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Laboratory and field studies of the fauna of the upper James Estuary : annual report submitted to Virginia Electric and Power Company

Virginia Institute of Marine Science

Laboratory and Field Studies of the Fauna of the Upper James Estuary

Annual Report

Submitted to

Virginia Electric and Power Company

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Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

ABSTRACT--FIELD STUDIES

Grab samples were taken at 31 stations in the Hog Island region of the James River to evaluate the benthic fauna. All species of infauna taken were identified and weighed. Sediment particle size analysis was made at each station. This region is characterized by a low diversity. The dominant organism, Rangia cuneata, may occur in densities up to 1,000/m^2. Other organisms common to the area are Congeria leucophaeata, Scolecolepides viridis, Corophium lacustre, Leptocheirus plumulosus and Cyathura polita.

ABSTRACT--LABORATORY STUDIES

Laboratory studies were made to determine the effects of temperature shock on oyster larvae, Crassostrea virginica. 10° and 15° temperature shocks were used. Growth rate, mean mortality and percent setting were measured. Growth rate and setting were improved by a 10° temperature shock, while for 15° temperature-shocked larvae growth rate and setting were lower than control groups. Mortality rate was increased by both 10° and 15° temperature shocks.

INTRODUCTION

The objective of this project is to describe the James River fauna in the region of the Virginia Electric and Power Company (VEPCO) Surry Nuclear Power Station at Hog Island. The study is divided into two parts. A field study (Part I) is being carried out by Mr. Thomas Cain and Mr. Richard Peddicord. Experimental laboratory studies (Part II) are being conducted by Mr. Robert Diaz.

The present phase of the field study is to quantitatively and qualitatively describe the benthic fauna. Benthic species and communities are considered to be the best indicators of environmental changes because of their relatively long lives, immobility and differing ability to tolerate stress. The field study will provide a basis for comparison with a future study to be made after the plant is in operation.

Laboratory studies are being made to determine the tolerance of the larvae of the Virginia oyster Crassostrea virginica to sudden rises in temperature. The oyster was chosen as a test animal for the following reasons: abundance, availability, economic importance and distribution. The temperature range in which the tests are run is that which will most probably be encountered in the condensers of steam electric plants.

PART I

METHODS

The procedure for selection of sampling stations was based on sediment type and the area most likely to be influenced by thermal discharge. An earlier study of the James River by Moncure and Nichols (1968) provided the authors with preliminary sediment data. Model studies conducted by Pritchard (1967) indicated the area of maximum influence of thermal discharge was in Cobham Bay with a tongue of heated water extending around Hog Point. On the average tidal cycle, less than one-third the width of the estuary is influenced by water of 2°C above ambient temperatures. The selected stations are concentrated in Cobham Bay. Some stations, for comparative purposes, were located in areas not likely to be reached by the effluent. The locations of the 31 stations selected are presented in Fig. 1.

All 31 stations were sampled in May 1969 and eight in September 1969, as established at the April 7, 1969, meeting of the Task Force on Surry environmental studies. A 21-foot aluminum boat equipped with a davit and winch was used. Two grabs per station were obtained with a 0.07 m^2 modified Van Veen grab. To minimize sampling error, only those samples brought up in a closed grab were used. The contents of the grab were then washed through a 2.0 mm screen. All organisms and materials retained on the screen were preserved in 10% formalin solution. The temperature of the sediment and the surface salinity were taken at the eight stations sampled in September.

The samples were washed through a 0.5 mm screen at the laboratory, transferred to pans, and the organisms removed by examination under a dissecting microscope. All organisms were identified to species and counted. The larger organisms were blotted dry and weighed to the

nearest 0.1 gram. Shell length and distance across the umbones of the molluscs were measured to the nearest millimeter with a Vernier caliper.

During the spring sampling series, a sediment sample was taken at each station to determine sediment particle size. A 1-inch diameter hand corer was used, and samples were taken to a depth of 5 cm. The samples were treated with a 4% solution of Calgon to disperse soil aggregates. Separation of the sand fraction was made by dry sieving through U. S. Standard Mesh Sieves. The mud fraction was analyzed by the standard pipette technique which is based on Stokes law of settling velocity. The sediment fractions were divided into five size classes: clay (particle diameter less than 3.9 μ); silt (diameter 3.9 μ to 63 μ); fine sand (63 μ to 250 μ); coarse sand (250 μ to 2 mm); and granules (greater than 2 mm).

RESULTS AND DISCUSSION

Upper estuaries are areas of transition between the more stable environments of both the contiguous sea and the freshwater tidal river. This region exhibits increased gradients and fluctuations of both abiotic and biotic factors. Physical factors, such as salinity, exert a greater influence on the community than the biological factors of competition and predation. Therefore, animal species of physically controlled communities do not develop complex biological interrelationships. The number of different species is usually much lower in upper estuaries than in the nearby marine or freshwater habitats; however, the number of individuals may be quite large. In general, the brackish water

environment is inhabited by relatively few species and constitutes an unstable and immature ecosystem (Carriker, 1967; Kinne, 1967; Greene, 1968).

Hog Point is in the region of transition between the fresh tidal river and the estuary proper. The high river flow in the spring covers most of the stations with fresh water. In late summer and fall, all stations normally exhibit measurable salinity. The flood of August 1969 produced low salinities for that time of year. Any effect this may have had on the benthic fauna was not apparent in our September samples. The number of individuals and species sampled at each station in May and in September is presented in Table I.

A sediment grain size analysis was conducted for each station. The type of sediment found at a particular station indicates which organisms can live there. The results of these analyses were useful in determining whether all major sediment types were being sampled and whether the stations were well distributed among the various sediments. This procedure also provides a partial basis for comparing the final results of this study with investigations in other areas. The sediment was sampled to a depth of only 5 cm since few organisms characteristic of low-salinity areas live deeper than this. Since the authors sought only size differences of biological, rather than geological, significance, only five size classes were used. The results of the grain size analyses are presented in Table II. In Table III, the sediment types at each station are briefly characterized by the dominant size class or classes.

The dominant organism in the area, in terms of both biomass and numbers, is the marsh clam Rangia cuneata. This clam is found in

communities with only a few other small species (M. L. Wass, personal communication). The number of these clams taken in the station samples varied considerably. Grabs taken at station 31 (May) and stations 9 and 14 (September) contained no R. cuneata, while station 10 (May) and station 26 (September) produced over 150 clams each. Age, as estimated by shell length (Wolfe and Petteway, 1968), varied from less than one year to over five years. Clams collected in sandy substrates appeared to be larger (mean length of 42 mm) and fewer in number than those collected in muddy areas (mean length of 32 mm). This is in agreement with work done by Fairbanks (1963) in Lake Pontchartrain, Louisiana. However, a T-test showed no significant difference at the 5% level between the length of clams from different substrates.

Some of the other common organisms found were Congeria leucophaeata, Scolecolepides viridis, Corophium lacustre, Leptocheirus plumulosus and Cyathura polita. The bivalve mollusc C. leucophaeata appears to exhibit a clumped distribution since at many stations none were found, while at station 10 (May) 178 were identified. The distribution of this species is limited by the fact that it attaches only to hard substrates which are furnished primarily by exposed R. cuneata shells. The spionid polychaete S. viridis, although not occurring in large numbers, was widely distributed, being found at 25 of 31 stations in May and 5 of 8 stations sampled in September. C. lacustre, an oligohaline amphipod, usually inhabits mud tube nests in silty or muddy bottoms (Crawford, 1937). It is common in the upper estuarine portions of the York-Pamunkey and Rappahannock rivers as well as the Hog Island region (Feeley and Wass, unpublished manuscript). L. plumulosus, an estuarine amphipod, and

C. polita, a euryhaline isopod, were both common in the May samples but none were found in September, perhaps because of the August flood. The above fauna, except for R. cuneata, is similar to that found in the Pocasset River, Massachusetts, by Sanders et al. (1965).

Species diversity of the area is low as compared to Hampton Roads (Boesch and Richardson, personal communication). There is a general trend toward increased diversity as salinity increases in most estuaries (Emery et al., 1957). This is probably due to the more extreme physical conditions of the upper estuary which impose physiological stress on the inhabitants (Sanders, 1968). The dominant organism, R. cuneata, has a dense population and contributes nearly all the biomass of the benthic community. The importance of this organism to the food web of the area has not been established, but it appears to be a part of the diet of the blue crab Callinectes sapidus and the catfish Ictalurus catus (Fairbanks, 1963), two of the commercially important inhabitants of the upper James estuary.

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TABLE I

Species, Number of Individuals and Total Wet Weight Biomass at Each Station for May and September 1969

MAY

1	
Rangia cuneata	26
Congeria leucophaeata	8
Brachidontes recurvus	1
Balanus improvisus	
Biomass	305.0 g
2	
Rangia cuneata	23
Biomass	221.2 g
3	
Rangia cuneata	5
Scolecolepides viridis	5
Lepidactylus dytiscus	6
Laeonereis culveri	1
Leptocheirus plumulosus	1
Biomass	133.6 g
4	
Rangia cuneata	13
Scolecolepides viridis	6
Leptocheirus plumulosus	5
Monoculodes edwardsi	1
Biomass	200.0 g
5	
Rangia cuneata	2
Biomass	15.2 g
6	
Rangia cuneata	7
Scolecolepides viridis	1
Biomass	112.2 g
7	
Rangia cuneata	18
Leptocheirus plumulosus	22
Scolecolepides viridis	8
Cyathura polita	2
Biomass	299.0 g
8	
Rangia cuneata	51
Scolecolepides viridis	1
Leptocheirus plumulosus	1
Biomass	613.3 g
9	
Rangia cuneata	12
Scolecolepides viridis	18
Congeria leucophaeata	4
Tubulanus pellucidus	1
Gemma gemma	1
Biomass	161.3 g
10	
Rangia cuneata	157
Congeria leucophaeata	178
Brachidontes recurvus	4
Scolecolepides viridis	1
Balanus improvisus	
Biomass	2001.0 g
11	
Rangia cuneata	13
Scolecolepides viridis	3
Biomass	430.6 g
12	
Rangia cuneata	2
Lepidactylus dytiscus	4
Scolecolepides viridis	3
Macoma phenax	1
Biomass	100.9 g
13	
Rangia cuneata	18
Scolecolepides viridis	15
Tubulanus pellucidus	1
Leptocheirus plumulosus	4
Biomass	236.4 g

Table I continued

MAY

14	
Rangia cuneata	4
Corophium lacustre	2
Scolecolepides viridis	1
Biomass	160.9 g
15	
Rangia cuneata	5
Leptocheirus plumulosus	30
Scolecolepides viridis	6
Corophium lacustre	13
Macoma phenax	1
Balanus improvisus	
Biomass	142.0 g
16	
Rangia cuneata	1
Scolecolepides viridis	2
Corophium lacustre	1
Balanus improvisus	
Biomass	20.0 g
17	
Rangia cuneata	3
Congeria leucophaeata	37
Brachidontes recurvus	2
Corophium lacustre	5
Scolecolepides viridis	4
Cyathura polita	2
Balanus improvisus	
Biomass	82.3 g
18	
Rangia cuneata	73
Congeria leucophaeata	105
Corophium lacustre	55
Brachidontes recurvus	13
Cyathura polita	15
Scolecolepides viridis	3
Gammarus daiberi	2
Biomass	936.0 g
19	
Rangia cuneata	2
Congeria leucophaeata	2
Scolecolepides viridis	5
Corophium lacustre	4
Cyathura polita	1
Leptocheirus plumulosus	1
Tubulanus pellucidus	1
Biomass	35.5 g
20	
Rangia cuneata	4
Leptocheirus plumulosus	15
Scolecolepides viridis	11
Tubulanus pellucidus	1
Monoculodes edwardsi	1
Macoma phenax	1
Biomass	143.3 g
21	
Rangia cuneata	21
Scolecolepides viridis	15
Brachidontes recurvus	4
Congeria leucophaeata	3
Macoma phenax	3
Gemma gemma	1
Cyathura polita	1
Balanus improvisus	
Biomass	351.8 g
22	
Rangia cuneata	58
Scolecolepides viridis	2
Macoma phenax	1
Tubulanus pellucidus	1
Biomass	659.0 g
23	
Rangia cuneata	23
Scolecolepides viridis	18
Macoma phenax	2
Leptocheirus plumulosus	27
Laeonereis culveri	14
Cyathura polita	6
Biomass	675.4 g
24	
Rangia cuneata	9
Macoma phenax	2
Gemma gemma	7
Laeonereis culveri	2
Scolecolepides viridis	1
Leptocheirus plumulosus	1
Unidentified capitellid	2
Biomass	177.1 g
25	
Rangia cuneata	119
Scolecolepides viridis	1
Balanus improvisus	
Biomass	1394.6 g

Table I continued

MAY

26	
Rangia cuneata	7
Leptocheirus plumulosus	1
Gemma gemma	1
Cyathura polita	2
Biomass	112.9 g
27	
Rangia cuneata	67
Leptocheirus plumulosus	1
Scolecolepides viridis	1
Biomass	985.6 g
28	
Rangia cuneata	8
Brachidontes recurvus	2
Leptocheirus plumulosus	8
Cyathura polita	3
Edotea triloba	2
Congeria leucophaeata	1
Tubulanus pellucidus	2
Victorella pavida	
Biomass	100.0 g
29	
Rangia cuneata	2
Macoma balthica	3
Macoma phenax	1
Leptocheirus plumulosus	2
Corophium lacustre	2
Cyathura polita	2
Laeonereis culveri	1
Biomass	90.0 g
30	
Rangia cuneata	4
Macoma balthica	3
Scolecolepides viridis	4
Leptocheirus plumulosus	5
Corophium lacustre	2
Tubulanus pellucidus	2
Cyathura polita	1
Victorella pavida	
Biomass	67.8 g
31	
Macoma phenax	5
Leptocheirus plumulosus	27
Scolecolepides viridis	6
Brachidontes recurvus	1
Cyathura polita	4
Biomass	6.0 g

SEPTEMBER

3	
Rangia cuneata	9
Scolecolepides viridis	4
Laeonereis culveri	2
Biomass	297.0 g
9	
Macoma phenax	2
Scolecolepides viridis	2
Biomass	5.0 g
11	
Rangia cuneata	43
Macoma phenax	1
Biomass	500.2 g
14	
Laeonereis culveri	4
Scolecolepides viridis	6
Biomass	0.1 g

Table I continued

SEPTEMBER

17	
Rangia cuneata	1
Scolecolepides viridis	9
Laeonereis culveri	5
Lepidactylus dytiscus	1
Biomass	38.0 g
22	
Rangia cuneata	14
Biomass	153.0 g
26	
Rangia cuneata	159
Victorella pavida	
Biomass	1502.0 g
30	
Rangia cuneata	5
Scolecolepides viridis	1
Macoma phenax	2
Victorella pavida	
Biomass	74.1 g

TABLE II

Sediment Size Class Distribution of Core Samples Taken in May 1969

Station Number	% total weight < 3.9 μ clay	% total weight 3.9 μ to 63 μ silt	% total weight 63 μ to 250 μ fine sand	% total weight 250 μ to 2 mm coarse sand	% total weight > 2 mm granules
1	27.56	69.92	2.52	0.00	0.00
2	45.29	52.76	1.94	0.00	0.00
3	1.66	7.53	74.94	15.86	0.00
4	17.04	82.73	0.23	0.00	0.00
5	46.92	48.59	4.27	0.22	0.00
6	0.87	0.32	74.81	23.99	0.00
7	35.16	64.57	0.27	0.00	0.00
8	19.24	78.49	2.27	0.00	0.00
9	28.98	29.19	29.20	12.62	0.00
10	30.33	32.35	27.95	9.37	0.00
11	64.02	26.22	9.41	0.34	0.00
12	1.62	3.56	81.16	13.65	0.00
13	29.84	66.30	3.86	0.00	0.00
14	3.16	6.89	73.30	16.64	0.00
15	13.91	12.32	60.79	12.98	0.00
16	48.17	50.70	1.13	0.00	0.00
17	0.76	0.85	51.70	46.11	0.58
18	2.90	1.82	4.02	28.03	63.32
19	18.60	78.58	2.82	0.00	0.00
20	11.61	9.81	23.84	54.74	0.00
21	25.55	23.92	47.01	3.52	0.00
22	19.99	77.64	2.22	0.15	0.00
23	29.27	17.64	50.66	2.43	0.00
24	3.31	5.52	78.72	12.45	0.00
25	59.09	32.63	8.28	0.00	0.00
26	48.19	45.68	6.12	0.00	0.00
27	29.53	56.58	13.10	0.78	0.00
28	12.57	85.85	1.58	0.00	0.00
29	26.52	18.66	37.56	17.26	0.00
30	24.91	62.70	11.77	0.62	0.00
31	9.68	89.56	0.76	0.00	0.00

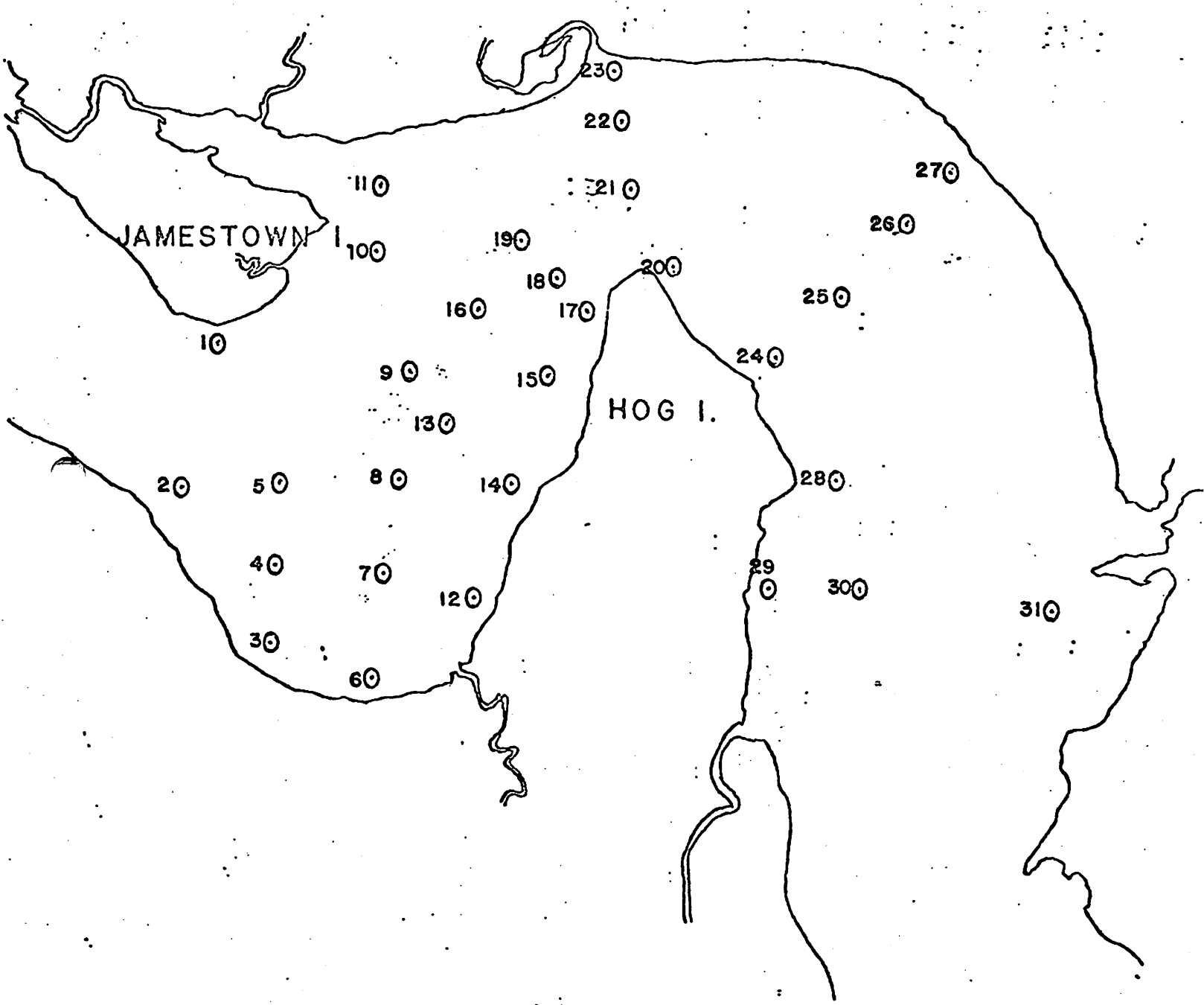
Note: Station 31 also contained shell fragments too large to be sampled with the sediment corer used.

TABLE III

Station Number, Sediment Type, Numbers of Species and Individuals at each James River Station for May and September 1969

Station Number	Sediment Type	Species		Individuals	
		May	September	May	September
1	silt	4		36	
2	silt, clay	1		23	
3	sand	5	3	18	15
4	silt	4		25	
5	silt, clay	1		2	
6	sand	2		8	
7	clayey silt	4		50	
8	silt	3		53	
9	sand, silt, clay	5	2	36	4
10	sand, silt, clay	5		340	
11	silty clay	2	2	26	44
12	sand	4		10	
13	clayey silt	4		38	
14	sand	3	2	7	10
15	sand	6		55	
16	silt, clay	4		5	
17	sand	7	4	53	16
18	granular	7		268	
19	silt	7		16	
20	sand	6		33	
21	sand, silt, clay	8		47	
22	silt	4	1	62	14
23	clayey sand	7		91	
24	sand	7		24	
25	silty clay	3		121	
26	silt, clay	4	2	12	169
27	clayey silt	3		69	
28	silt	8		27	
29	clayey sand	7		13	
30	silt	8	4	22	8
31	silt	5		43	

Figure 1. Sampling station numbers and locations in James River.



PART II

METHODS AND MATERIALS

The oyster larvae used in this study were obtained from adult oysters spawned at the Virginia Institute of Marine Science. A stock culture of these larvae was maintained in an 80-liter polyethylene container at a concentration of 5 to 10 larvae per ml. The stock culture was fed 25 ml of pure Monochrysis per liter of culture every 24 hours. The water was changed every 48 hours by filtering the larvae through an appropriate size stainless steel screen. The polyethylene container was cleaned and the larvae were resuspended in the new water. An antibiotic (0.2 cc/liter of Combistrep) was also added at each water changing to reduce the bacterial population. The water was changed every 48 hours to prevent the buildup of metabolic products, dead oyster larvae and bacteria.

The desired temperature changes were obtained by using a heat exchanger (Fig. 2). The heat exchanger consists of two parts, a constant temperature bath and a tube. The constant temperature bath is a 20-liter stainless steel tank 46 cm by 38 cm (18" x 15"), surrounded with 5 cm of insulating material. This unit was enclosed in a closely-fitted wooden box to prevent deterioration of the insulation. Water was used as the heat-transfer medium, and heat was provided by one 1000-watt glass immersion heater and two 1000-watt Portatemp units. The three heaters are capable of maintaining temperatures in a range of 10° to 80°C above ambient temperature. The heat exchange tubes were made of 1" I.D. Pyrex glass tubing. The experimental animals pass through the tube receiving a temperature rise proportional to the

bath temperature and their flow rate. Two shapes have been developed for the heat exchange tubes (Fig. 3). The first tube is sigmoid and 75 cm in length. The sigmoid tube provides quick entrainment time and large temperature rises, 10° to 20°C in 5 to 9 seconds. The second tube design is S-shaped and about 150 cm in length. The S-shaped tube will be used for long entrainment times and either large or small shock temperatures. A shock temperature is the amount of heat the experimental animal receives above the ambient temperature as it flows through the heat exchanger. For example, if the ambient temperature of a group of experimental oysters was 25°C, and after entrainment of 5 seconds in the heat exchanger their temperature was 35°C, the oyster would have received a shock temperature of 10°C. The entire range of shock temperatures and entrainment times produced by the heat exchanger was 10°C in 15 seconds to 20°C in 9 seconds.

The test animals pass through the heat exchanger by gravity with the rate of flow controlled by an adjustable hose clamp (Fig. 2). The larvae, after being subjected to an appropriate temperature rise, were collected in a one-gallon jar and allowed to return to ambient temperature. Depending upon the magnitude of the shock temperature administered, the larvae were within 1°C of their ambient temperature in 30 to 60 minutes. Control larvae were run through a tube similar to the heat exchange tube through which the experimental animals were run. However, the control animals do not receive a temperature rise. The experimental and control larvae were then maintained exactly as the stock culture only in one-gallon jars.

To determine the effect of temperature shocks on the oysters, samples of the experimental and control groups were withdrawn every time their water was changed. From these samples, the growth and mortality

of the oysters could be calculated. The procedure for the sampling is as follows. The larvae were screened, washed and homogeneously resuspended in 300 ml of water. To determine the total number of larvae and their size, two 1-ml samples were taken. The remaining larvae were returned to the appropriate jars and the concentration adjusted to 5-10 larvae per ml. This procedure was followed until the oysters start to set. Set is the metamorphosis of the oyster larvae into young oysters. When the oysters set, they attach to a hard substrate and are no longer part of the meroplankton. The term used to describe a group of recently set oysters is spat. The spat were counted separately from the larval oysters. The number of set oysters was added to the total number of living oysters so as not to bias the estimate of mortality. When the setting was completed, the experiment was terminated.

EXPERIMENTAL DESIGN

Three types of experiments are planned:

1) Variable temperature-constant salinity. This series of experiments will deal solely with the influence of sudden temperature rises on the oyster larvae. The salinity will be held at 20 o/oo. This section will consist of 30 individual experiments to include three thermal shocks of 10°, 15° and 20°C and ten different larval ages from 1 day to 20 days in 48-hour increments (Fig. 4).

2) Variable salinity-constant temperature. This series of experiments was designed to determine the sole effect of sudden salinity changes on the oyster larvae. The temperature will be held at 25°C. Thirty experiments will be carried out to include salinity changes of

2.5 o/oo, 5 o/oo, and 6.4 o/oo with larval ages from 1 to 20 days in 48-hour increments (Fig. 5).

3) Variable temperature-variable salinity. These experiments should determine whether there is any synergistic effect to the interaction of changing salinity and changing temperature. In order to cover the three variables of shock temperatures (the same as in part one), salinity changes (the same as part two), and age of larvae thoroughly, 90 experiments will be carried out. The 90 experiments can be considered a 3 x 3 x 10 matrix with temperature, salinity and age factors, respectively, as variables (Fig. 6).

DATA

The variable temperature-constant salinity experiment was the first to be carried out. The results to this date are compiled in Tables IV, V, and VI. Seven of the thirty individual experiments have now been completed. The numerical counts of larvae were variable because of the great difficulty encountered in obtaining consistent homogeneous samples for counting. The size of the larvae was acquired from the average of 20 individual larvae chosen at random from the samples taken for total counts. The decrease in mean length found in several of the experiments was due to the prolific setting of larger larvae leaving the smaller, slower growing larvae behind. The unusually long life span of the larvae was attributed to heavy red tides which occurred during the period when York River water was being drawn for changing of the larval water.

Data have also been collected on the initial reactions of oyster larvae to thermal shocks. These data have been previously presented and excerpts may be found in the Appendix.

DISCUSSION

Preliminary results of the variable temperature-constant salinity experiment show that a temperature shock of 10° or 15°C did not appear to bring about any significant difference in growth rates between experimental and control groups (see Figs. 19, 21, 22, 23 and 25 for 10°ΔT, and Figs. 20, 24 and 26 for 15°ΔT). The initial growth of larvae given a 10°ΔT lagged behind the control's growth by 24 to 36 hours. Within 3 to 7 days, the experimental larvae's growth rate attained that of the control in four of the five 10°ΔT experiments run. They exceeded the control's rate of growth by a slight amount. In 12-, 14- and 17-day-old larvae (Figs. 19, 23 and 25, respectively), the growth rate oscillated. First, the control groups had a higher rate than the experimental, etc. With 13-day-old larvae (Figs. 21 and 22), the control's growth rate never surpassed that of the two experimental groups after the initial depression of the experimental group was exceeded. The larvae that received a temperature shock of 15°C did not grow as well as the larvae that received a 10°ΔT. Only one time did the larvae subjected to a 15°ΔT surpass the rate of growth of the control for a 2-day period (Fig. 24). The apparent greater growth rate of experimental larvae in Fig. 26 was due to the setting of the larger control larvae.

The influence of temperature shock on the setting of oyster larvae is difficult to ascertain, since two to three weeks may lapse from the

time the larvae were heated to the time they set. Replication will be needed to discern any effect of the temperature shock. Fig. 27 compares the percent experimental and control larvae that set. Only one of the four 10°Δ T experimental groups did not set a larger proportion than its corresponding control group. None of the 15°Δ T experimental group approached the percent set by corresponding control groups.

Figs. 7 to 18 show the death rate for each of the experiments run. Two of the eight experimental groups had a lower mortality than their control group (see Table VI). More data will be needed to determine whether the temperature shock increased the mortality rate. It appears that a temperature shock may tend to increase the mortality rate, but it is not known if the increase will be significant.

Comparing the two shock temperatures, it appears that larvae that received a 10° temperature shock grew better than the 15° temperature-shocked larvae. The 10° temperature-shocked larvae also appeared to have a larger percent set than 15° temperature-shocked larvae. Comparing the mortality of 10° and 15° temperature-shocked larvae, the 15°Δ T 14-day-old larvae have a lower mortality than the 10°Δ T 14-day-old larvae. The 15°Δ T 12- and 17-day-old larvae had a slightly higher mortality than the 10° temperature-shocked larvae.

It appears, from these data, that a temperature shock of 10°C may improve the growth rate and setting of oyster larvae. Mortality may be increased by both a 10° and a 15° temperature shock. For a 15° temperature shock, growth rate and setting may be slightly lower than normal.

TABLE IV

Variable Temperature-Constant Salinity Data,
Mean Length and Total Number of Larvae

Experimental Group

Days After ΔT	10°ΔT, 12-day-old larvae		15°ΔT, 12-day-old larvae	
	Size (μ)	Number	Size (μ)	Number
0	132.2		132.2	
2	157.2	6,150	141.8	3,900
5	184.5	4,650		2,000
8	191.8	3,300	180.6	1,750
11	236.2	3,400	194.6	1,550
14	281.7	3,150	253.3	
17	320.4	2,400	242.0	1,350
21	318.3	1,800	263.0	1,000
	10°ΔT, 13-day-old larvae		11°ΔT, 13-day-old larvae	
	Size (μ)	Number	Size (μ)	Number
3	116.0	8,700	108.0	8,000
6	132.0	8,100	132.0	6,700
9	177.0	8,500	186.0	7,200
12	207.0	6,800	213.0	8,000
15	259.0	5,300	271.0	5,700
17	310.0	3,100	269.0	6,000
	10°ΔT, 14-day-old larvae		15°ΔT, 14-day-old larvae	
	Size (μ)	Number	Size (μ)	Number
0	137.2		137.2	
3	169.8	5,400	162.8	5,250
6	191.0	4,200	184.0	5,000
9	222.6	4,350	206.0	5,300
12	230.3	4,250	216.7	3,700
15	282.7	3,600	256.7	4,200
18	282.0	2,700	257.3	4,050
	10°ΔT, 17-day-old larvae		15°ΔT, 17-day-old larvae	
	Size (μ)	Number	Size (μ)	Number
0	162.3		162.3	
3	179.2	8,100	187.7	4,650
6	234.0	5,950	192.2	3,150
9	263.8	6,150	233.2	3,300
12	291.0	4,200	301.7	2,700
15	330.0	3,900	323.6	2,400

TABLE IV continued

Control Group

Days After ΔT	0ΔT, 12-day-old larvae Size (μ)	Number
0	132.2	
2	156.5	7,950
5	186.4	7,200
8	199.0	6,150
11	236.0	5,250
14	290.0	4,300
17	309.3	4,050
21	319.3	4,500
	0ΔT, 13-day-old larvae	
	Size (μ)	**Number**
3	116.5	15,900
6	149.5	14,900
9	172.0	11,800
12	188.0	11,900
15	227.5	11,500
17	267.0	11,500
	0ΔT, 14-day-old larvae	
	Size (μ)	**Number**
0	137.2	
3	172.0	8,850
6	179.5	8,400
9	223.8	7,500
12	236.0	5,400
15	275.3	5,700
18	263.3	5,800
	0ΔT, 17-day-old larvae	
	Size (μ)	**Number**
0	162.3	
3	194.2	11,250
6	219.0	8,250
9	275.0	7,500
12	305.7	6,300
15	314.7	5,250

TABLE V

Variable Temperature-Constant Salinity
Setting Data

ΔT (°C)	Age of Larvae (Days)	Total Number Set	% Set
		Experimental Group	
10	12	436	21.8
15	12	52	5.2
10	13	1,530	40.3
11	13	105	1.7
10	14	121	3.9
15	14	153	3.8
10	17	1,500	41.7
15	17	0	0.0
		Control Group	
0	12	709	18.6
0	13	6	0.05
0	14	2,500	45.5
0	17	1,500	28.6

TABLE VI

Variable Temperature-Constant Salinity
Mean Mortality

ΔT (°C)	Age of Larvae (Days)	Total Number Dead	% Dead
		Experimental Group	
10	12	3,900	64
15	12	2,800	72
10	13	4,100	49
11	13	2,000	25
10	14	2,600	48
15	14	1,000	19
10	17	2,700	33
15	17	2,200	48
		Control Group	
0	12	2,800	35
0	13	4,400	28
0	14	600	7
0	17	4,400	39

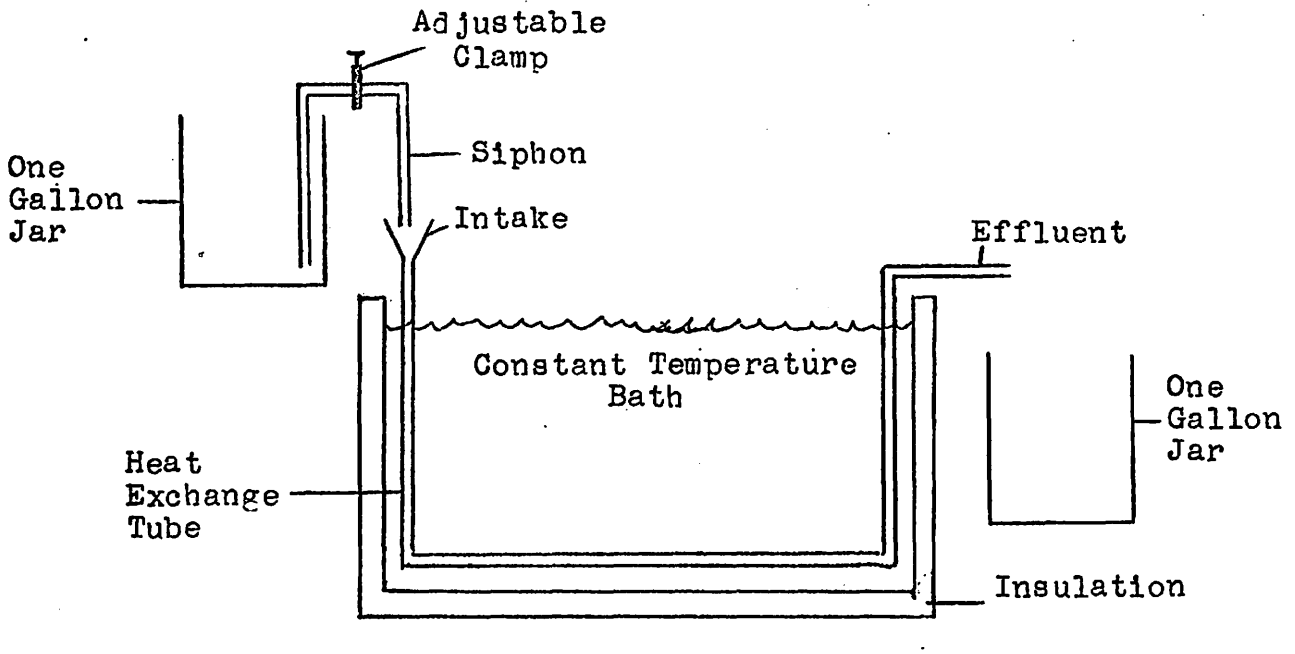


Fig. 2 Heat Exchanger

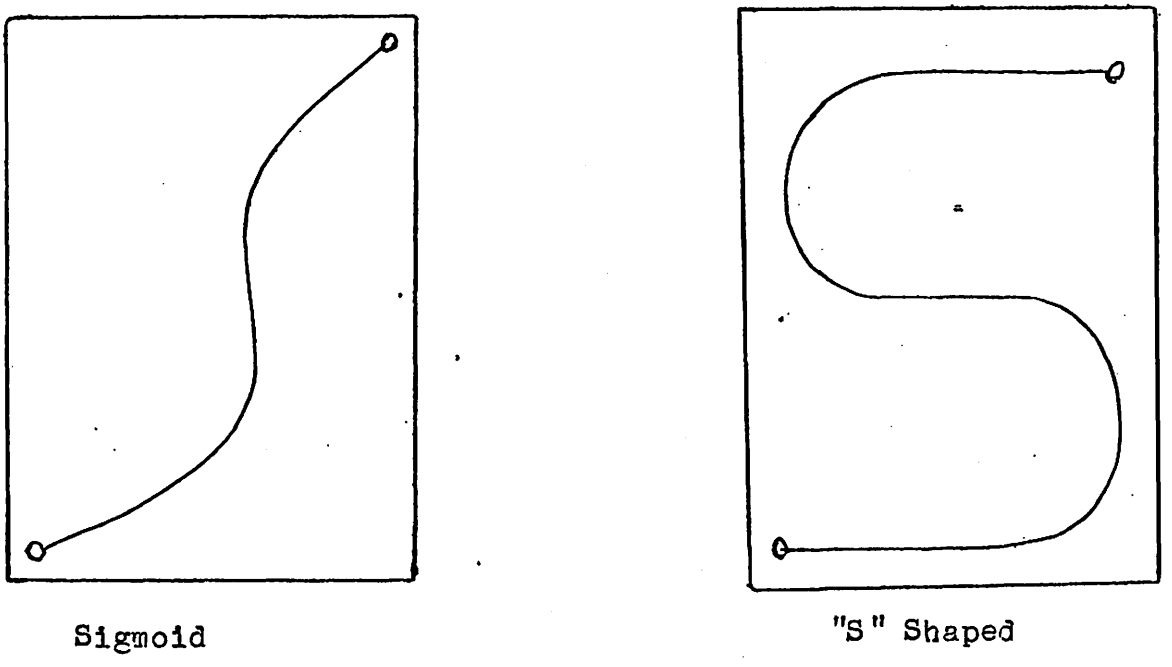


Fig. 3 Heat Exchange Tubes

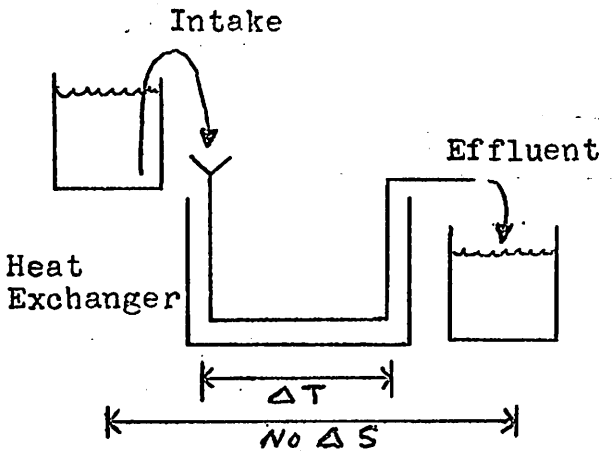


Fig. 4

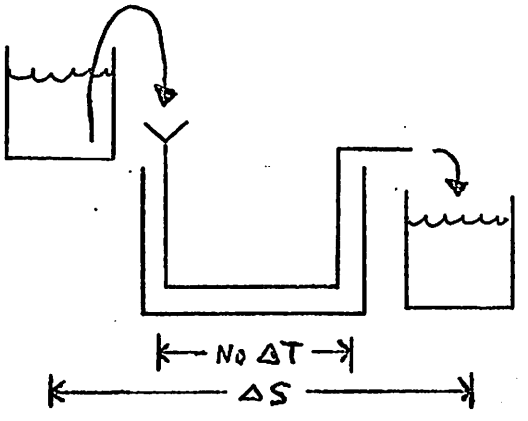


Fig. 5

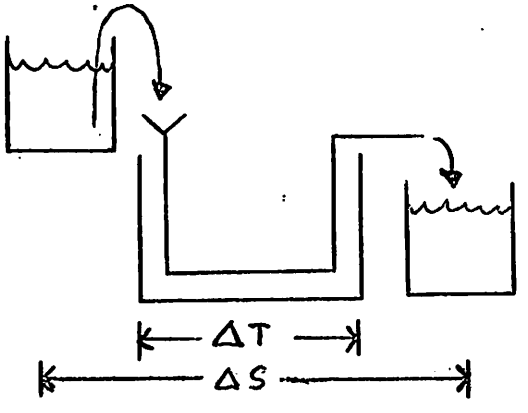


Fig. 6

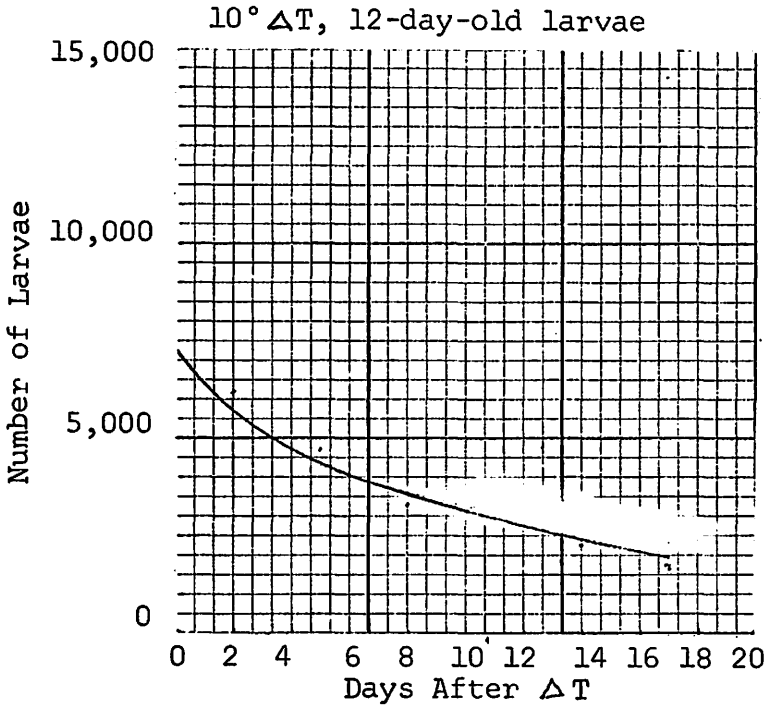


Fig. 7

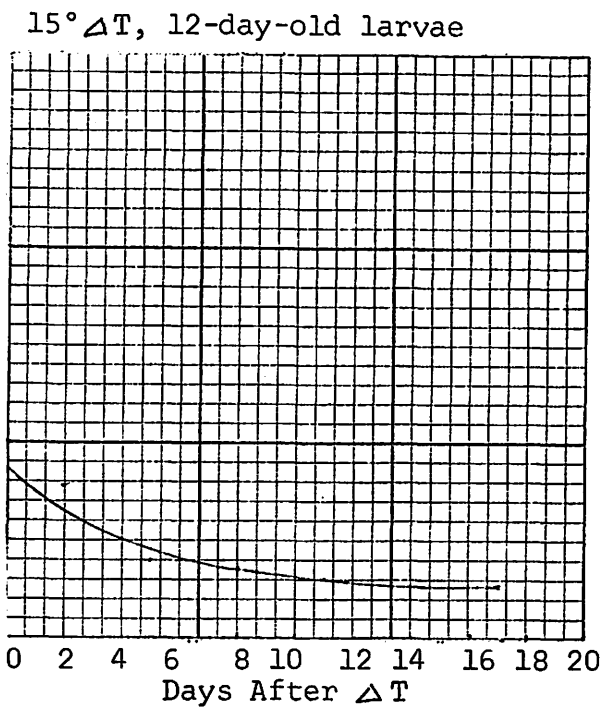


Fig. 8

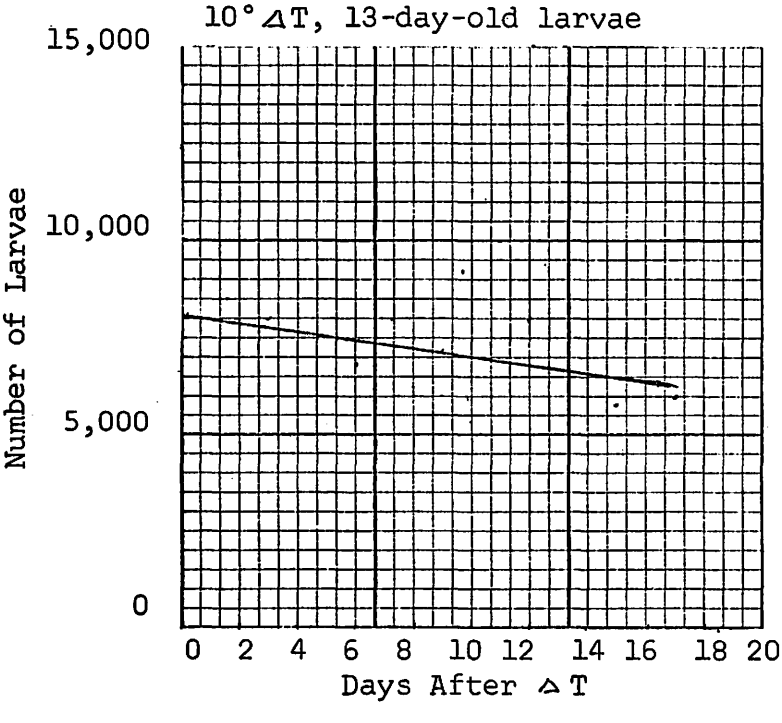


Fig. 9

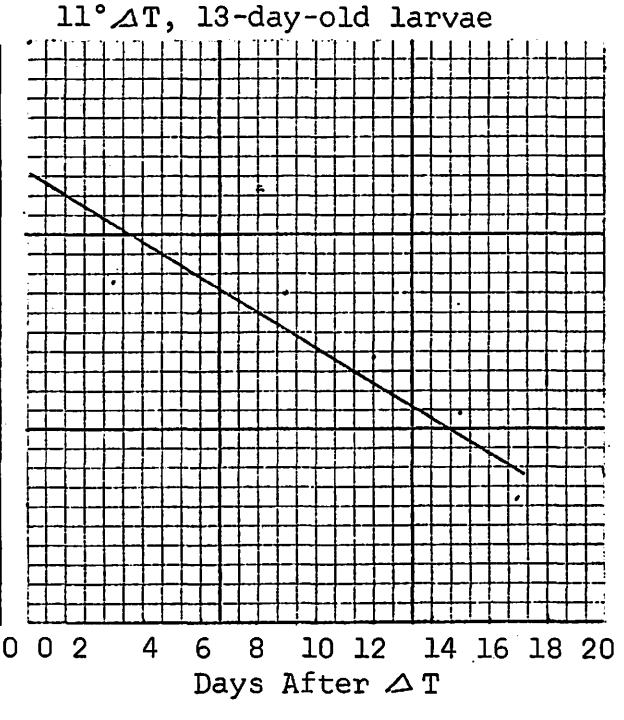


Fig. 10

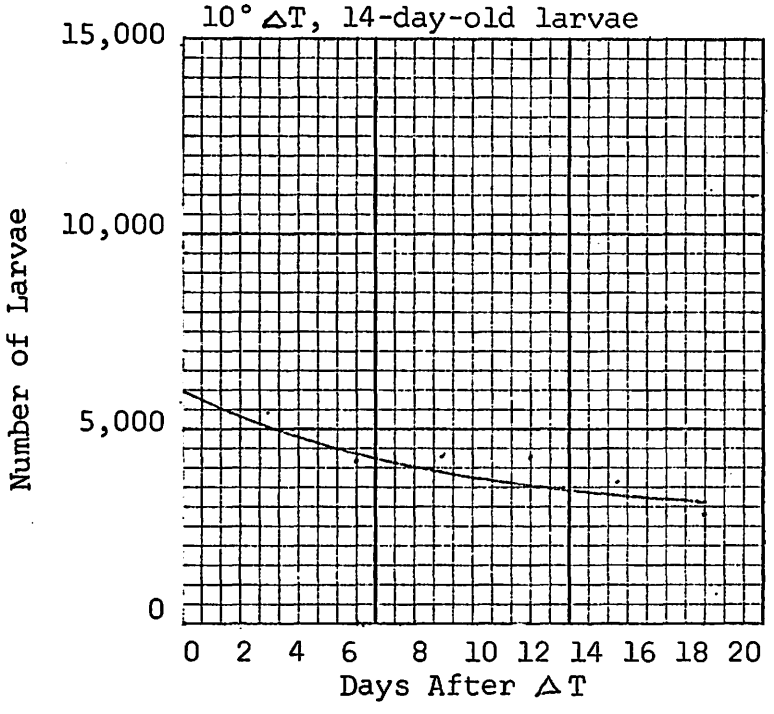


Fig. 11

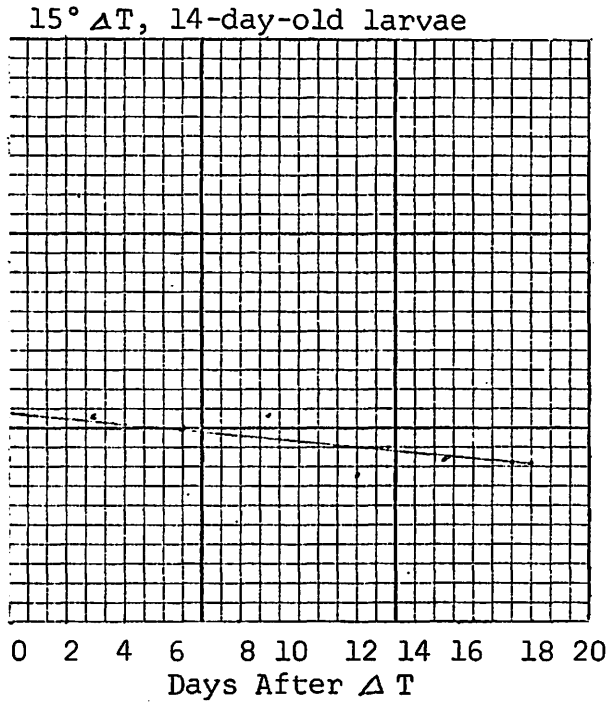


Fig. 12

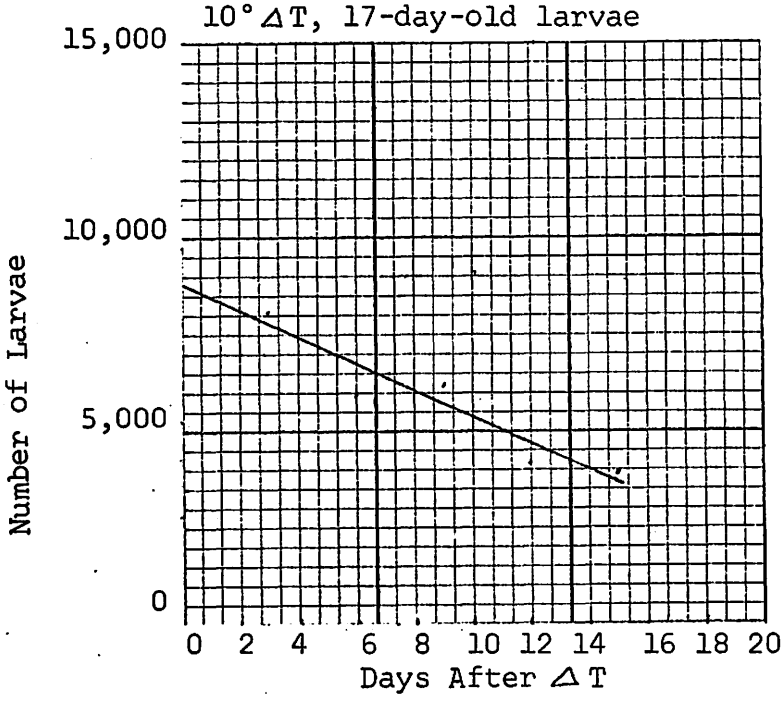


Fig. 13

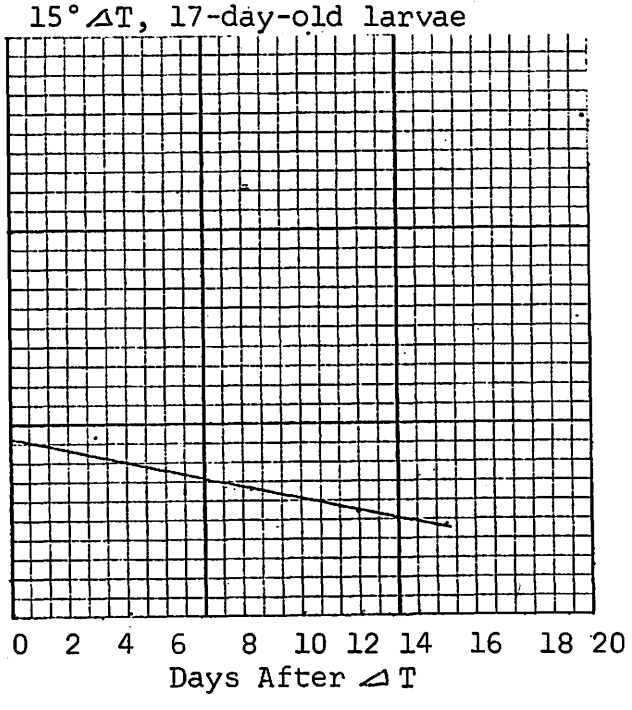


Fig. 14

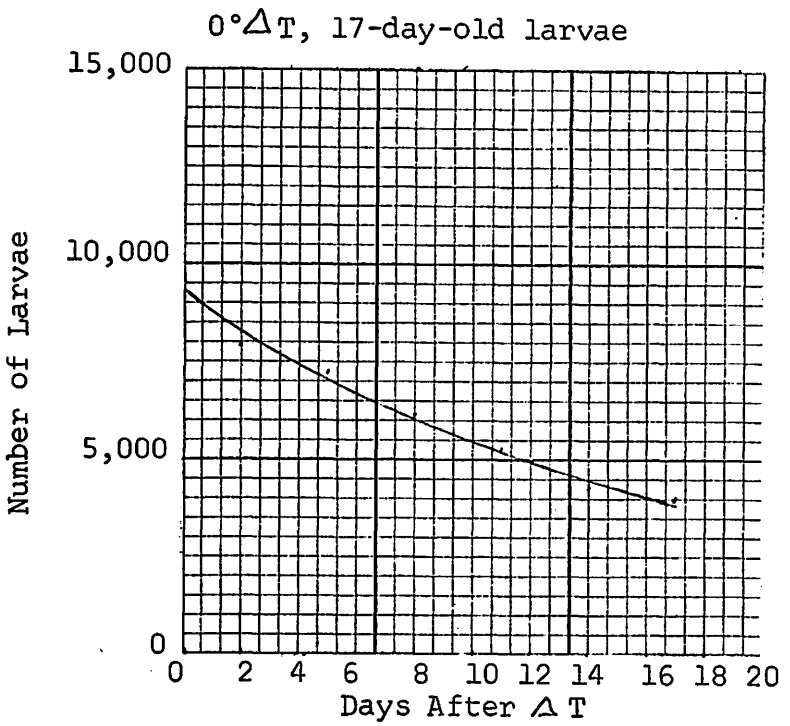


Fig. 15

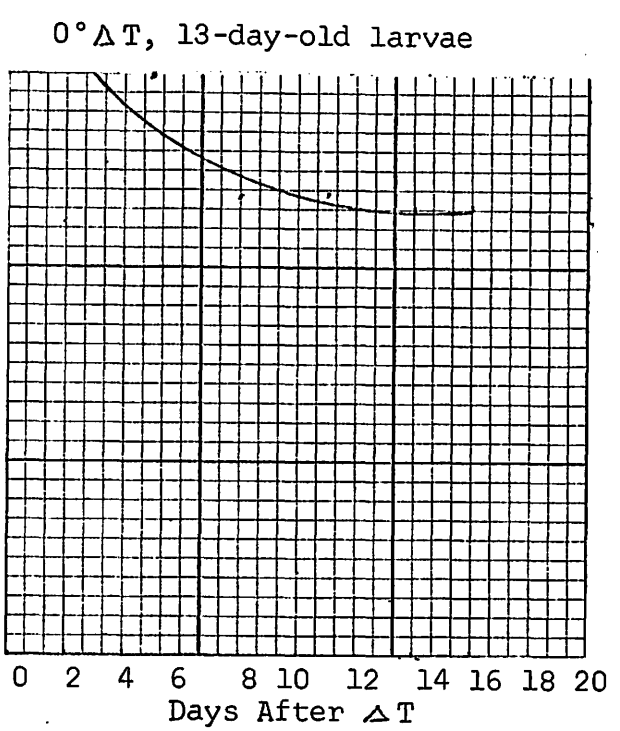


Fig. 16

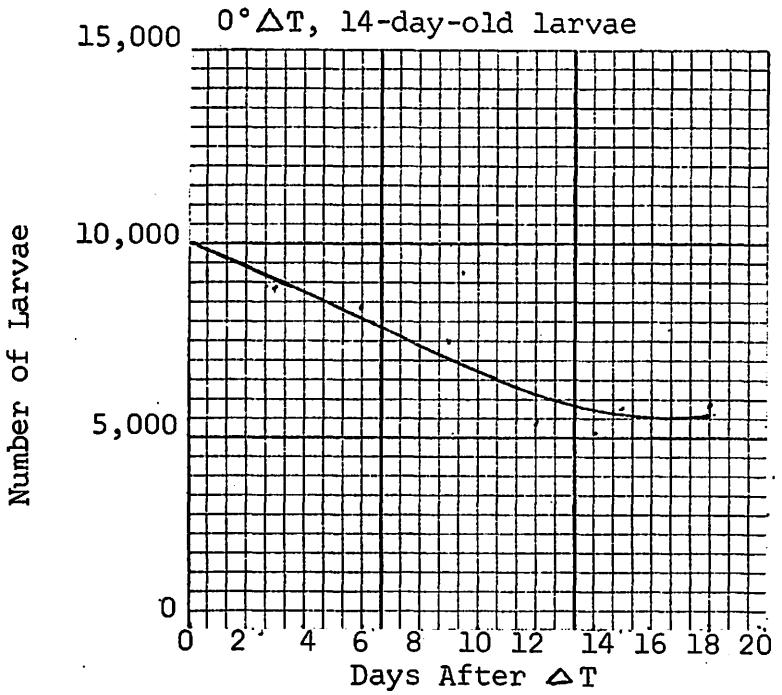


Fig. 17

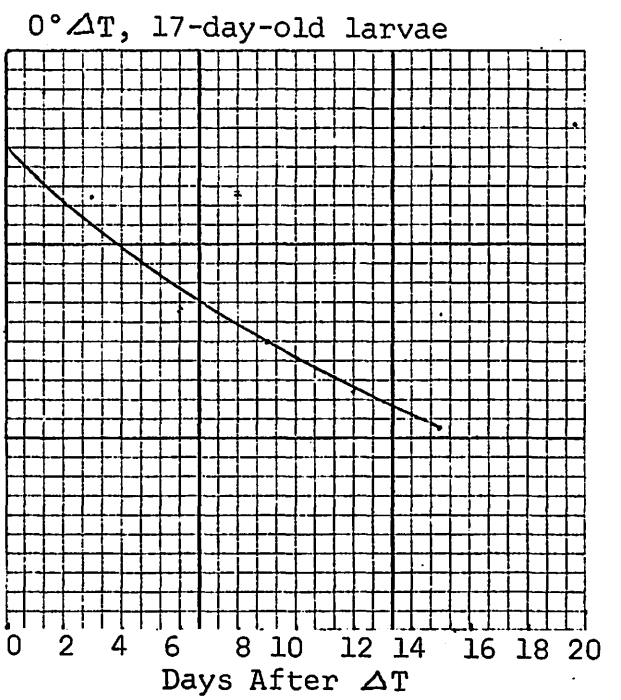


Fig. 18

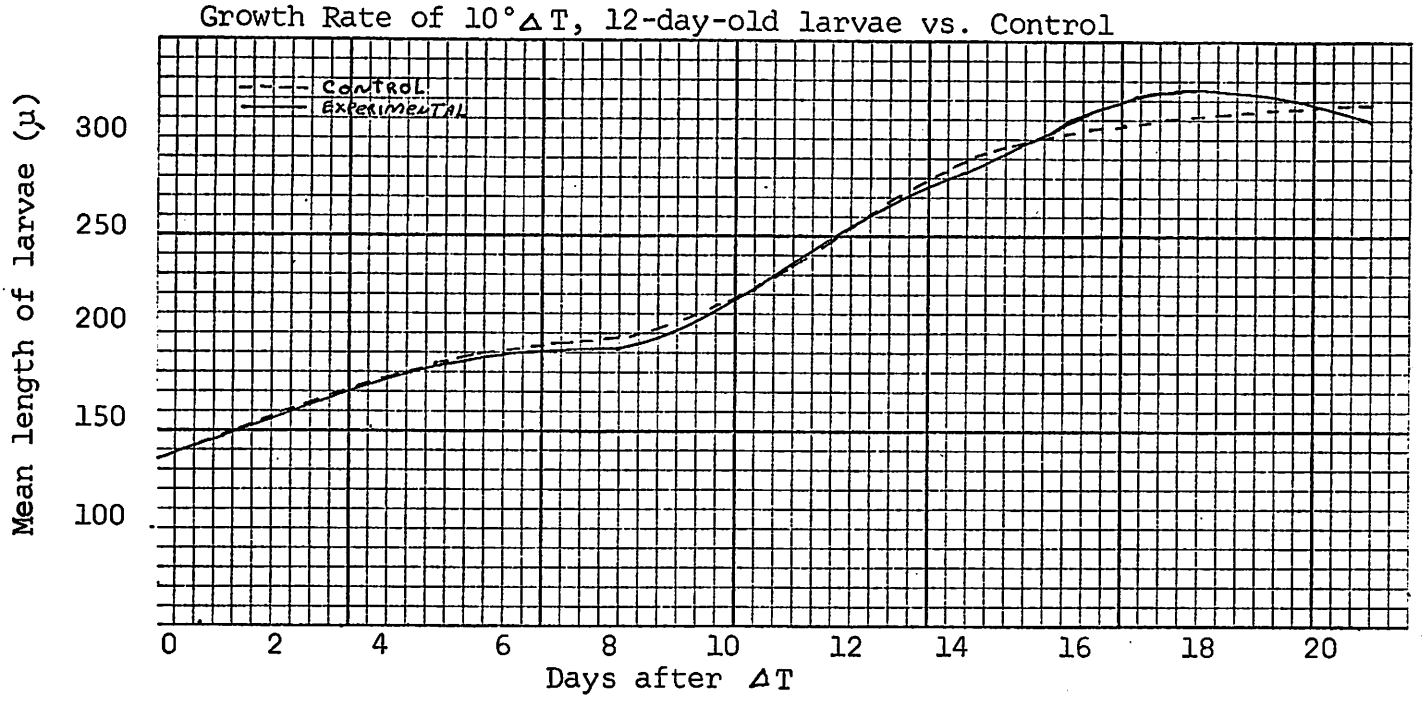

Growth Rate of 10°Δ T, 12-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after Δ T

Fig. 19

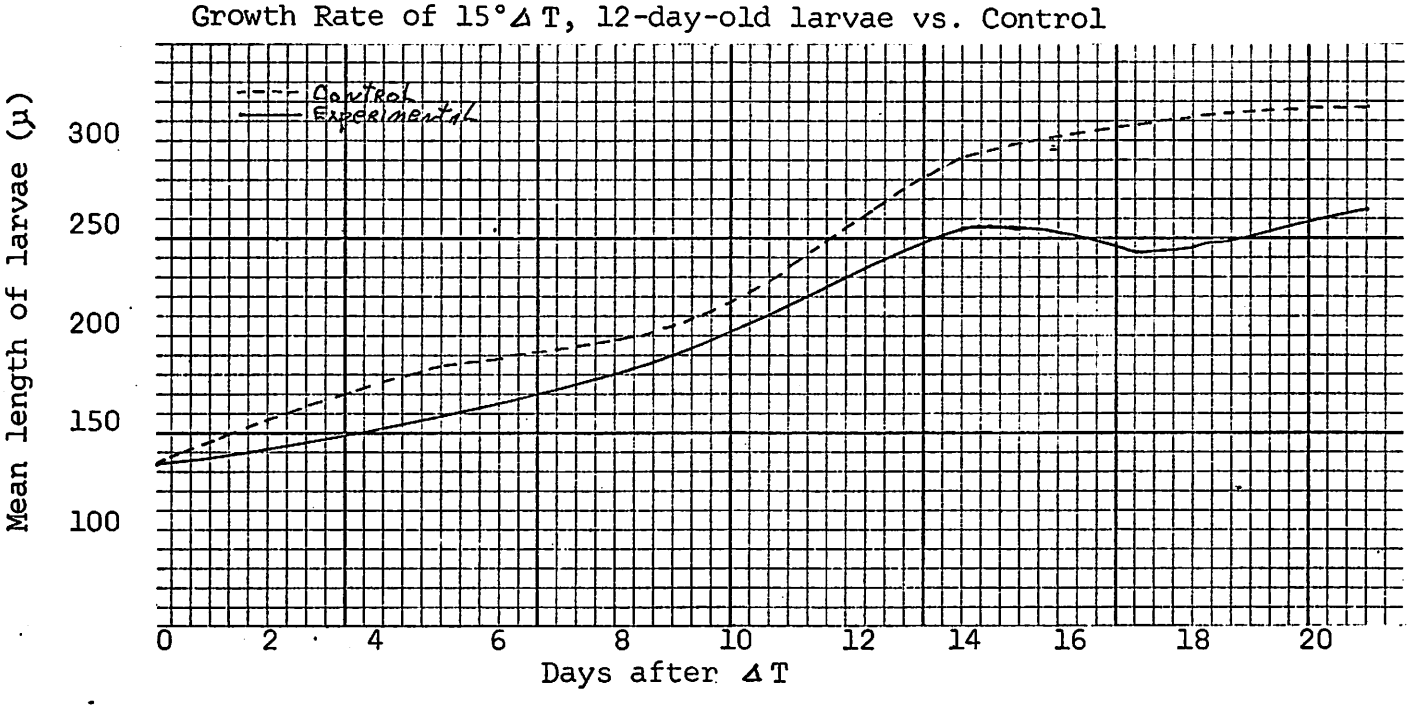

Growth Rate of 15°Δ T, 12-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after Δ T

Fig. 20

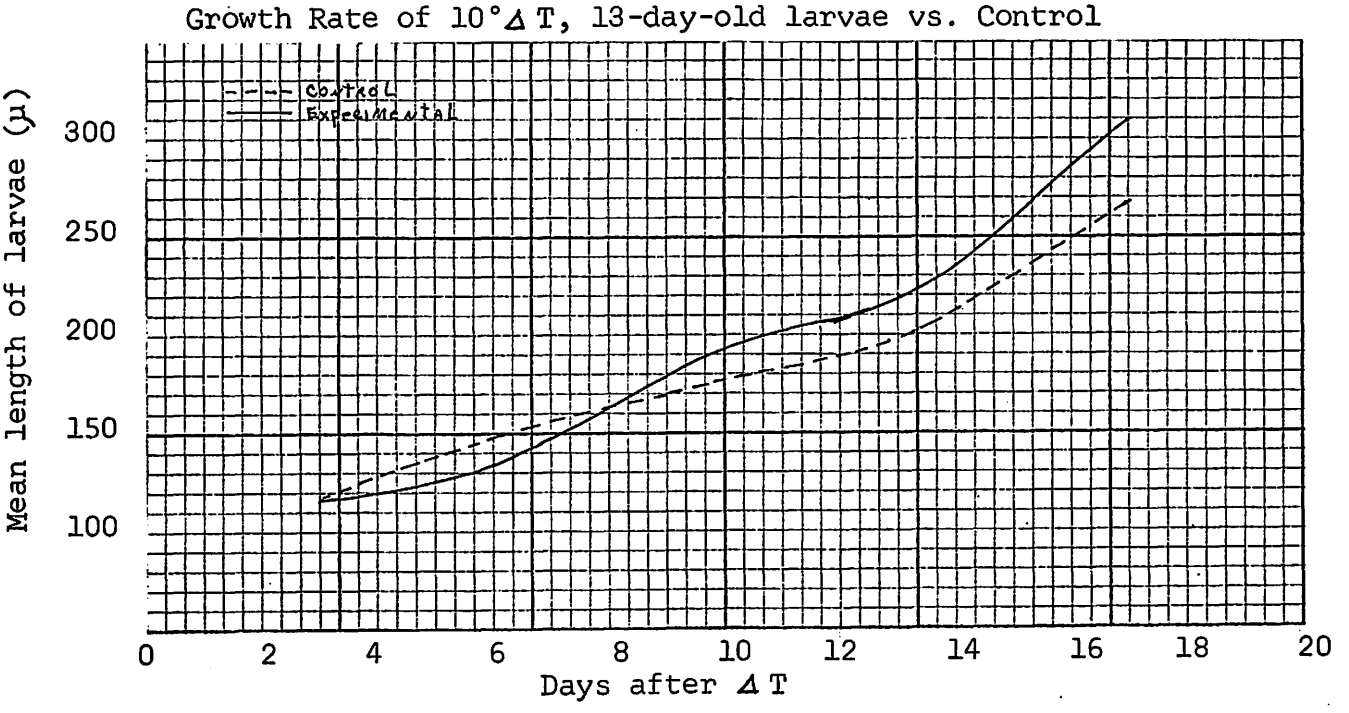

Growth Rate of 10°Δ T, 13-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after Δ T

Fig. 21

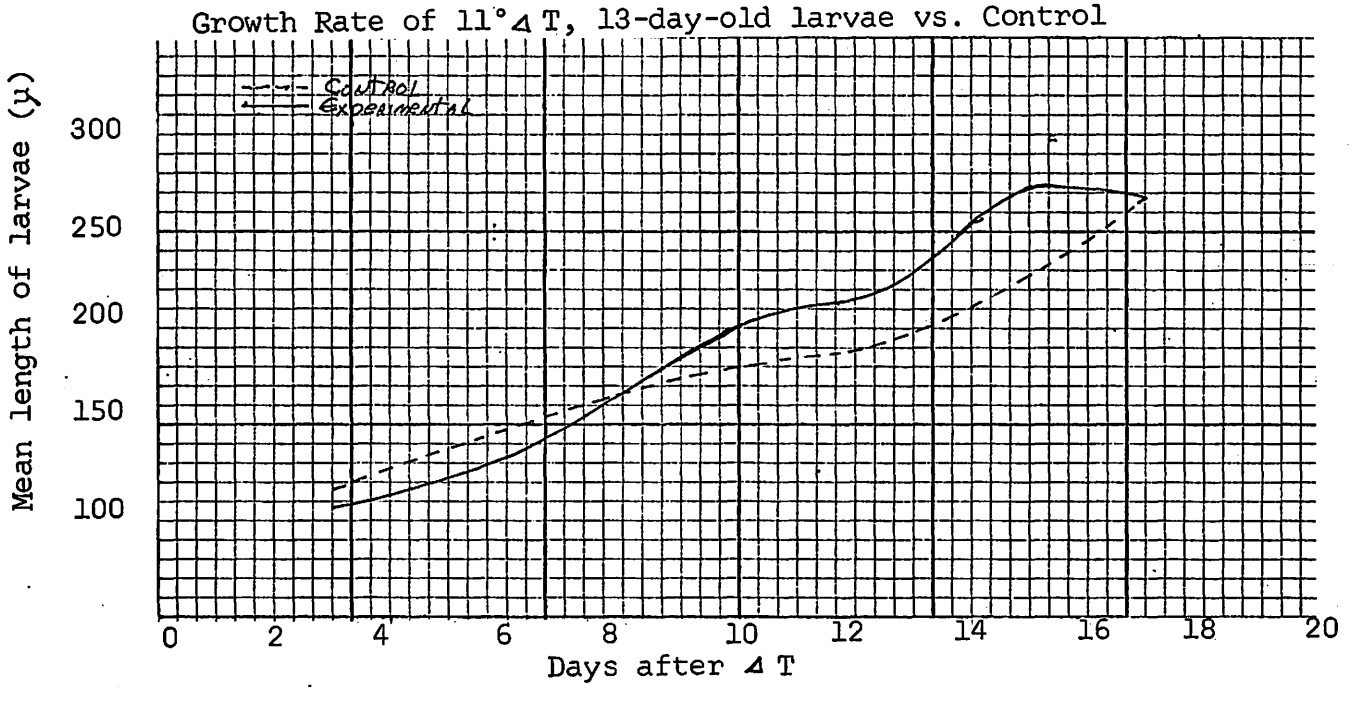

Growth Rate of 11°Δ T, 13-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after Δ T

Fig. 22

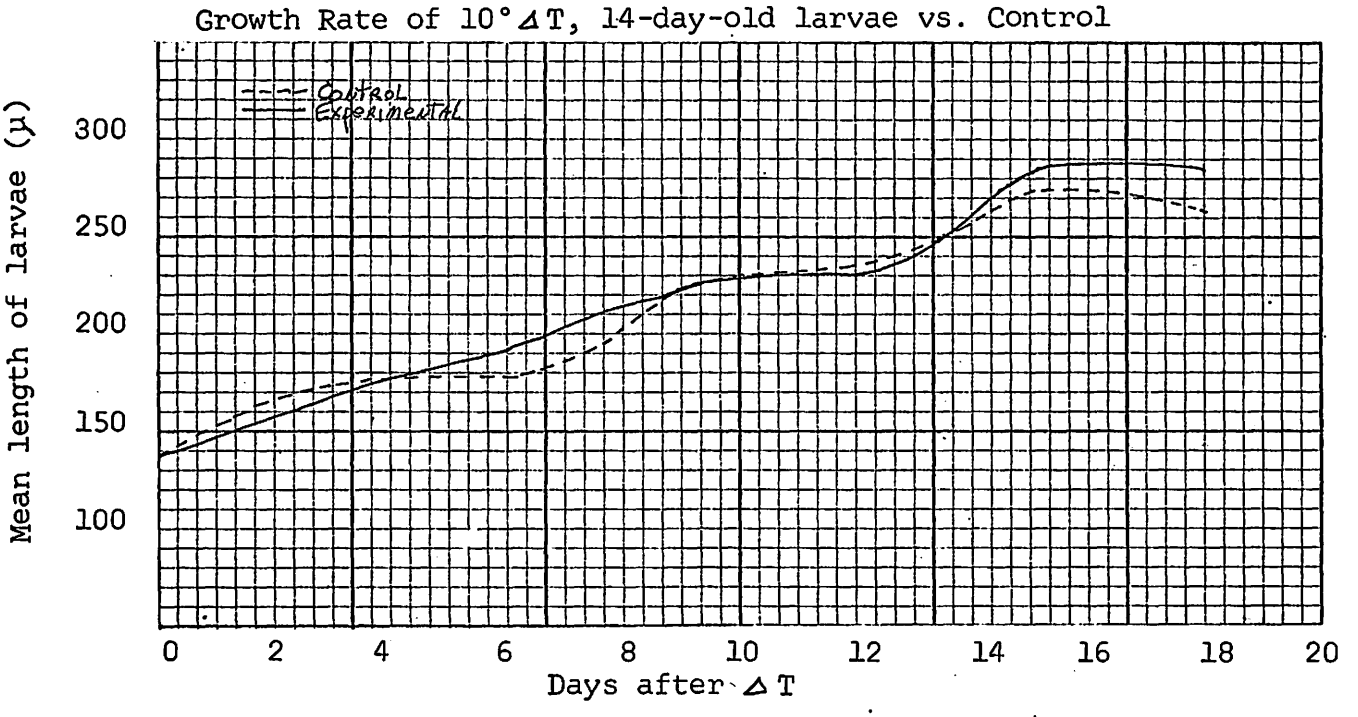

Growth Rate of 10° ΔT, 14-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after ΔT

Fig. 23

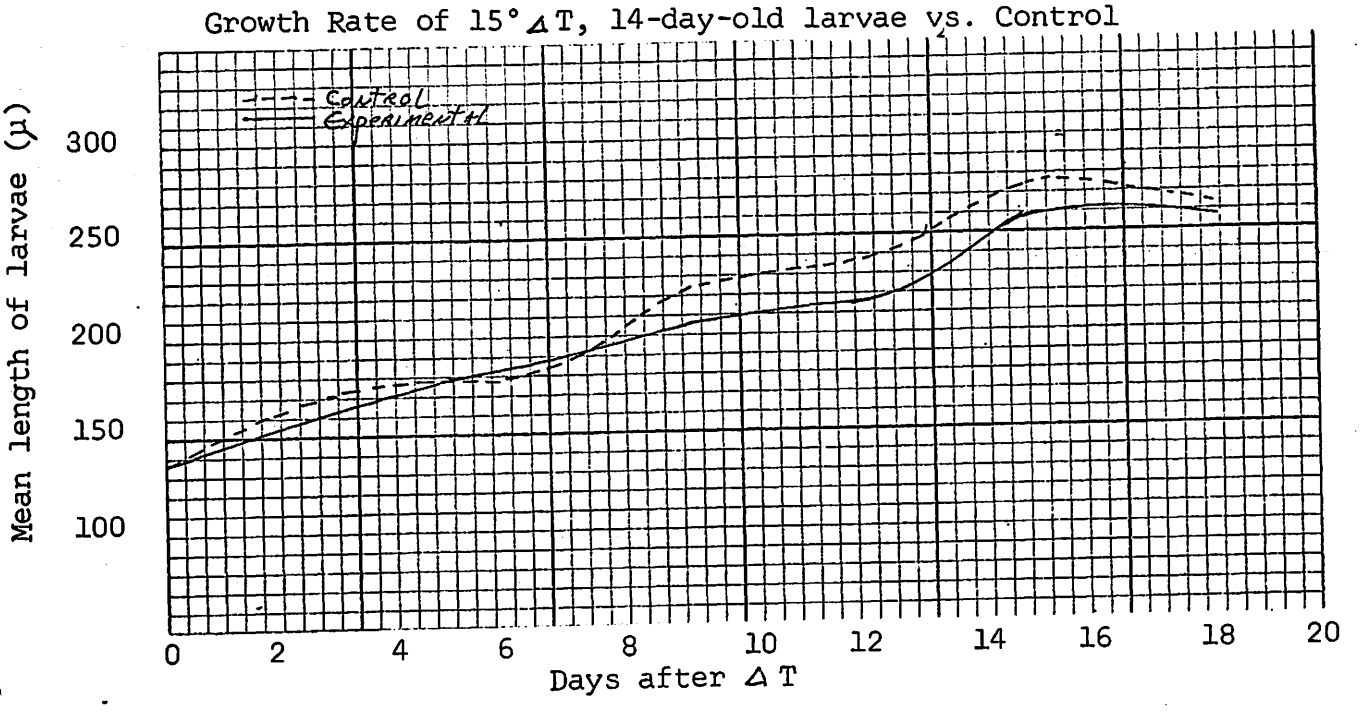

Growth Rate of 15° ΔT, 14-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
18
20
Days after ΔT

Fig. 24

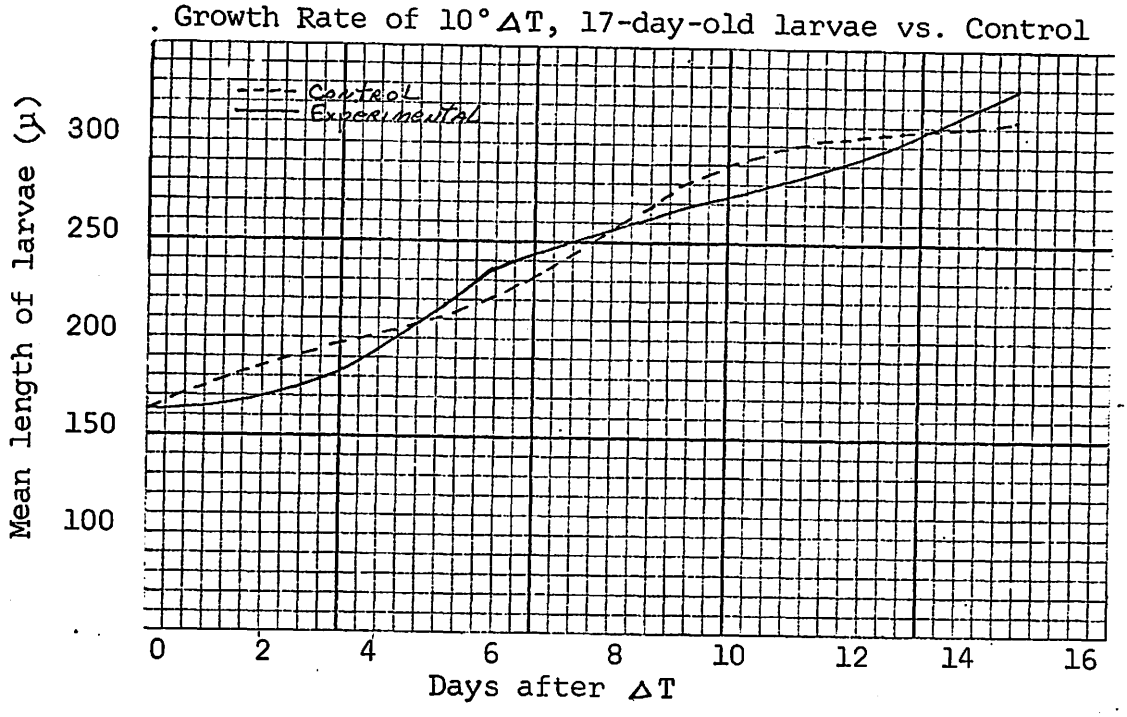

Growth Rate of 10° ΔT, 17-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
Days after ΔT

Fig. 25

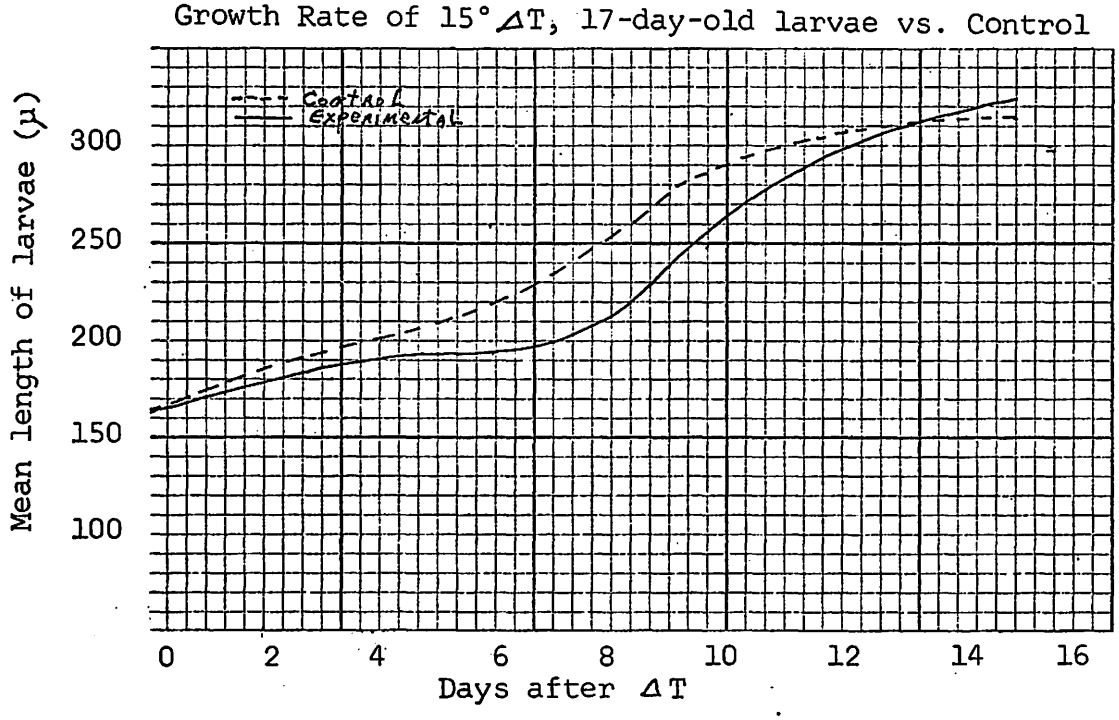

Growth Rate of 15° ΔT, 17-day-old larvae vs. Control
Control
Experimental
Mean length of larvae (μ)
300
250
200
150
100
0
2
4
6
8
10
12
14
16
Days after ΔT

Fig. 26

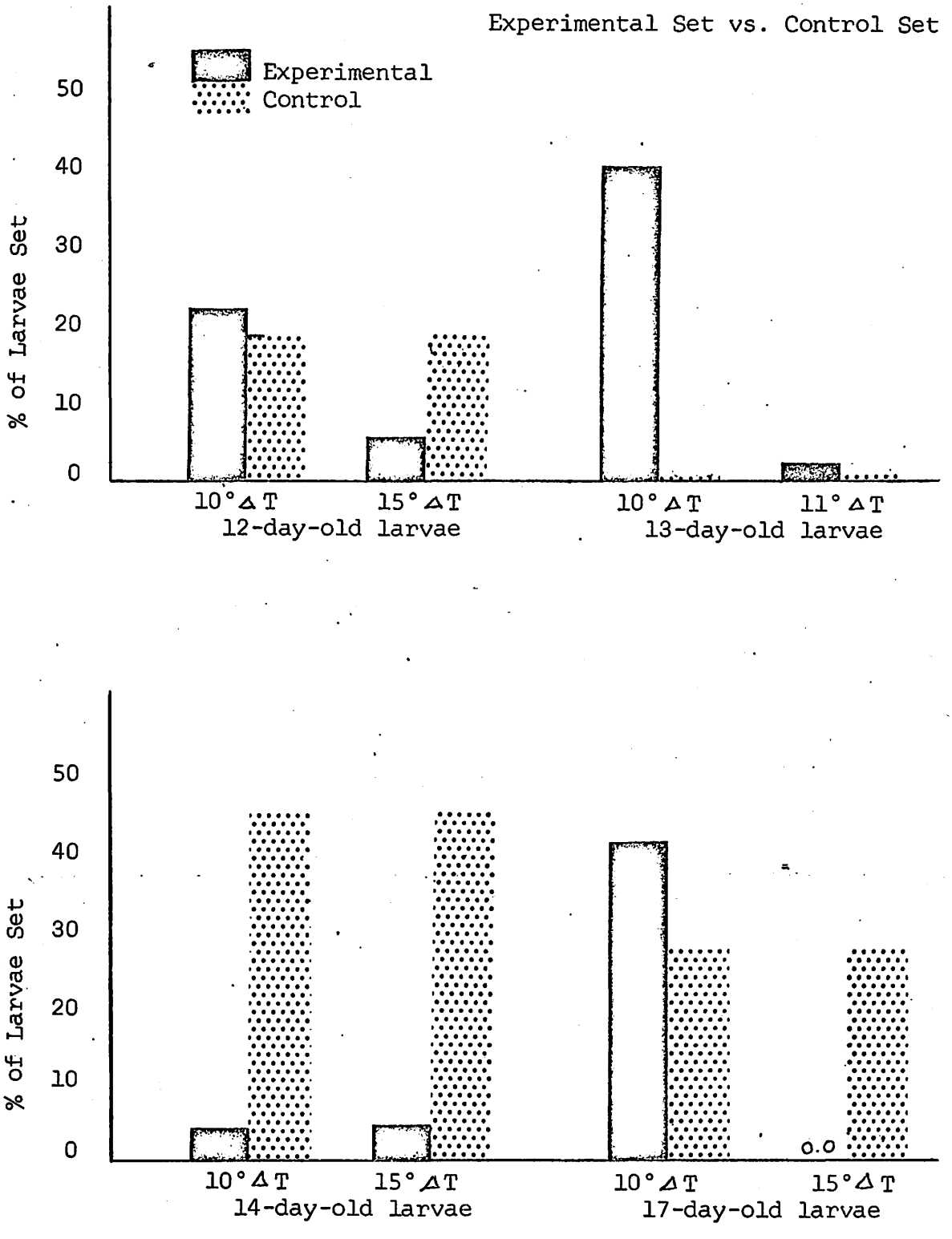

Experimental Set vs. Control Set
Experimental
Control
% of Larvae Set
50
40
30
20
10
0
10°ΔT
15°ΔT
12-day-old larvae
10°ΔT
11°ΔT
13-day-old larvae
% of Larvae Set
50
40
30
20
10
0
0.0
10°ΔT
15°ΔT
14-day-old larvae
10°ΔT
15°ΔT
17-day-old larvae

Fig. 27

A P P E N D I X

INITIAL REACTIONS OF OYSTER LARVAE TO THERMAL SHOCK

To determine the effect of temperature shock on larval oysters, the respective percent control on bottom figure was subtracted from the percent experimental on bottom figure. The effect of temperature shock on the larvae is presented in Table 1. The apparent contradiction in some of the experiments showing negative effects from the ΔT may be due to the larvae being agitated, heated and dumped into a recovery container. Initially, the larvae react by attaching to the bottom by byssal threads. With time, they detach and become more active than the controls which have not been subjected to such rigorous physiological changes. This recovery holds in general for acclimation temperatures below 20°C and a ΔT below 30°C. Generally, there was a very small recovery, indicating some permanent damage may have been incurred with acclimation temperatures above 20°C accompanied by a ΔT greater than 15°C.

These data show a cut-off point where damage from temperature shock will occur. This point is related to the upper lethal temperature of the larvae. Particular attention should be placed on the higher acclimation temperatures where a small ΔT will exceed the organisms' tolerance. For Crassostrea virginica larvae, the cut-off point was a ΔT above 30°C at acclimation temperatures below 20°C. For acclimation temperatures above 20°C, the cut-off is a ΔT of 15°C. For particular combinations of acclimation temperatures and ΔT, see Figs. 1-5.

The following graphs show the percent larvae on the bottom due to a thermal shock. Acclimation temperatures range from 10° to 32°C for C. virginica. Data were taken at one-half hour intervals. Temperature shock ranges from 8° to 30°C and are graphed on the abscissa axis. Each graph is a time period of one-half hour.

FIGURE 1

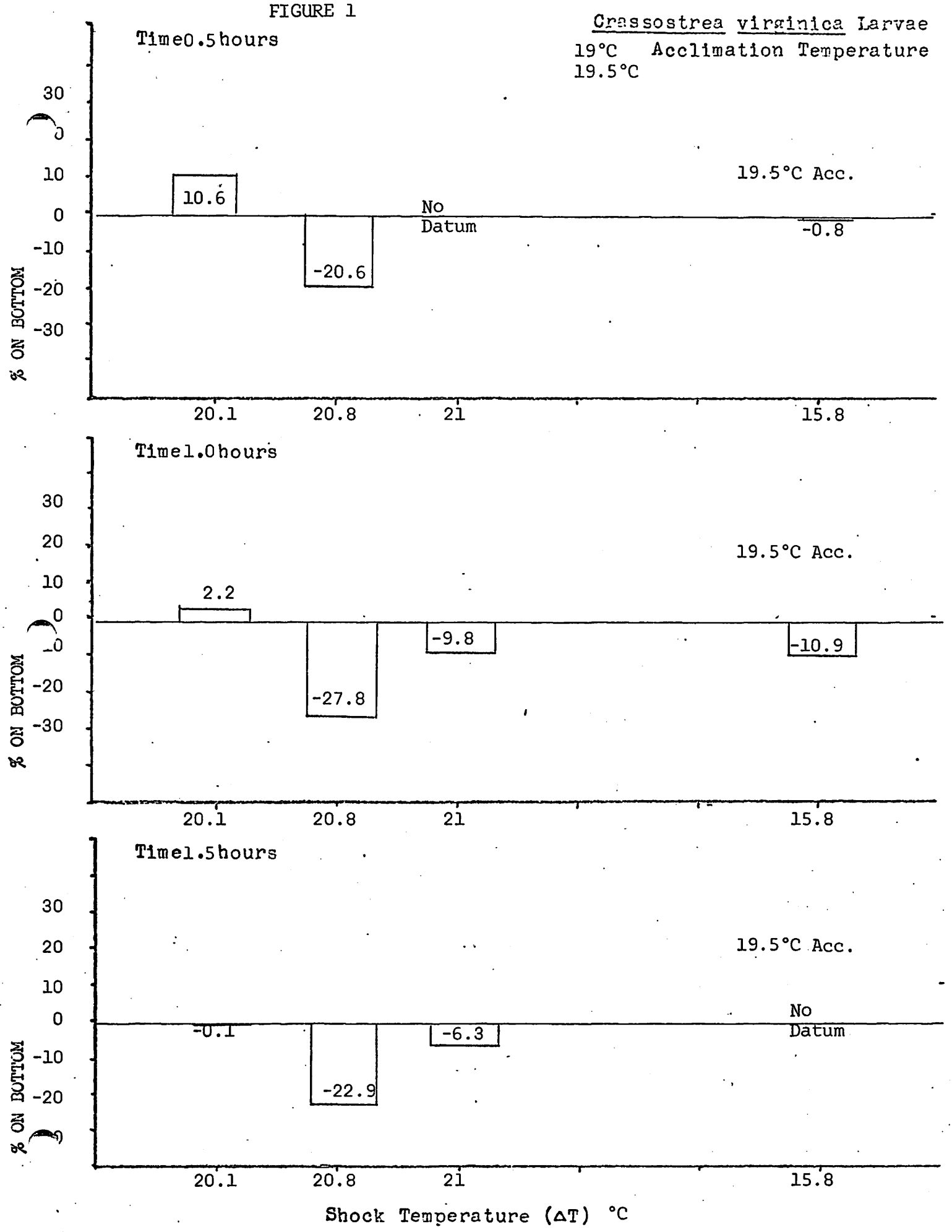

Crassostrea virginica Larvae
19°C Acclimation Temperature
19.5°C
Time0.5hours
19.5°C Acc.
10.6
No
Datum
-0.8
-20.6
% ON BOTTOM
30
20
10
0
-10
-20
-30
20.1
20.8
21
15.8
Time1.0hours
19.5°C Acc.
2.2
-9.8
-10.9
-27.8
Time1.5hours
19.5°C Acc.
-0.1
No
Datum
-6.3
-22.9
Shock Temperature (ΔT) °C

FIGURE 2

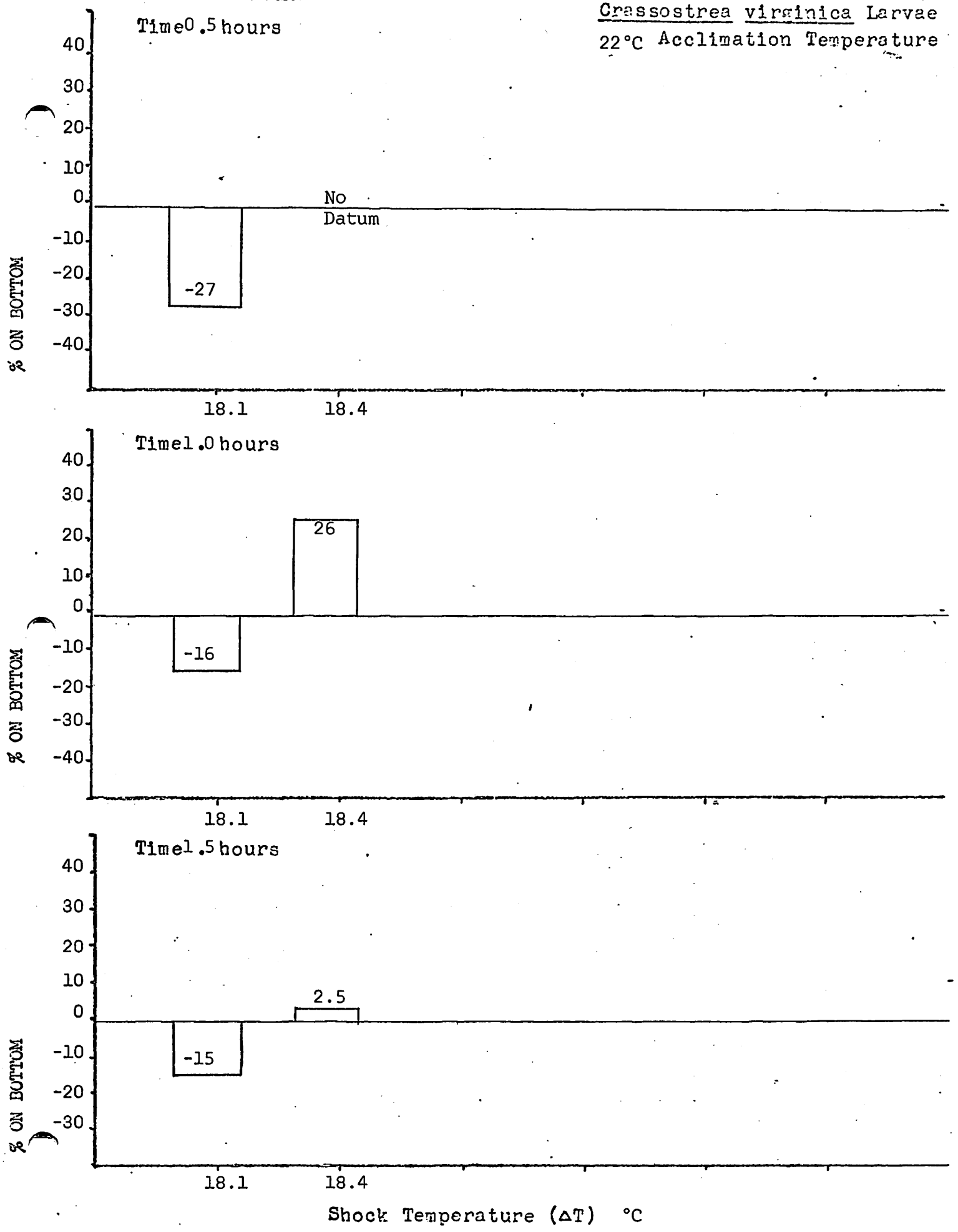

Crassostrea virginica Larvae
22°C Acclimation Temperature
Time 0.5 hours
40
30
20
10
0
-10
-20
-30
-40
No Datum
-27
% ON BOTTOM
18.1
18.4
Time 1.0 hours
26
-16
Time 1.5 hours
2.5
-15
Shock Temperature (ΔT) °C

FIGURE 3.

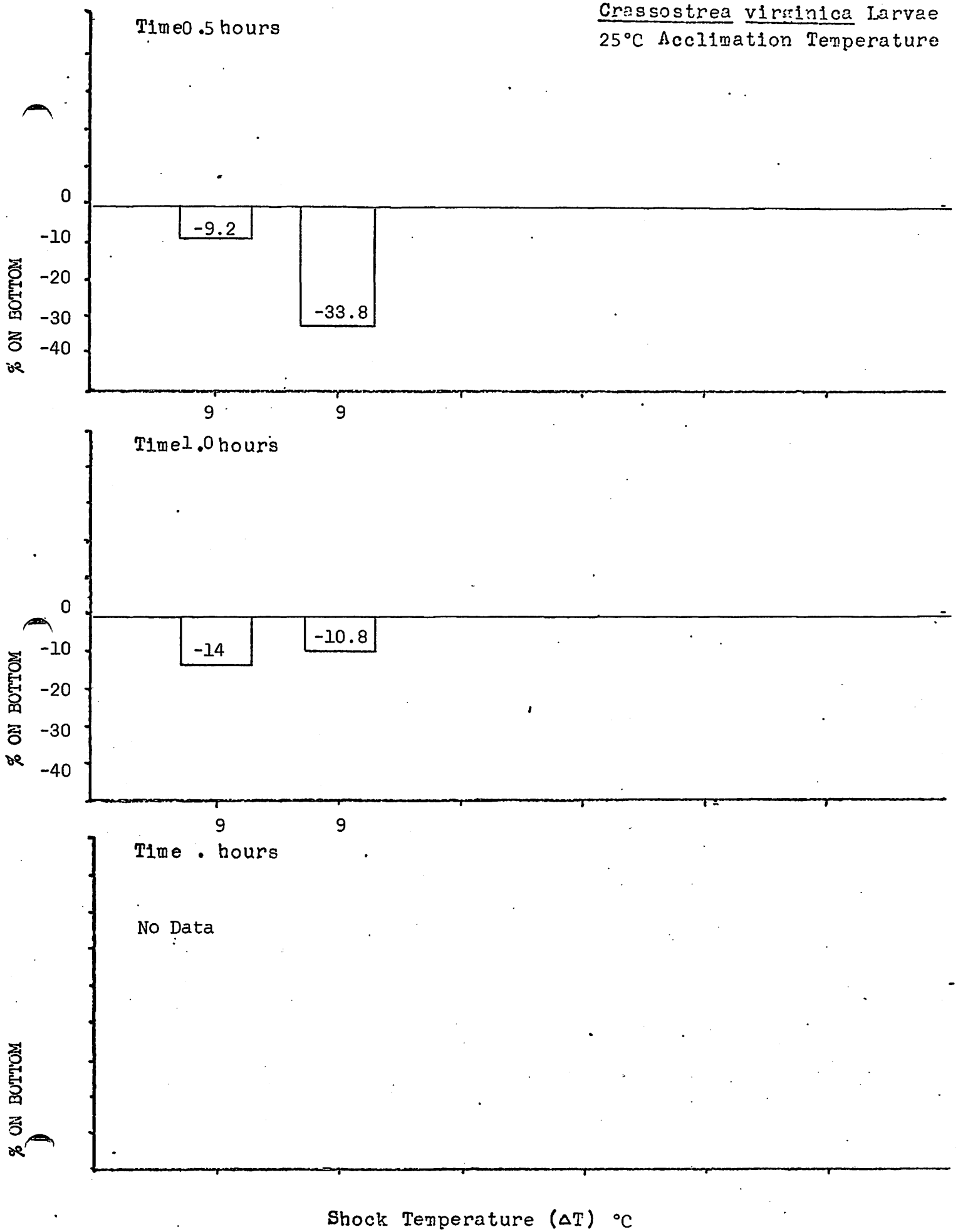

Crassostrea virginica Larvae
25°C Acclimation Temperature
Time0.5 hours
0
-10
-20
-30
-40
% ON BOTTOM
-9.2
-33.8
9
9
Time1.0 hours
0
-10
-20
-30
-40
% ON BOTTOM
-14
-10.8
9
9
Time . hours
No Data
% ON BOTTOM
Shock Temperature (ΔT) °C

FIGURE 4.

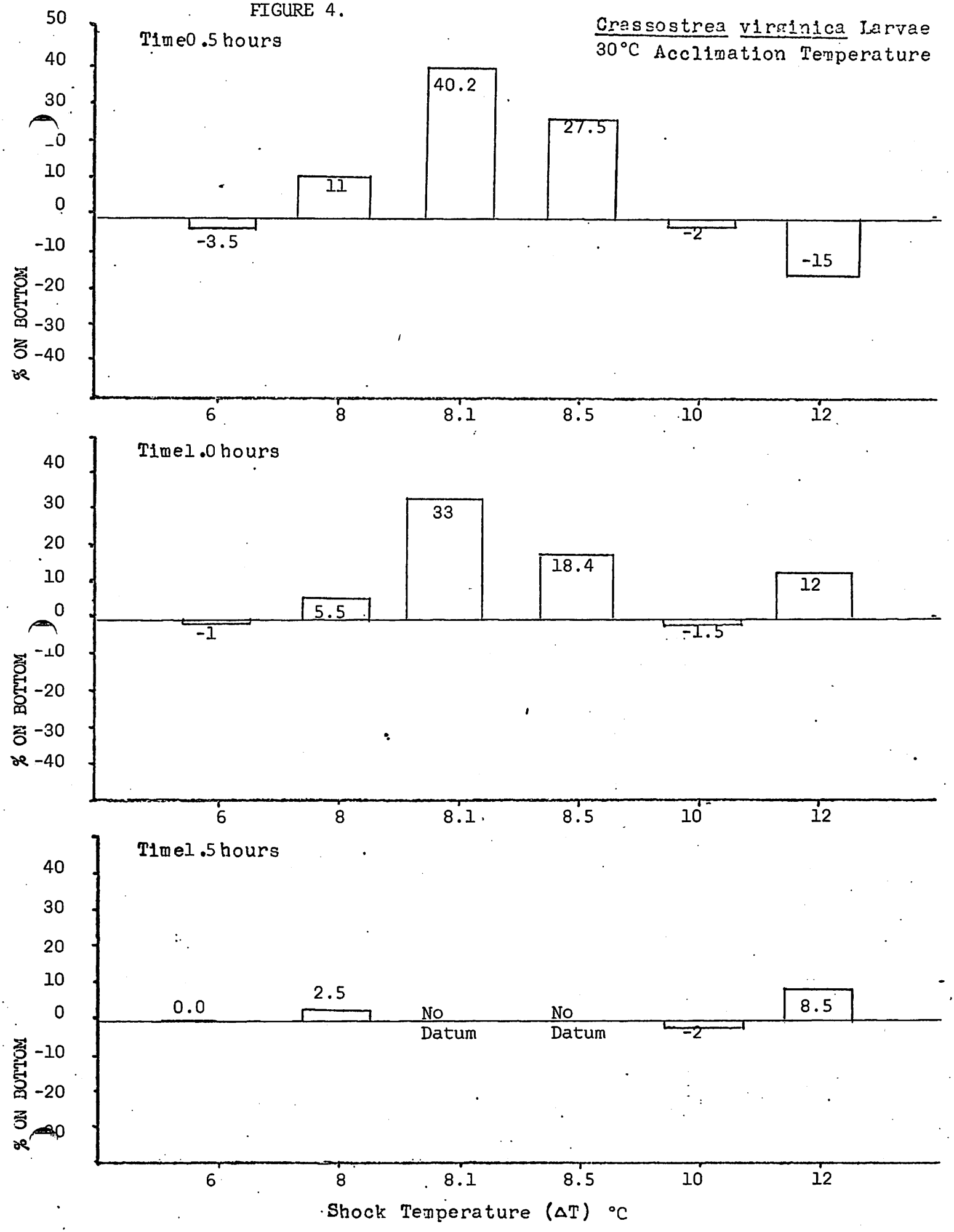

Crassostrea virginica Larvae
30°C Acclimation Temperature
Time0.5 hours
40.2
27.5
11
-3.5
-2
-15
Time1.0 hours
33
18.4
12
5.5
-1
-1.5
Time1.5 hours
0.0
2.5
No Datum
No Datum
-2
8.5
% ON BOTTOM
50
40
30
20
10
0
-10
-20
-30
-40
6
8
8.1
8.5
10
12
Shock Temperature (ΔT) °C

FIGURE 4 continued.

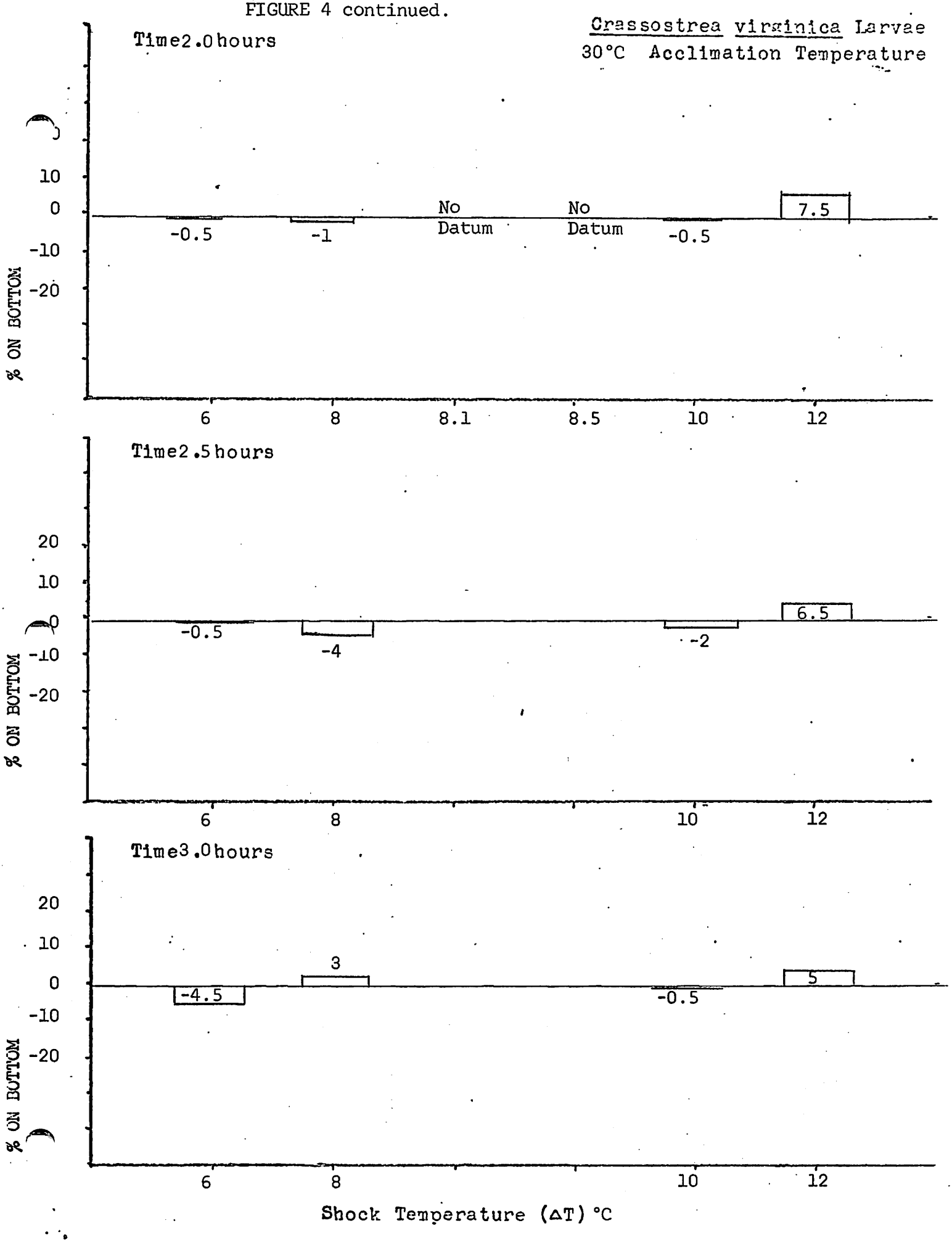


FIGURE 5.

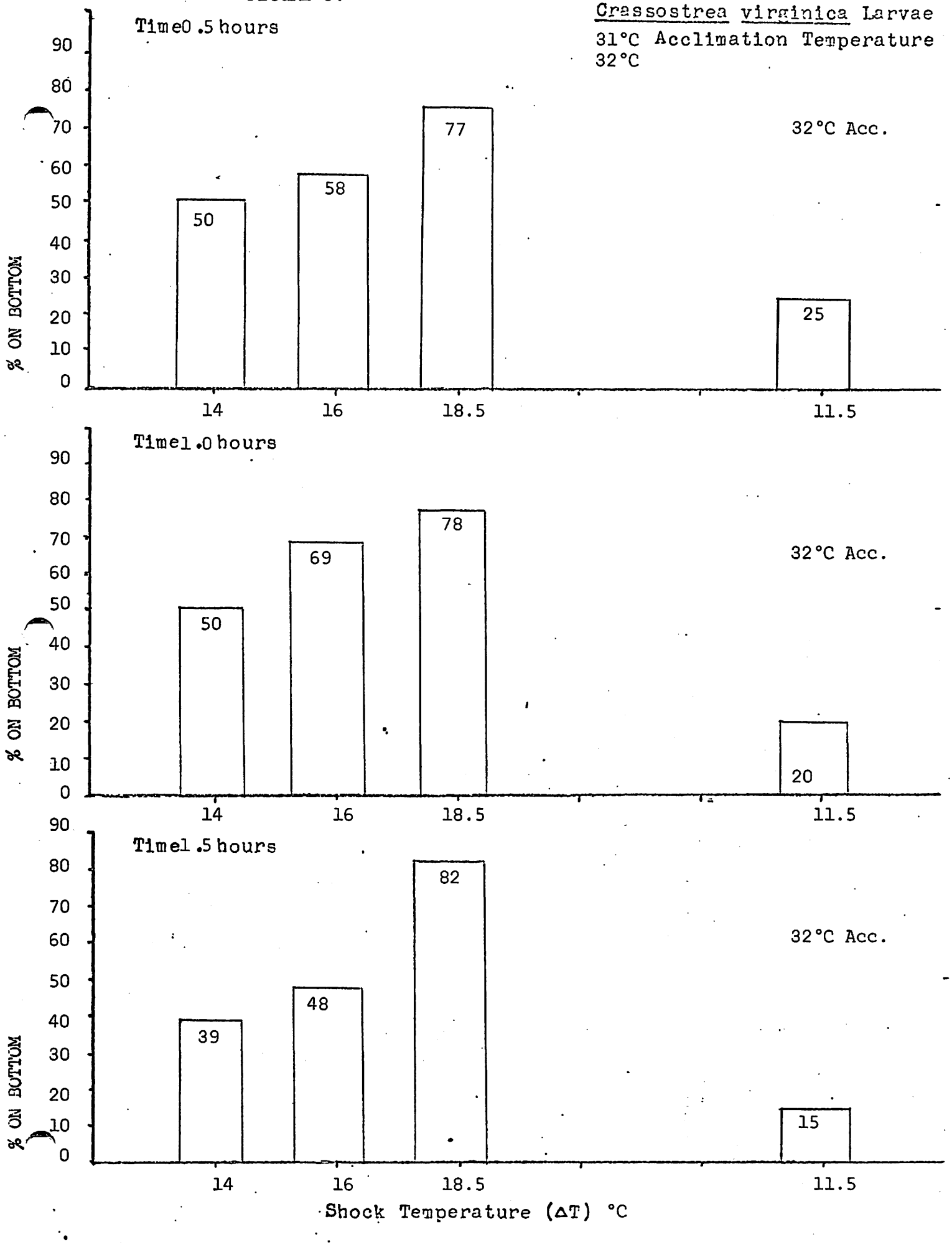

Crassostrea virginica Larvae
31°C Acclimation Temperature
32°C
Time0.5 hours
32°C Acc.
% ON BOTTOM
90
80
70
60
50
40
30
20
10
0
50
58
77
25
14
16
18.5
11.5
Time1.0 hours
32°C Acc.
% ON BOTTOM
50
69
78
20
14
16
18.5
11.5
Time1.5 hours
32°C Acc.
% ON BOTTOM
39
48
82
15
14
16
18.5
11.5
Shock Temperature (ΔT) °C

FIGURE 5 continued.

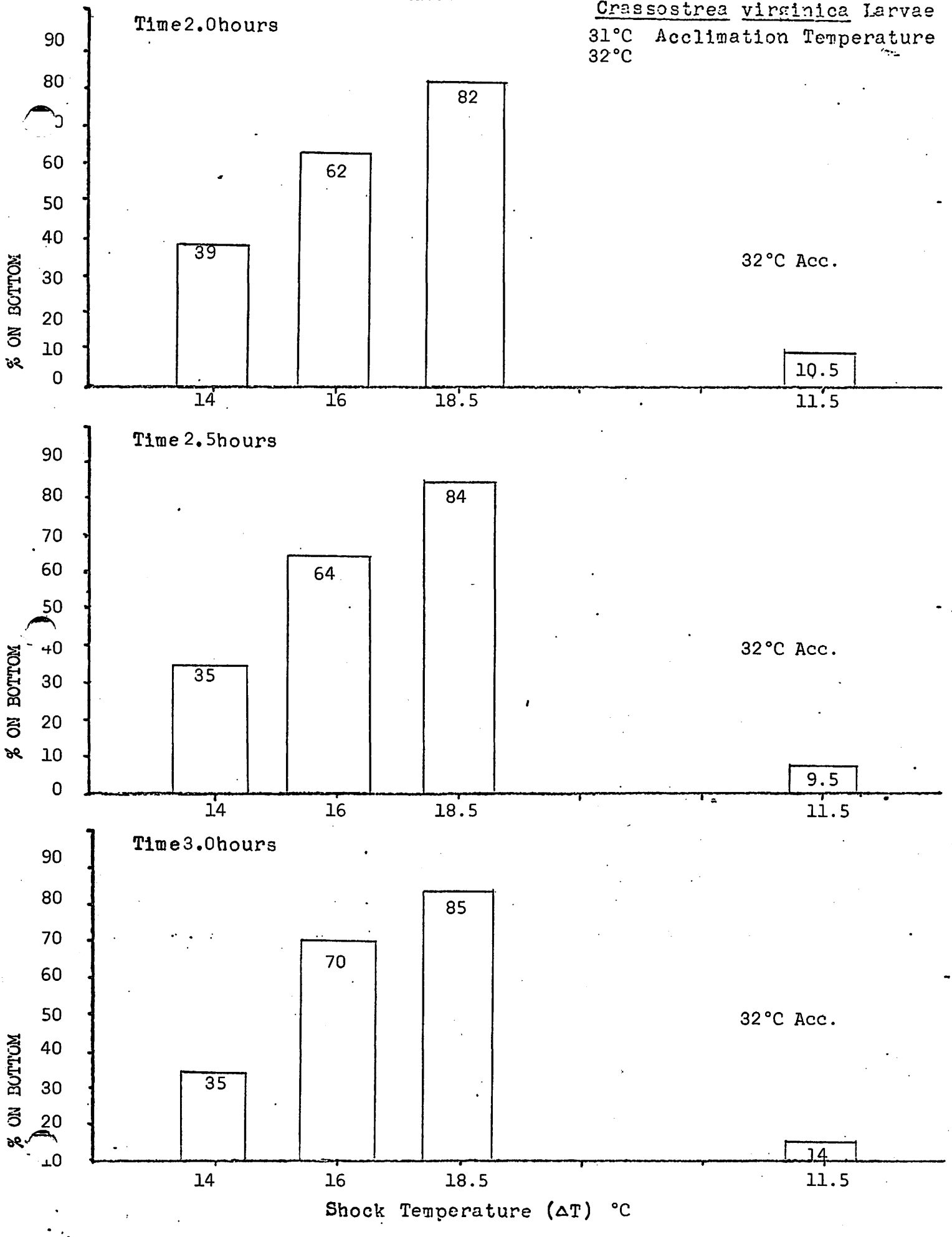


Table 1

Crassostrea virginica larvae on bottom due to ΔT
(Experimental % minus control %)

Acc. Temp. °C	ΔT	% on bottom after time (hours)					
		0.5	1.0	1.5	2.0	2.5	3.0
5	17	7	-26	-27	27.5	-34	-12.5
5	32		16	21.5	23	12	16
5	33	13	-16.5	-11.5	-23.5	-31	-10.5
5	35		17	17.5	8.5	7	26
5	36	4.5	-15.5	-14.5	-25	-34.5	-19.5
10	27.5	4	23	21.5	19.5	18	4
10	31.4	3.1	-13.7	-12.5	-28.5	-10.9	
10	31.8		- 0.3	- 1.7	- 7.9	10.5	
10	32	18.5	46.5	49.5	47	37.5	27
10.5	30	-12.2	- 8.1	- 1.1	5.3		
11	25	- 8	2.7	- 3.6	- 3.1	- 7	- 5.2
11	29	-22	-13.3	2.4	- 5.6	-12.5	- 6.7
11	29	-27.2	- 7.9	- 1.9	- 5.7		
11	31	10.5	23.2	16.4	17.9	8	4.3
11	33.5	8.5	23.2	32.9	24.9	16	21.3
11	38	1	19.2	31.4	25.9	25.5	23.3
19	20.1	10.6	2.2	- 0.1	9.5		
19	20.8	-20.6	-27.8	-22.9	-11.0		
19	21.0		- 9.8	- 6.3	- 2.5		
19.5	15.8	- 0.8	-10.9				
22	18.1	-27	-16	-15	- 6.5		
22	18.4		26	2.5	- 5		
22.5	20.7	6.5	26	26.5	22.5		
22.5	21.3		72.5	67.5	62.5		
23	22	56.3	59.5	54.1	59.5		
23	23	60.3	68	72.1	72.5		
23	25.3	55.3	74	63.6	67.5		
23	26.6	65.8	81	77.1	80		
25	9	- 9.2	-14				
25	9	-33.8	-10.8				
30	6	- 3.5	- 1	0.0	- 0.5	- 0.5	- 4.5
30	8	11	5.5	2.5	1	- 4	3
30	8.1	40.2	33.1				
30	8.5	27.5	18.4				
30	10	- 2	- 1.5	- 2	- 0.5	- 2	- 0.5
30	12	-15	12	8.5	7.5	6.5	5
31	14	50.5	49.5	39	39	35	35
31	16	58.5	69	48.5	62.5	64.5	69.5
31	18.5	77	79	81.5	82	83.5	85.5
32	11.5	25	21.5	15	10.5	9.5	14

Table 1 continued

ΔT	Acc. Temp. °C	% on bottom after time (hours) 0.5	1.0	1.5	2.0	2.5	3.0
6	30	11	8	9	7	8	4
8	30	25	15	11	9	4	11
9	25	45.4	26.2				
9	25	20.8	29.4				
8.5	29.5	41.5	27.4				
8.1	29.9	54.2	42.1				
10	30	12	7.5	6.5	7	6	7.5
12	30	29	21	17	15	14.5	13
15.8	19.5	11.8	10				
14	31	68	60.5	50.5	50.5	47	44.5
16	31	76	80	70	74	76.5	79
11.5	32	42.5	32.5	26.5	22	21.5	23.5
18.5	31	94.5	90	93	93.5	95.5	95
18.4	22.1		51.5	29.5	19.5		
18.1	22.1	20	9.5	12	18		
17	5	78	41	31	30.5	23	32
20.7	22.5	43	45.5	48	45		
21.3	22.5		92	79	85		
21	19		69.2	72.4	65.9		
20.8	19	51.4	51.2	55.8	57.4		
20.1	19	82.6	81.2	78.6	77.9		
22	23	85.5	75.5	72	76		
23	23	89.5	84	90	89		
25.3	23	84.5	90	81.5	84		
26.6	23	95	97	95	96.5		
25	11	78	70	52	54	54	53
29	11	64	54	58	51.5	48.5	51.5
27.5	10	80	67	60.5	54.5	57.5	56.5
29	11	58.8	59.4	53.7	51.4		
30	10.5	61.8	58.2	55.8	52.4		
31.4	10	59.3	53.2	54.9	42.9	41.1	
31.8	10		66.6	65.7	63.5	62.5	
32	10	79.5	75	78.5	82	69	74
31	11	97.5	90.5	72	75	69	62.5
33.5	11	94.5	90.5	88.5	82	77	79.5
32	5		83	79.5	81	69	60.5
33	5	84	50.5	46.5	34.5	26	34
35	5		84	75.5	66.5	64	70.5
36	5	75.5	51.5	43.5	33	22.5	25
38	11	87	86.5	87	83	86.5	81.5