.000
ΔºF - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
0.0
84.000
168.000
252.000
336.000
420.000
504.000
588.000
672.000
756.000
840.000
Δ°F - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
TRANSFORMED PROPORTION SURVIVING
PROPORTION SURVIVING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
.00
.04
.15
.32
.51
.71
.87
.97
0.0
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168.000
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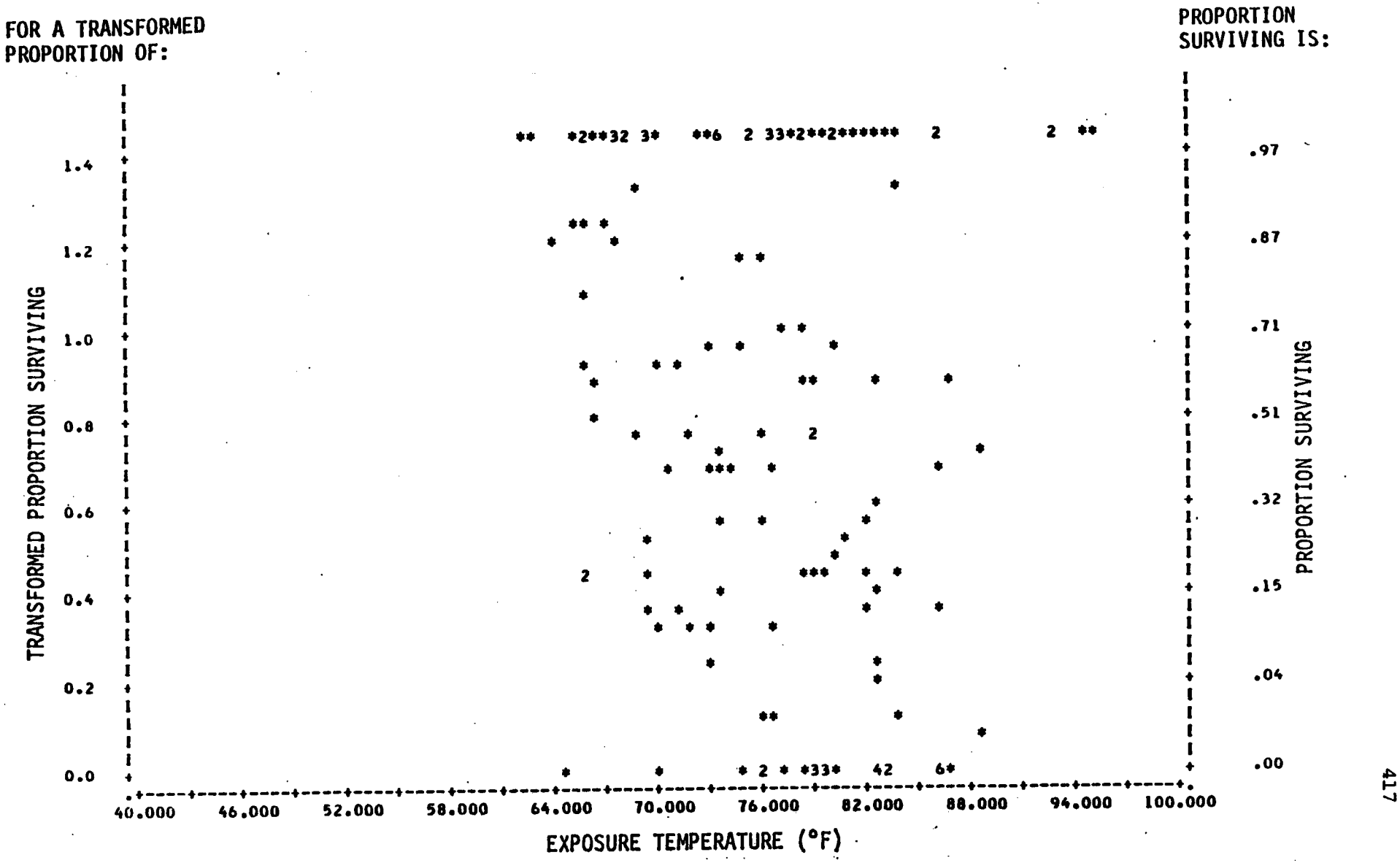
588.000
672.000
756.000
840.000
Δ°F - MINUTES EXPOSURE


FOR A TRANSFORMED PROPORTION OF:
PROPORTION SURVIVING IS:
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1.0
0.8
0.6
0.4
0.2
0.0
.97
.87
.71
.51
.32
.15
.04
.00
PROPORTION SURVIVING
40.000
46.000
52.000
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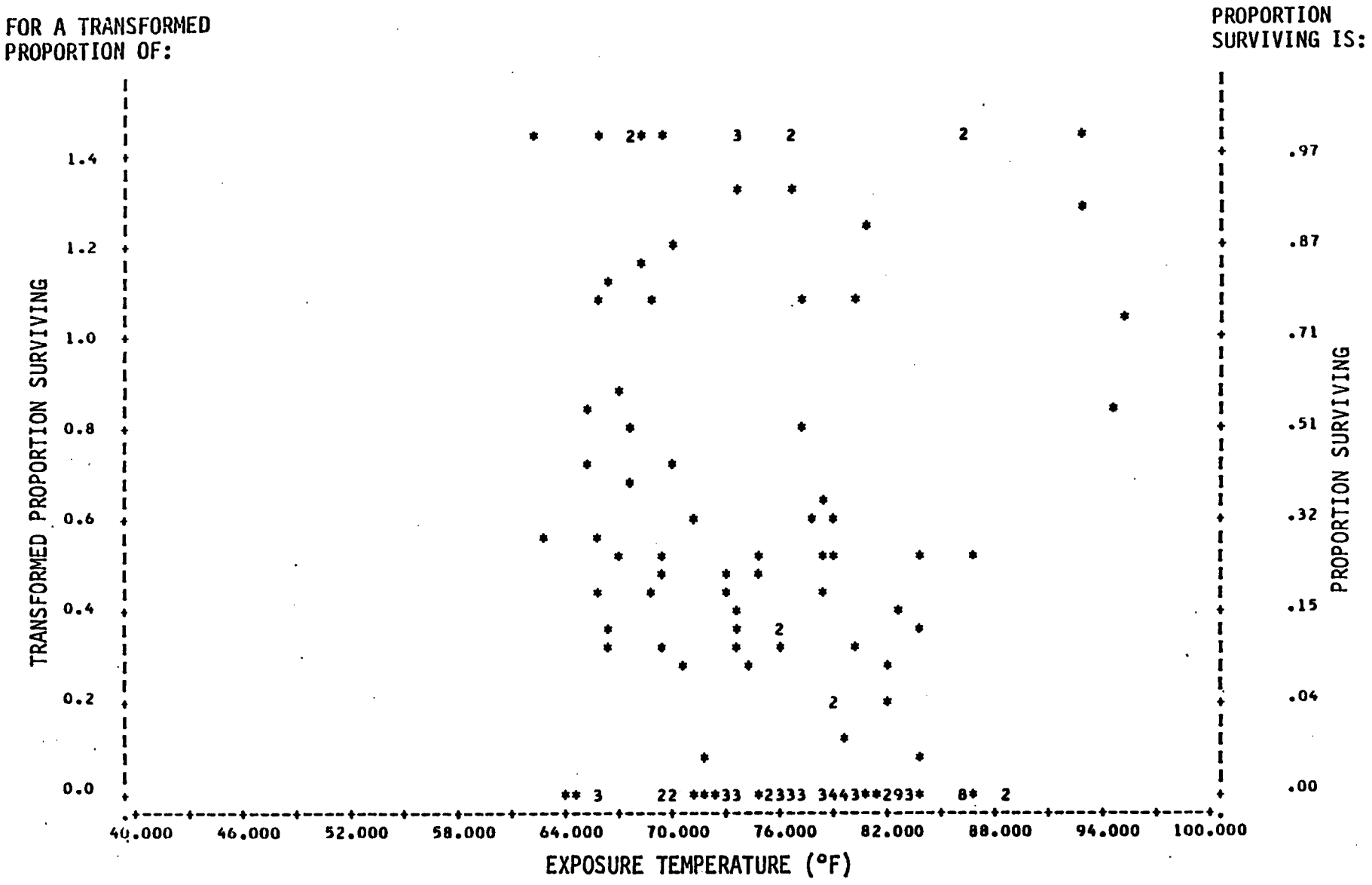
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)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0.6
0.4
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0.0
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.00
PROPORTION SURVIVING
40.000
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70.000
76.000
82.000
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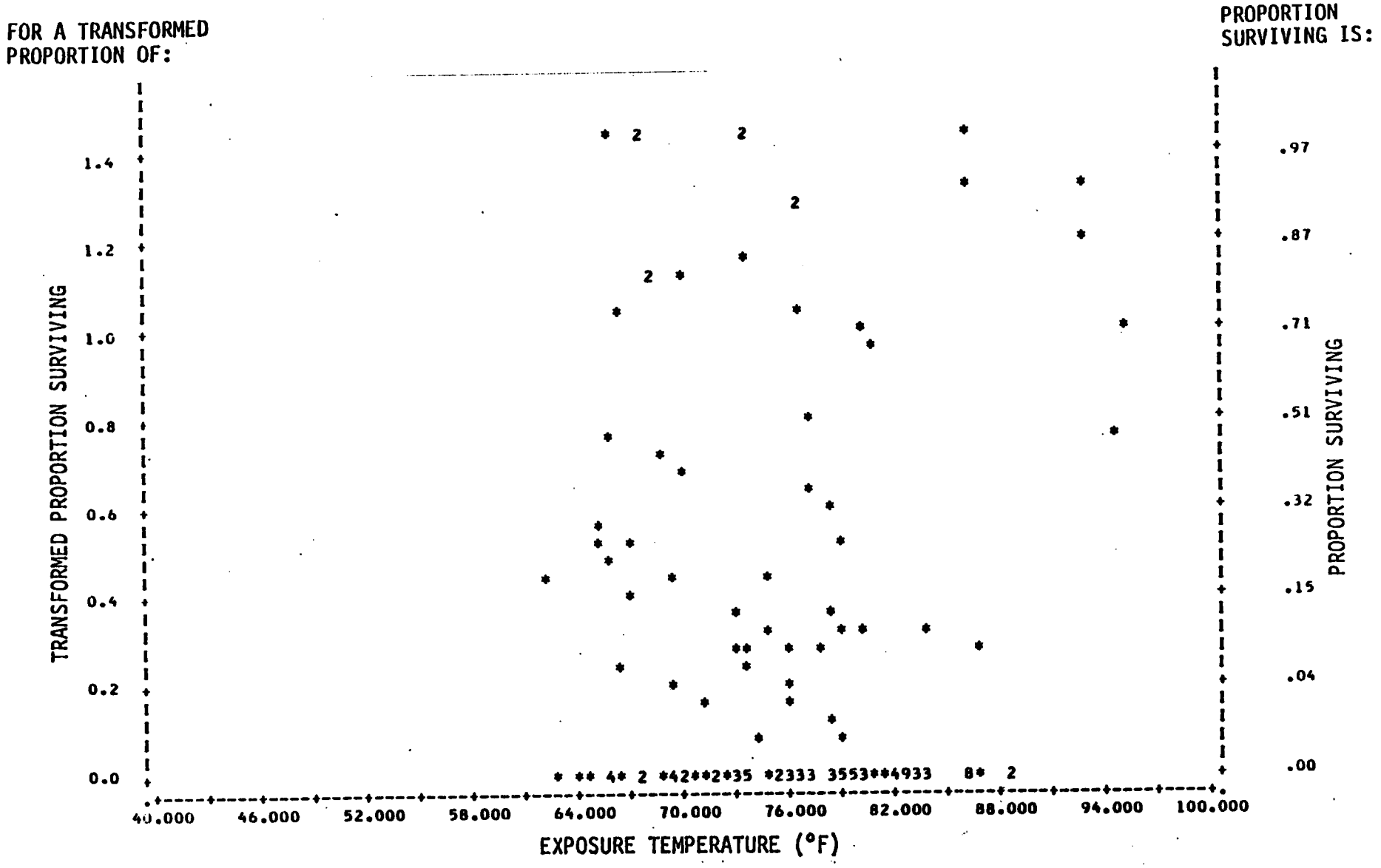
94.000
100.000
EXPOSURE TEMPERATURE (°F)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0.2
0.0
.97
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PROPORTION SURVIVING
40.000
46.000
52.000
58.000
64.000
70.000
76.000
82.000
88.000
94.000
100.000
EXPOSURE TEMPERATURE (°F)

Figure D.13f