ECOLOGY OF A REEF FORMING SERPULID
Hydroides norvegica

FINAL REPORT

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by

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INTRODUCTION

Experimental results reported herein were obtained on colonies of serpulid worms collected from a filter box (Fig. 1) through which water was pumped at a rate of about 1,000 gallons per day. The filter box was located within and the water was drawn from the cooling water intake system of the Central Power and Light Company plant located between the Port of Corpus Christi and Nueces Bay, Texas. Although at least three species of serpulids were identified from this locality during the spring of 1969, all specimens collected for experimentation included only Hydroides norvegica. Salinity of the water in the Port of Corpus Christi ranged from 29 to 35 ppt through the sampling period.

SALINITY TOLERANCES

The upper salt tolerance of H. norvegica was determined by placing specimens in sea water in open, aerated beakers so that evaporation caused salinity to increase slowly and regularly. Worm reactions to high salinity were much the same as reactions to low level heat stress described in the September 1969 Progress Report; that is, tentacles would generally appear to shrivel inward, and they would extend less and less from the calcareous tube as the adverse conditions continued or increased. Control specimens maintained at 30 to 35 ppt were observed simultaneously with specimens living at elevated salinities. Control specimens showed normal, full tentacle extension for all results reported.

The first signs of adverse reactions were observed just above 50 ppt. Worms survived for short periods above 55 ppt; but all showed considerable shriveling and withdrawal.

The lower salinity limit was tested by placing worms in sea water

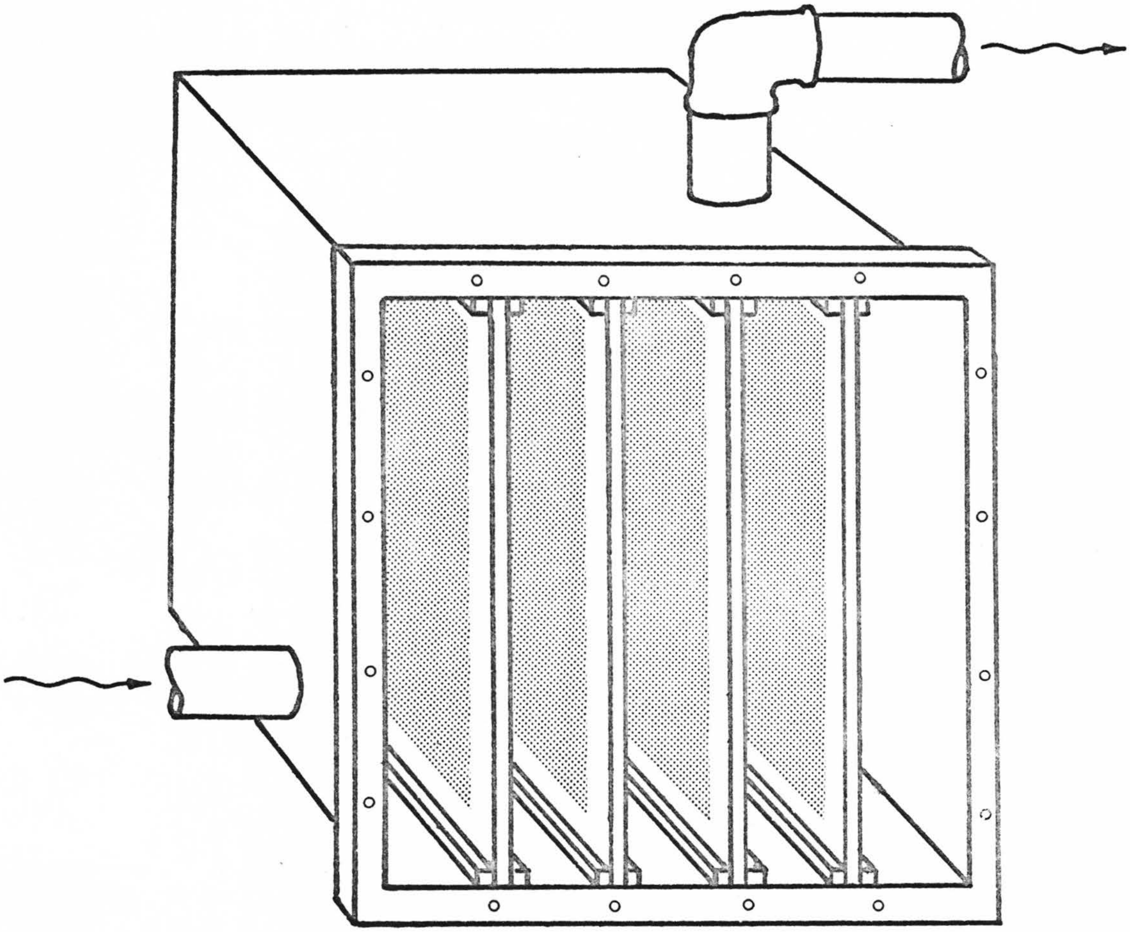


Figure 1. Collecting Box

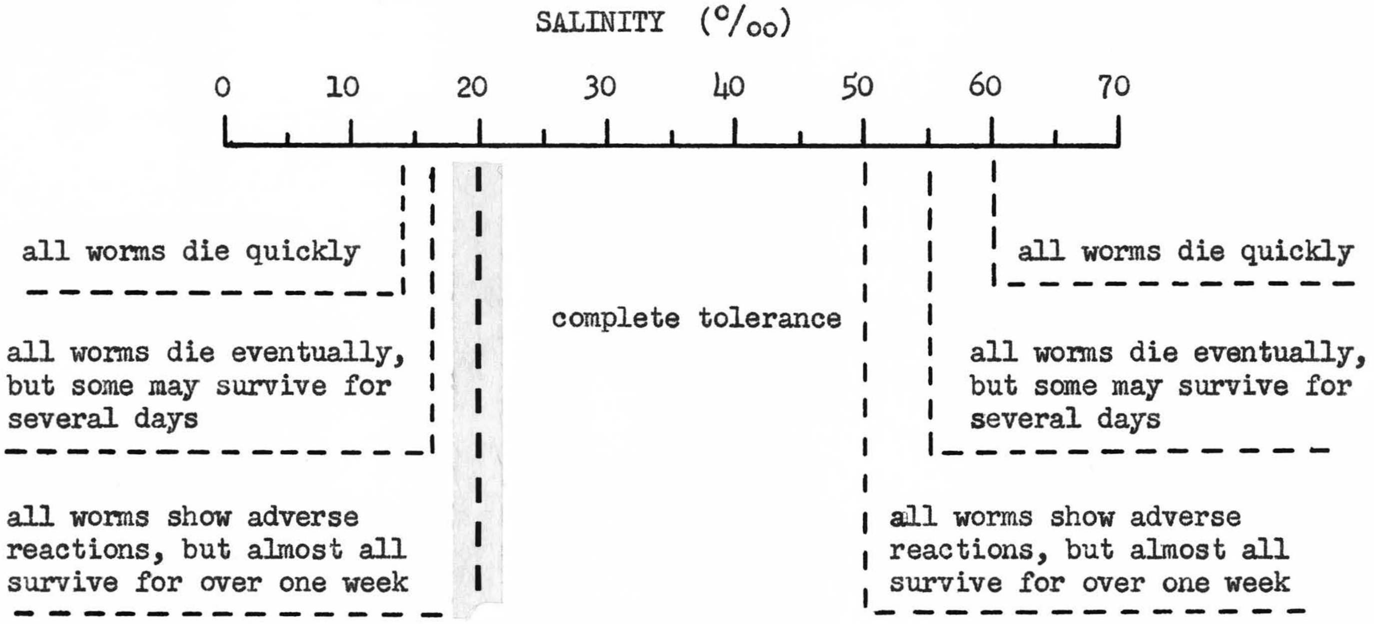
Flow is in the direction of the arrows. The front of the box is removed. It is plywood painted with polyesther resin like the rest of the box and has a bordering steel rim. The cover is attached with bronze bolts through the steel rim. A rubber gasket forms a water-tight seal. Screens were replaced every two weeks for one year for counting newly settled serpulids. Specimens for experimentation were collected from the sides of the box.

diluted with distilled water. Adverse reactions in addition to those already described included swelling due, no doubt, to osmotic absorbtion from the low salinity water. Worms were observed at salinities of 28, 26, 24, 22, 20, 18, 16, 14, and 12 ppt. Worms in water of 20 ppt and higher showed no adverse reactions for a period of two days. Worms held at 12 ppt died within 24 hours. Some worms held at 14 ppt survived for over 24 hours but almost all died within 48 hours. Most worms held at 16 to 18 ppt showed adverse reactions but less than 50% died in two days. These data are summarized in Figure 2.

TEMPERATURE TOLERANCE

It is well known that many marine organisms can survive higher temperatures when they are acclimated to warm waters than when they are acclimated to cold water. The temperature tolerances of H. norvegica was tested as a function of its acclimation to ambient water temperatures in the Central Power and Light Company cooling water intake system. Biweekly collections were made of both worm colonies and the water in which they were living. Only this water was used in experimentation. In the lab colonial specimens were placed in heated water maintained at specific temperatures by a Cole-Parmer Versa-Therm model 2156 Electronic Temperature Controller with a YSI model 401 thermistor probe input and a heating tape output. Worms were held at from 90 to 110^{O}F for from one to several hundred minutes and were then returned to the water in which they were collected which remained at room temperature (70 to 75^{O}). Specimens were examined 24 hours after experimentation and were judged to have received a lethal dosage of heat if it was impossible for a worm to retract into its tube due either to over

Figure 2. Salinity Tolerances of <u>Hydroides</u> <u>norvegica</u>



extension (beyond the thorax) or to deterioration of the more vital functions. The results of all experiments are shown in Appendix A.

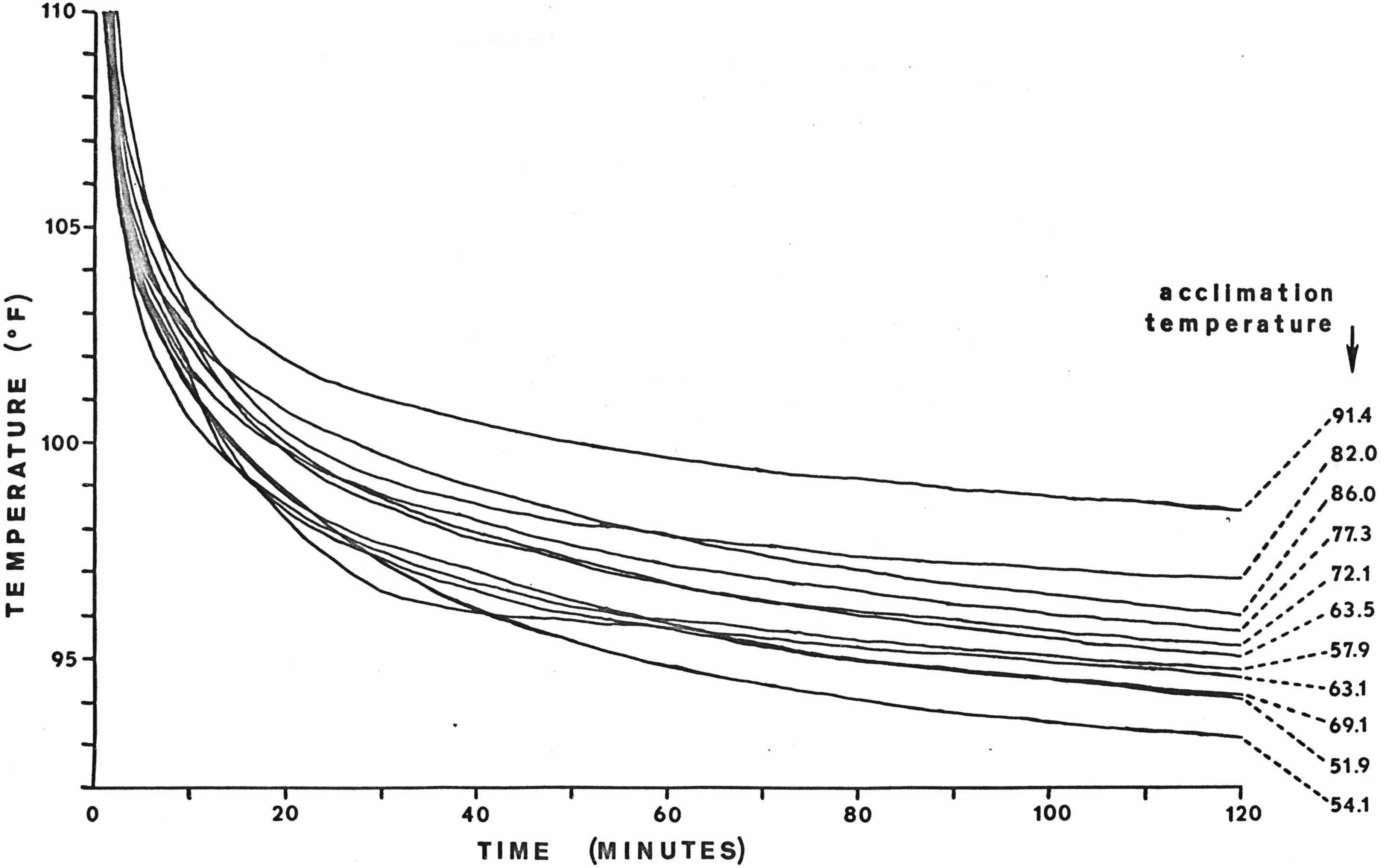
These data are summarized in Figures 3 and 4 and in Table 1. Figure 3 shows the temperature required to kill all worms (LD100 - lethal dosage for 100% mortality) as a function of the time the specimens are held at these temperatures. They are the same data as used in Appendix A but plotted with an arithmetic rather than a logarithmic time scale. It can be seen that a total change in environmental temperatures of about 40 F^o produced a shift of about 5 F^o in lethal temperature.

The decreasing slope of each curve approximates a geometric progression. The sum of all terms in such a progression can be calculated from the equation S (sum) = a/(1-r), where a is the first term in the progression and r is the ratio of each term to the preceding one in the progression. A minimum lethal temperature was calculated by measuring ratios of temperature decreases through 20 minute increments between 20 and 120 minutes on each experimentally derived curve. The sum of all decreases was then subtracted from the lethal temperature at each 20 minute interval between 40 and 100 minutes. Results of calculations from four points on each graph always were within 0.4^oC of each other and were within 0.2^oC in all but three cases (samples 4, 5, and 7).

A few data beyond 120 minutes suggest that these calculated minimal lethal temperatures tend to be high. In most experiments at least some mortality was observed at lower temperatures held for several hours.

Figure 3. Temperature Tolerances

Experimental time-temperature combinations which effect 100% mortality. Experimental procedure is described in the text. Anomalies in acclimation temperature sequence are tabulated in Table 1 and are discussed in the text.


110
105
100
95
TEMPERATURE (°F)
0
20
40
60
80
100
120
TIME (MINUTES)
acclimation temperature
91.4
82.0
86.0
77.3
72.1
63.5
57.9
63.1
69.1
51.9
54.1

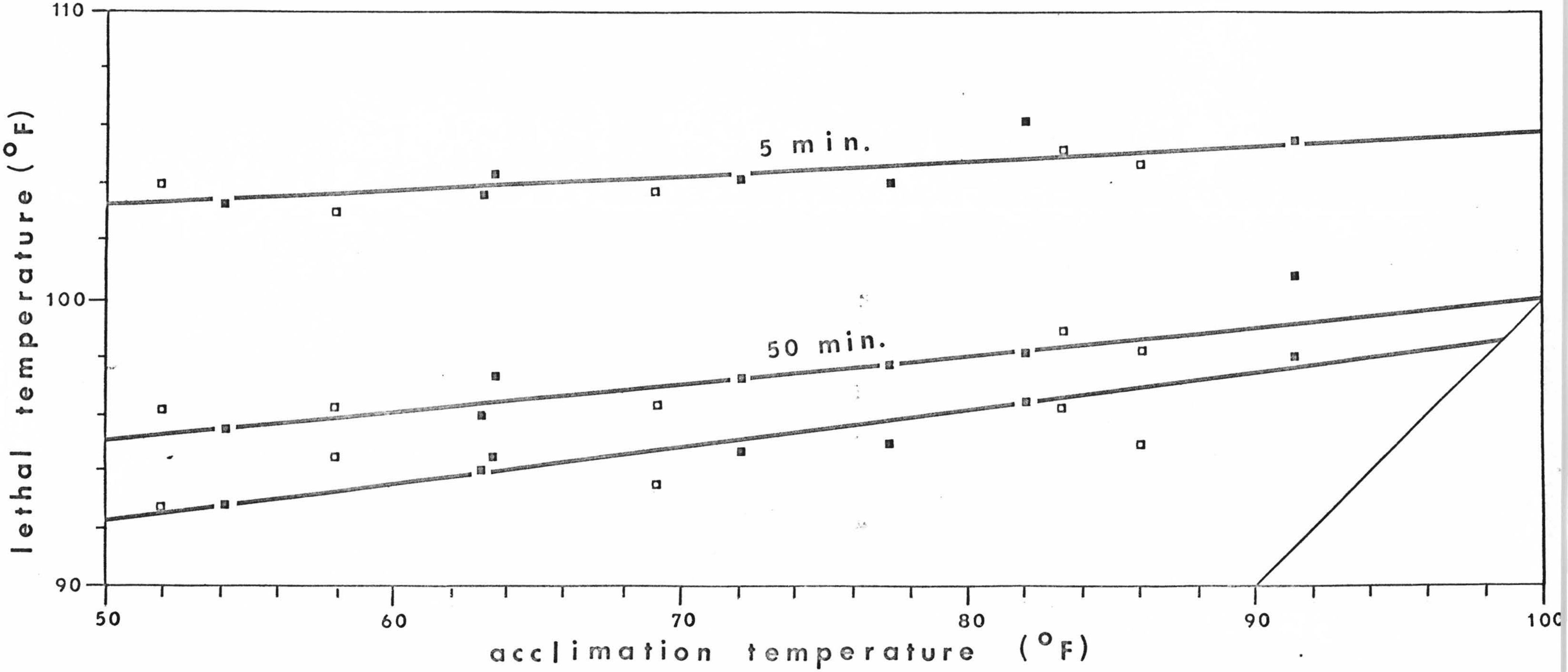


Figure 4. Lethal Temperatures va Acclimation Temperatures

Upper two lines indicate lethal temperatures at 5 and 50 minutes exposure. Lower line is for calculated minimal lethal temperatures. Solid squares are sequentially congruent data; open squares are anomalous data (see Table 1). Line in lower right represents the limiting case when acclimation temperature equals lethal temperature.

TABLE 1 Lethal Temperature vs. Acclimation Temperature

Samp. numb.	Accl. temp.	Leth.* temp.	Leth.** temp.	Remarks
A	91.4	98.1		acclimated in the laboratory for over one week.
B	86.0		95.0	acclimated in the laboratory for 3 days; this acclimation time is apparently too short.
C	83.3		96.3	elevated salinity (48.6 ppt); anomaly quite small.
1	82.0	96.5		
2	77.3	95.0		
3	72.1	94.8		
4	69.1		93.6	complete anomaly.
6	63.5	94.3		
5	63.1	94.1		
9	57.9		94.5	collected during rising ambient temperatures while almost all other were collected during falling temperatures.
8	54.1	92.8		
7	51.9		92.8	too little time for complete acclimation.

* - congruent in series of decreasing acclimation temperatures
** - anomalous in series of decreasing acclimation temperatures

All lethal temperatures are calculated from the data in Figure 3 according to the procedure described in the text. Ambient water temperatures and dates of collection for samples one through nine are shown in Figure 5.

Although the trend toward increasing tolerance with increasing acclimation temperature is clear, a number of points do not fall in the proper sequence. These anomalies are summarized in Table 1. Two anomalies are quite obviously due to incomplete acclimation. Samples A and B were collected at about 64°F and acclimated to higher temperatures in the lab. The tolerance of sample B should have been higher than for samples C and 1, but it was held at its acclimation temperature (86°F) for only three days while all other samples were acclimated for from one to two weeks. Sample 7, on the other hand, was collected in January, 1970, after a water temperature drop of 16 F° in 13 days (Figure 5). Apparently it had time to acclimate only to about 54°F rather than the 52° water in which it was collected.

A third anomaly (sample C) is very small and is very probably related to a salinity effect (Figure 6). Another small anomaly (sample 9) in which the lethal temperature is too high may be due to over or anticipatory acclimation to a rising ambient temperature. This sample was collected after a 5 F° rise in water temperature at the beginning of spring warming while almost all other samples were collected during the falling temperatures of autumn and winter. Breeding rates differed considerably during these contrasting seasons even though average water temperatures were the same for any two comparable collecting periods (see Figure 7). One last anomaly (sample 4) is totally unexplained.

Acclimation to temperatures above the maximums that occur naturally in the environment was not attempted. The highest possible acclimation temperature can be estimated by extrapolating the curve for lethal temperature at maximum exposure time in Figure 4 to the limiting case of acclimation temperature equals lethal temperature. This value lies

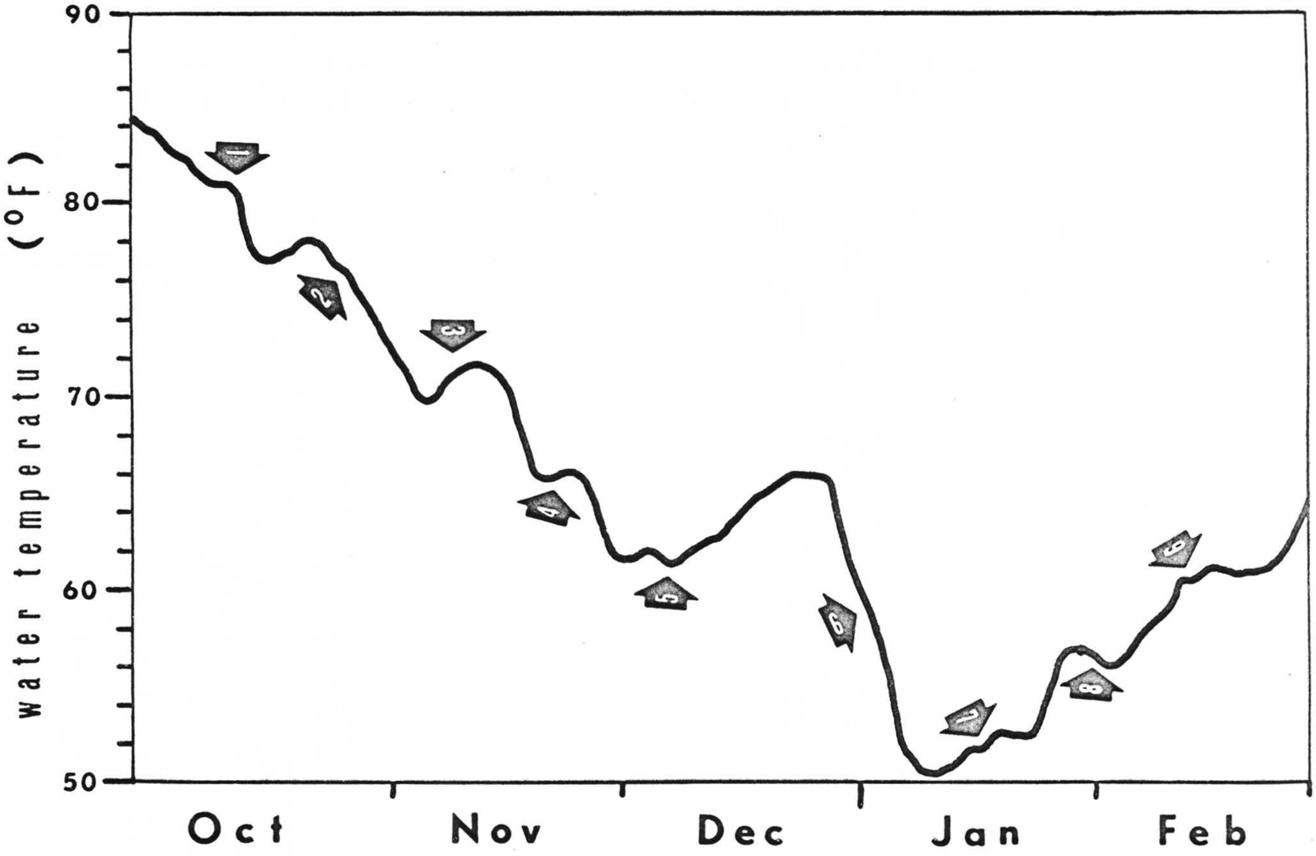
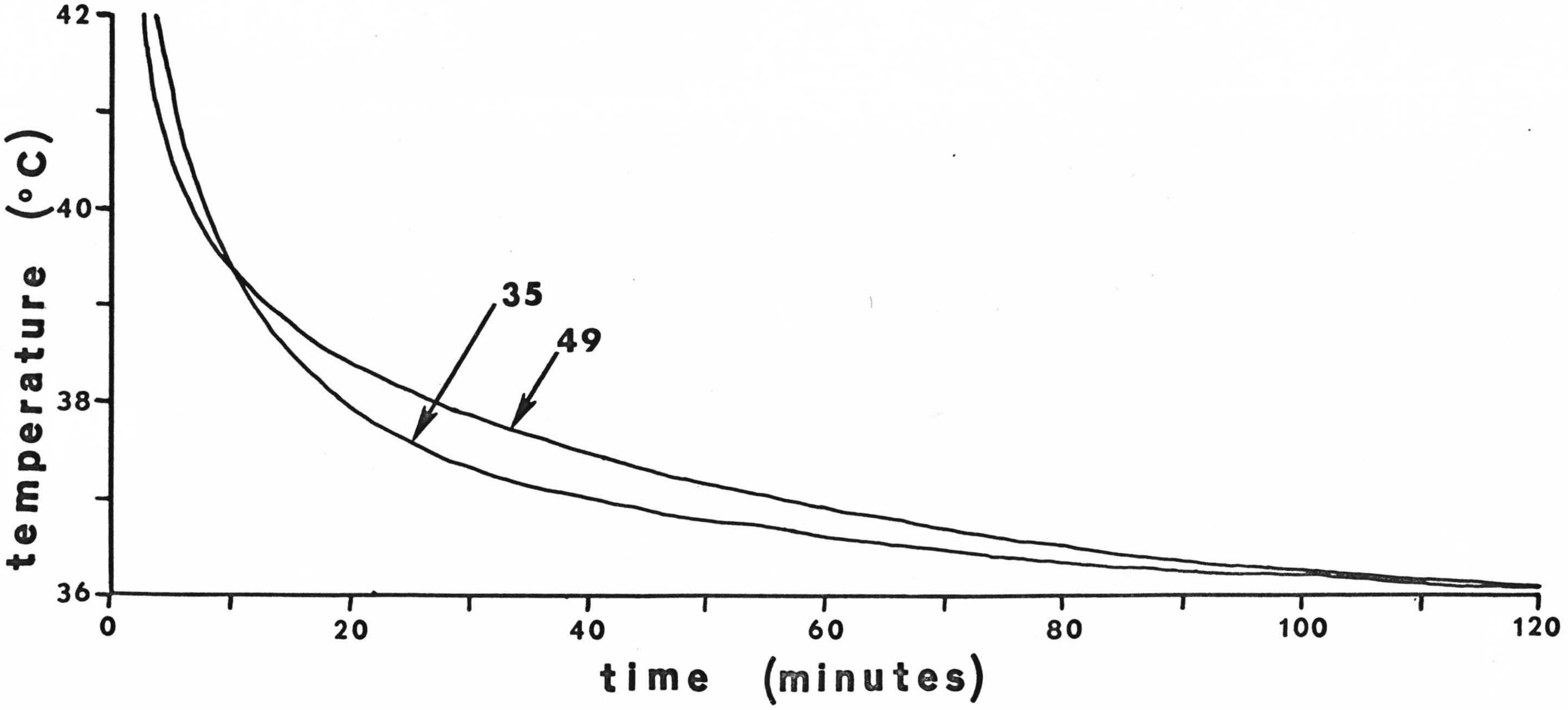


Figure 5. Ambient Temperatures

Water temperatures in cooling water intake system were measured by Central Power and Light Company personnel. Collection times of nine samples are indicated by numbered arrows.

Figure 6. Salinity Effect on Temperature Tolerance

Experimental time-temperature combinations which effect 100% mortality for two samples acclimated at nearly the same temperature. Curve labeled 35 (sample 1) was acclimated at 82°F and 35 ppt; curve labeled 49 (sample C) was acclimated at 83.3°F and 48.6 ppt.


temperature (°C)
42
40
38
36
0
20
40
60
80
100
120
time (minutes)
35
49

between 98 and 99 ^{O}F. This should be the limiting temperature for worm growth at the cooling water outfall.

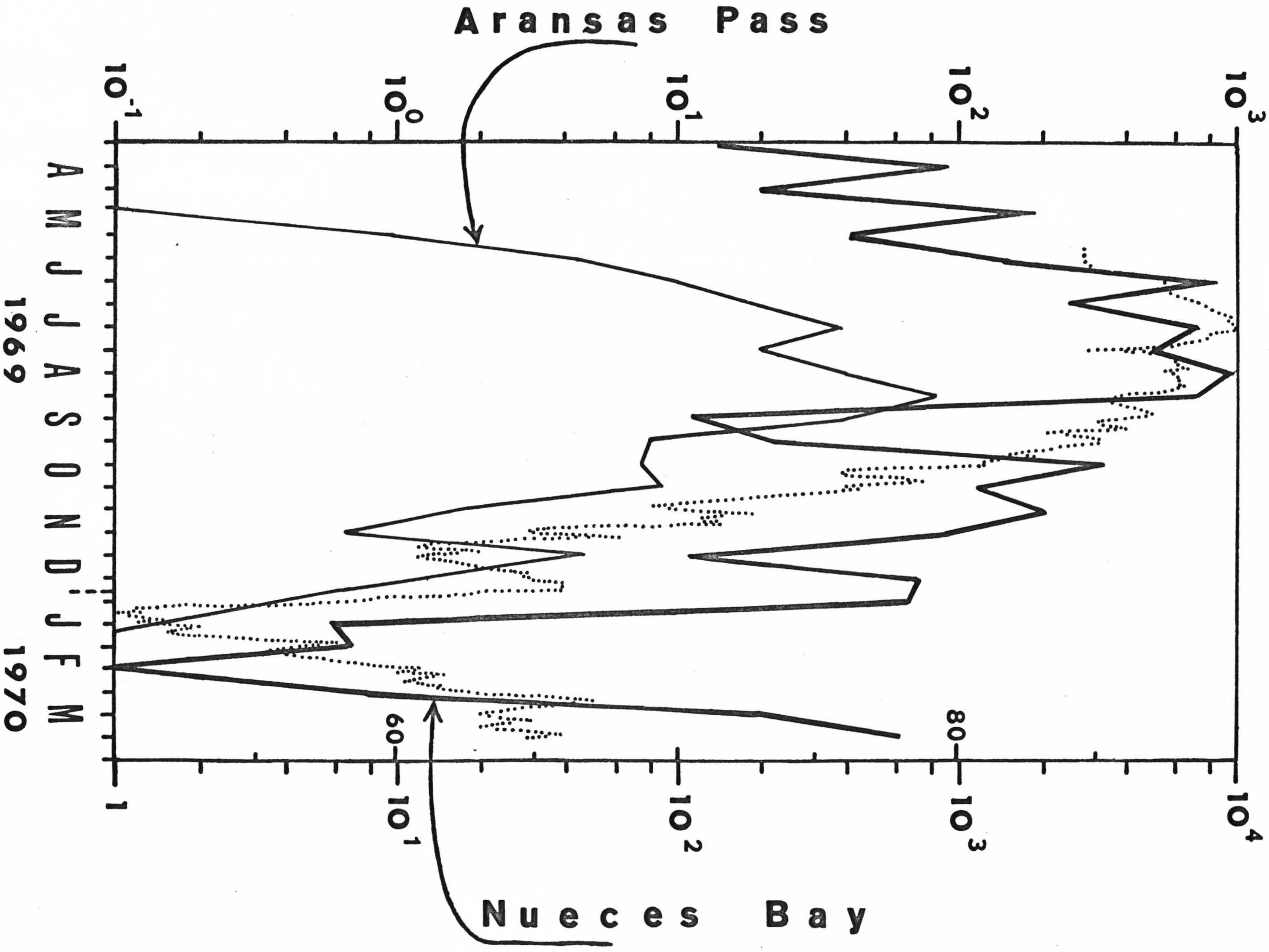
REPRODUCTION AND SETTLING

Plastic screens from the collecting box described earlier were examined biweekly for newly settled serpulids. Data were tabulated as worms per square meter per day (V_W). Figure 7 shows that this settling rate varied by four orders of magnitude over one year. Comparison with the rate of settling in a natural marine environment (Aransas Pass Inlet) shows that the rate of settling from water in the Port of Corpus Christi is about two orders of magnitude greater. This data must reflect the existence of a large, permanent population of serpulids in the harbor.

Variations in the settling rate in the Central Power and Light Company intake system show correlations with water temperatures through seasonal and short-term changes, phases of the moon, and water flow rate. Maximum settling frequency occurred from June through August while water temperature remained above 85^{O}. An order of magnitude decrease took place during the autumn from September through November while temperatures were dropping to about 70^{O}. The anomalously low settling rate recorded during the latter part of September does not correlate with any environmental observations but probably occurred when flow rate was curtailed or interrupted by temporary equipment failure. Another order of magnitude decrease in settling rate followed a water temperature drop from 70^{O} to almost 60^{O} at the beginning of December. A warm period during which water temperature rose back to 66^{O} was accompanied by a settling rate recovery of 3/4 of the autumn decrease. Settling practically ceased at the beginning of January

Figure 7. Settling Rates for 1969-70

Settling rates (V_w) are in worms/sq.m./day. Water temperatures at the Nueces Bay locality (CP&L power station) are in degrees F and are represented by the dotted line. Temperature scale is inside the border on the right side of the graph.


Aransas Pass
10^-1
10^0
10^1
10^2
10^3
A M J J A S O N D J F M
1969
1970
60
80
1
10^1
10^2
10^3
10^4
Nueces Bay

when water temperature dropped from 66° to 50°. The rate remained practically nil well into February until water temperature rose to 61°, but it jumped from one worm/m^2/day to 100/m^2/day as water temperature rose from 61° to 66° during early March. The rate then continued to rise almost another order of magnitude while temperature fluctuated between 63° and 67° when sampling ceased. Thus it seems that breeding commences when the environmental temperature exceeds about 61°-62°, and it may intensify by an order of magnitude as temperature rises to 70° and by another order of magnitude as temperature rises to 85° or 90°. The relationships between temperature and settling rates are summarized in Figure 8.

A rather regular biweekly fluctuation in settling rate can be noticed on Figure 7. This suggested a lunar periodicity, so the frequencies of highs and lows relative to adjacent points on this graph were plotted vs lunar phase as histograms (Figure 9). A coincidence of maximum highs and minimum lows marks the period of maximum settling rates. Considering the swimming period of the trochophorm larvae (6 to 7 days; note the 2nd Annual Report) the corresponding period of maximum breeding activity must follow the full moon by three or four days.

The phenomenon of lunar periodicity in polychaetes is well known for free living forms, but it has been described for only one sessile serpulid (<u>Mercierella</u> <u>enigmatica</u> in Brisbane, Australia; Straughan, 1968). In that case the situation seems to be quite different as breeding maxima coincide with neap tides (quarter phases), and the larval period is three weeks so that settling peaks occur during spring tides which usually accompany or follow shortly after full moons.

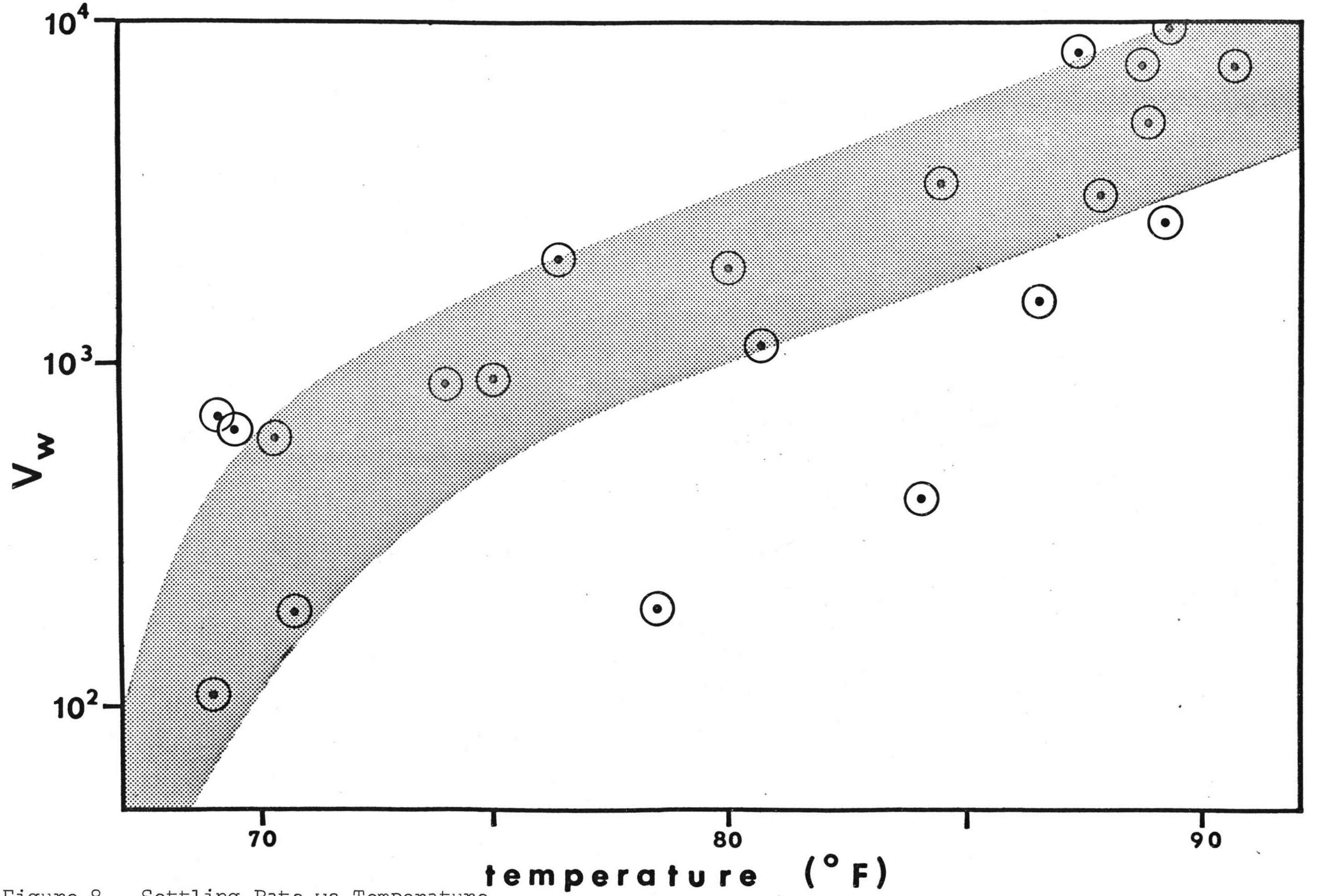


Figure 8. Settling Rate vs Temperature
Settling rate (V_W) is in worms/sq.m./day. Each data point represents the settling during a two week period. Temperature is average water temperature for that period. Scatter of data is probably due, in large part, to fluctuations associated with lunar periodicity (note Figures 8 and 9). These may be reduced by averaging V_W for several successive data points in temporal sequence. This produces the data points connected with a solid line. The temporal sequence of data follows that plot counterclockwise. Note the hysteretic effect between settling rates associated with rising and

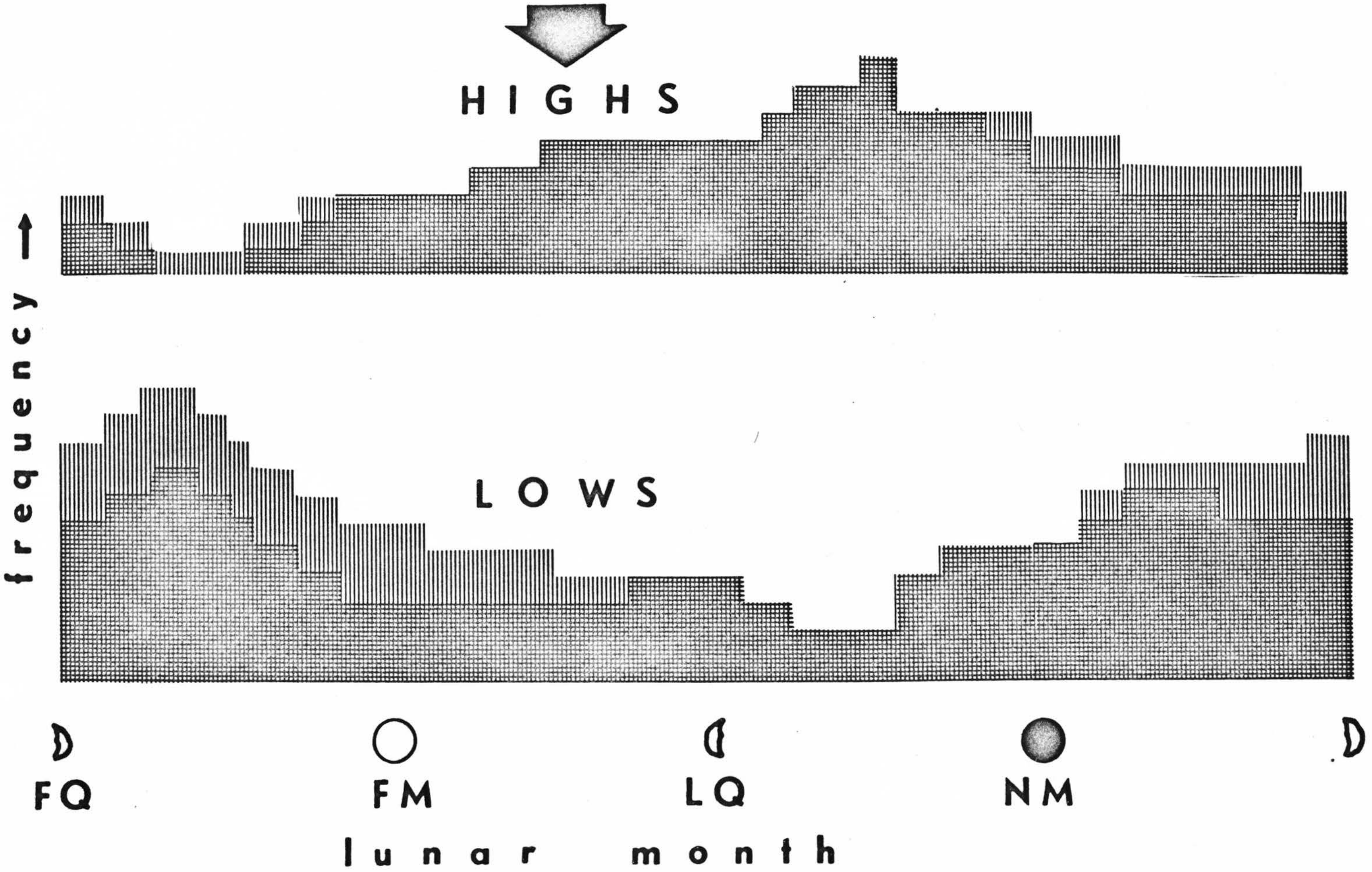


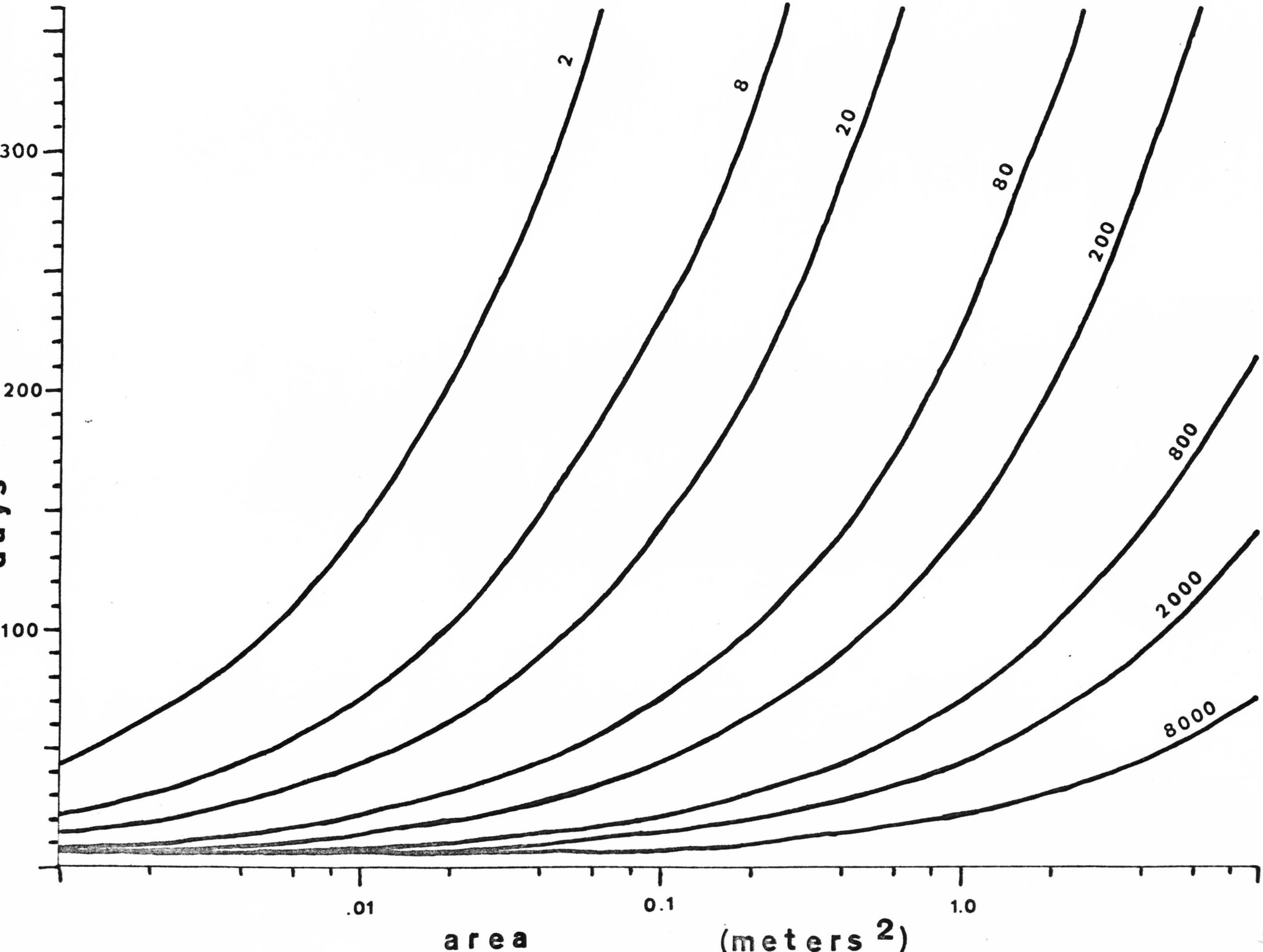
Figure 9. Relative Settling Rate vs. Lunar Phase

Data are taken from the settling rate curve in Figure 7. Width of bars used in histogram is the two week period preceding each collecting date. More heavily shaded areas represent unequivocal periods that are clearly higher or lower than both adjacent unequivocal points. More lightly shaded areas represent periods higher or lower than an adjacent unequivocal point but may actually be intermediate between that point and another. Arrow represents time of maximum breeding which is determined by subtracting the free swimming larval period (6 to 7 days) from the settling maximum.

The rate at which a surface is covered by newly settled worms may be calculated by knowing the settling rate (V_w) plus the area which one worm can cover during one day of growth (K_a). Although the rate of tube elongation decreases with time, the widths of the tubes increase in approximate compensation. Thus K_a may be considered a constant; and measurements indicate that its value is about 0.25×10^{-6} meters^2/day. The percent of area covered is then $100 \cdot V_w \cdot K_a$(days of worms growth). Since worms accumulate throughout the settling period, the total days of growth equals $1+2+3+\cdots+n$, where n is the number of days in the settling period. This is, of course, a simple arithmetic progression the sum of which equals $n(a+l)/2$ where a is the first term, l is the last term, and n is the total number of terms in the series. Thus in this case, Area (%) = $K_a V_w \frac{n(n+1)}{2} \cdot 100$. Curves for several settling rates are plotted in Figure 10.

The closing of conduits fouled by serpulids is greatest when growth is perpendicular to the surface of attachment; and this occurs only after all surface area is covered. Thus, to reduce the rate of accumulation it would be necessary to effect a 100% worm kill before 100% of the fouled surface is covered. The necessary frequency of this action can be determined from Figures 7, 8, and 10. Use of this determination requires the assumption that the settling rate in the collecting box is the same as the rate in the intake system. This assumption would require that the larvae within ½ inch of the tunnel walls settled on to the walls in about the same proportion as the larvae in the collecting box settle on to the plastic screens. Intuitively, this assumption seems reasonable, but I cannot verify it.

Figure 10. Surface Area Fouled by Continuous Settlement of Serpulid Worms. Cumulative area through time covered by serpulids settling at several different rates. Rates (V_W) in worms/sq.m./day are indicated by the number on each curve. Calculation of cumulative area is described in the text. Area of 1.0 meters represents 100% coverage, 0.1 meters represents 10%, etc.


days
300
200
100
.01
0.1
1.0
area (meters 2)
2
8
20
80
200
800
2000
8000

To be conservative one should, perhaps, use 50% coverage for the criterion of when to kill the worms.

On this basis, no kills are needed between January 1st and April 1st. After a kill on the first of April, accumulation of worms would not reach 50% coverage until about mid-May and again in mid-June. By this time the settling rate would have increased so that a kill at 50% coverage would be required every two weeks until mid-September. Then kills should be made in mid-October, mid-November, and finally at the end of December.

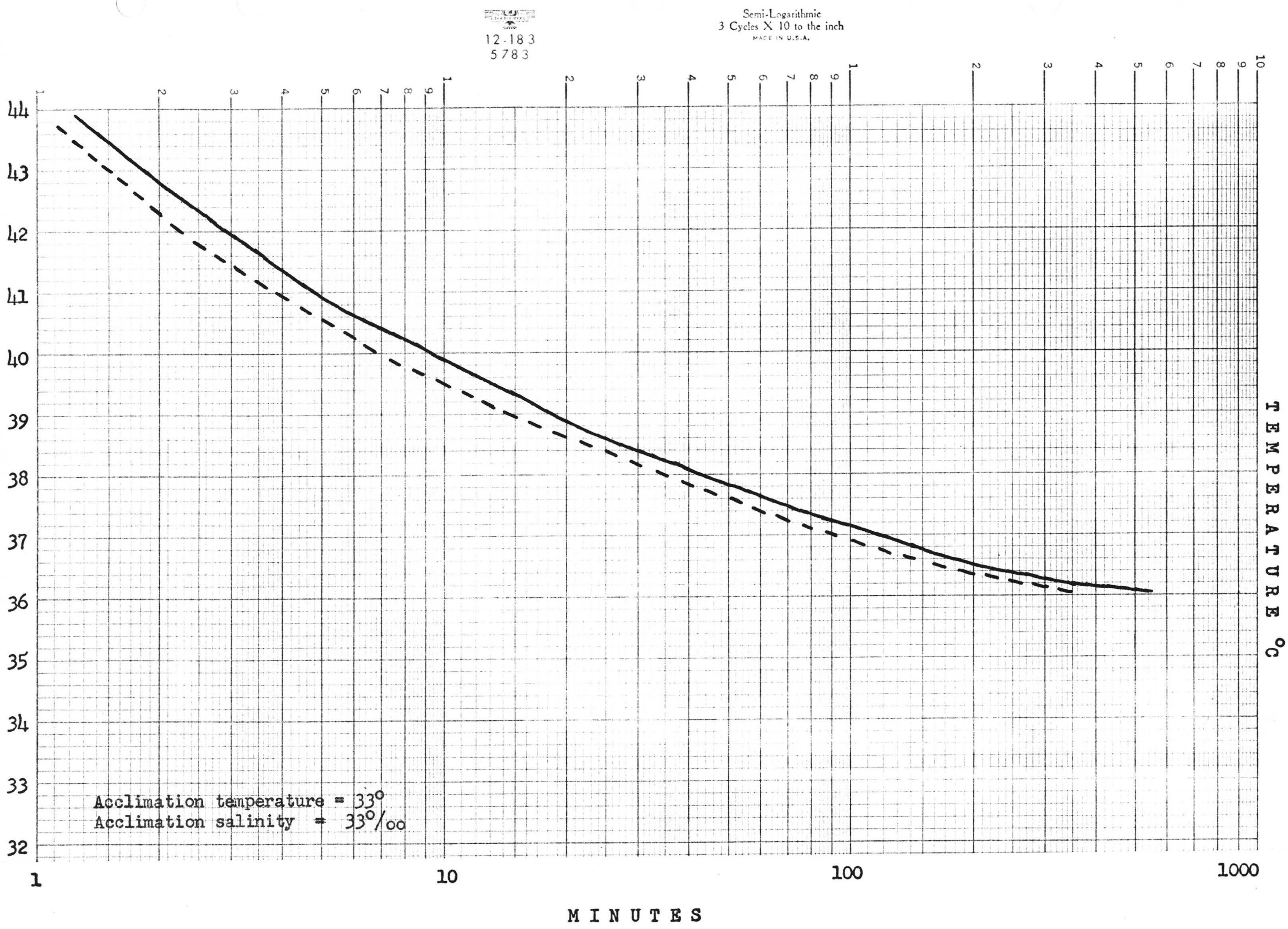
Assuming this procedure prevented any serpulids from growing perpendicularly from the tunnel walls, accumulation of worm tubes should not exceed 2½ centimeters (about one inch) per year or about 1/3rd of the present rate of build up.

Reference

Straughan, Dale. Ecological aspects of serpulid fouling; Australian Natural History, June, 1968, p. 59-64. (Appendix B)

Appendix A

The following series of graphs show the time it takes to effect a 100% kill (LD100) and a 50% kill (LD50) of serpulid worms as a function of water temperature. Experimental conditions are described in the text. Acclimation temperatures and salinities are noted on each graph. The graphs are arranged from highest to lowest acclimation temperature. LD100 is indicated by a solid line; LD50 is indicated by a dashed line.


Semi-Logarithmic
3 Cycles X 10 to the inch
MADE IN U.S.A.
12-183
5783
44
43
42
41
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39
38
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36
35
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32
1
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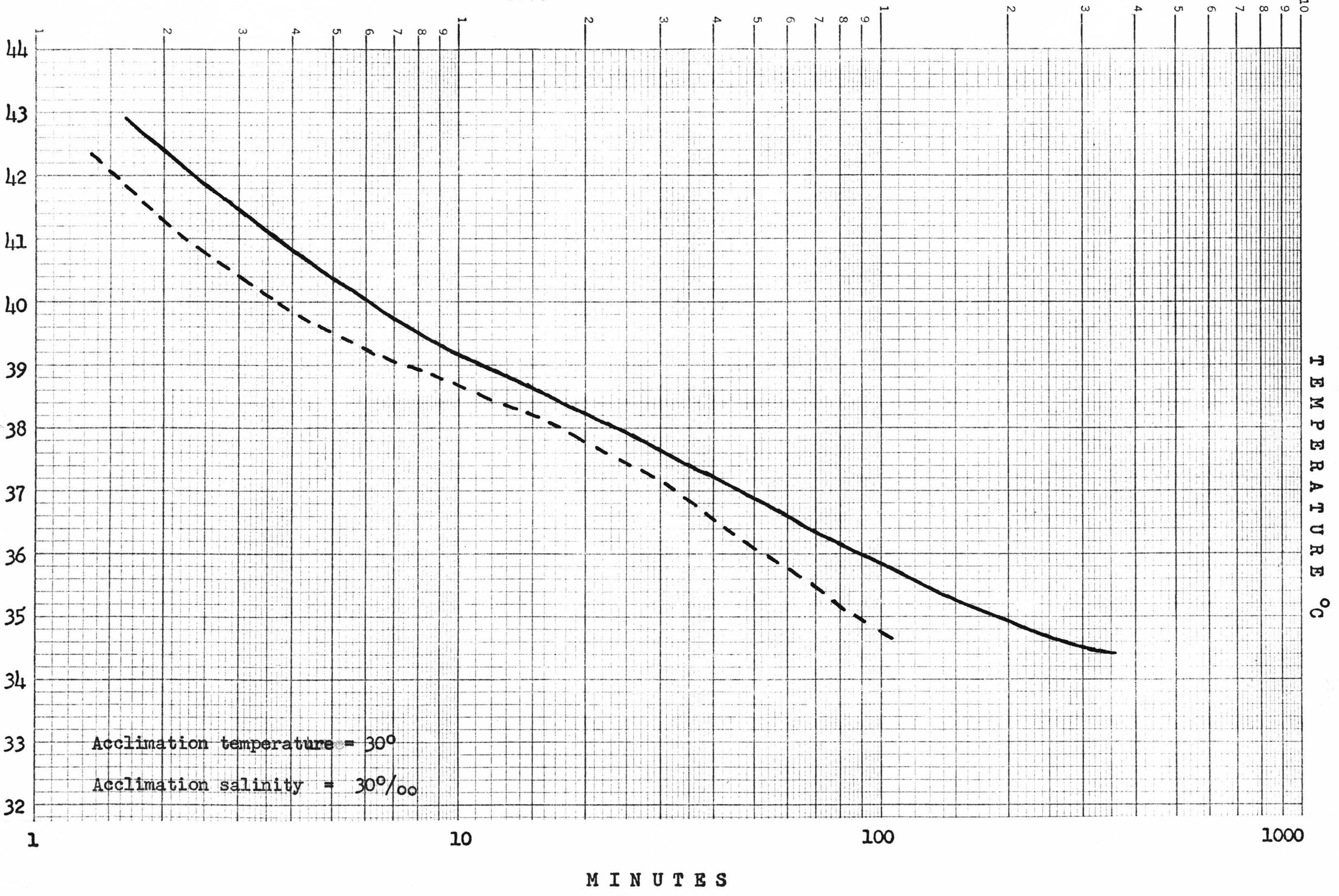
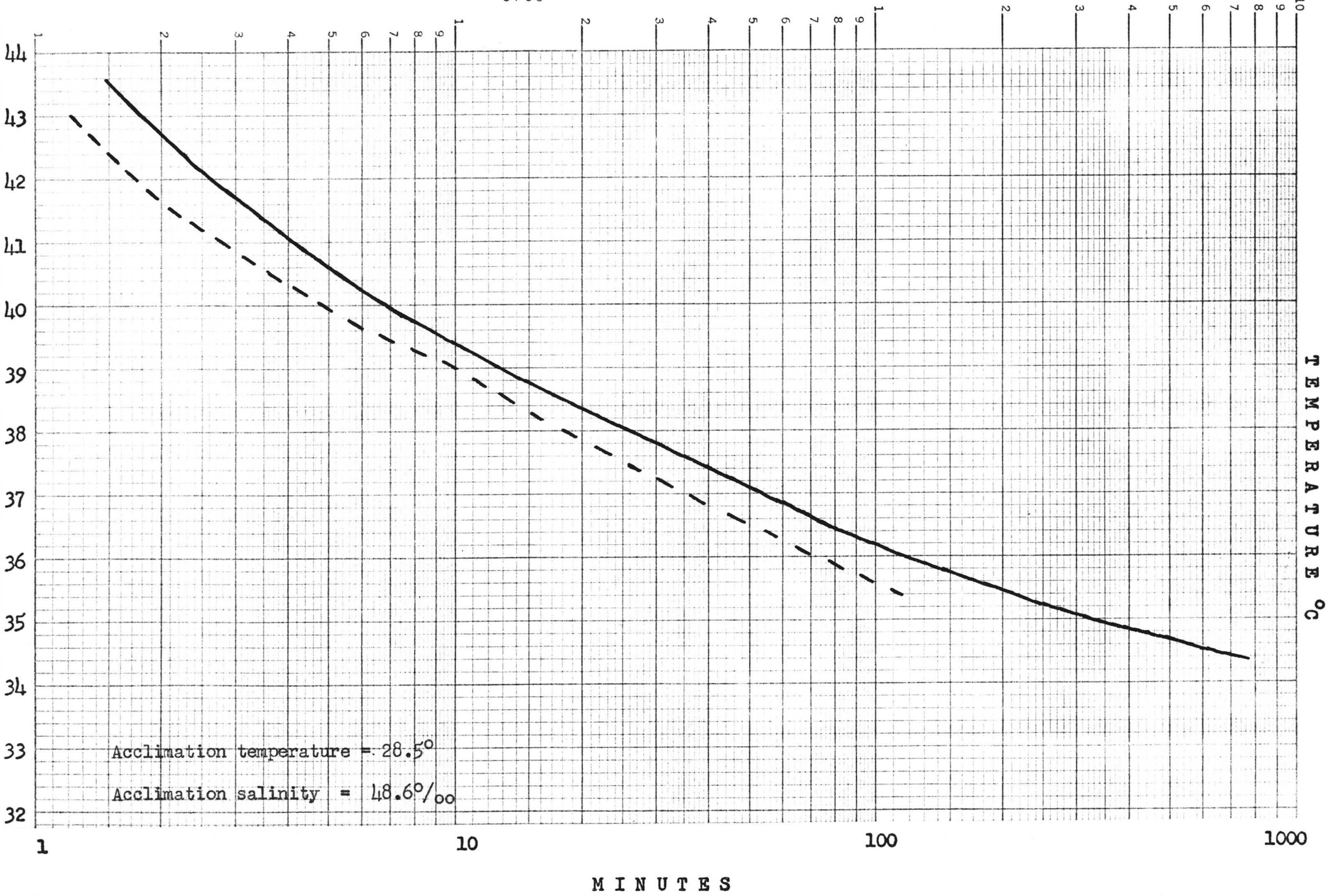
100
1000
MINUTES
TEMPERATURE °C
Acclimation temperature = 33°
Acclimation salinity = 33°/oo



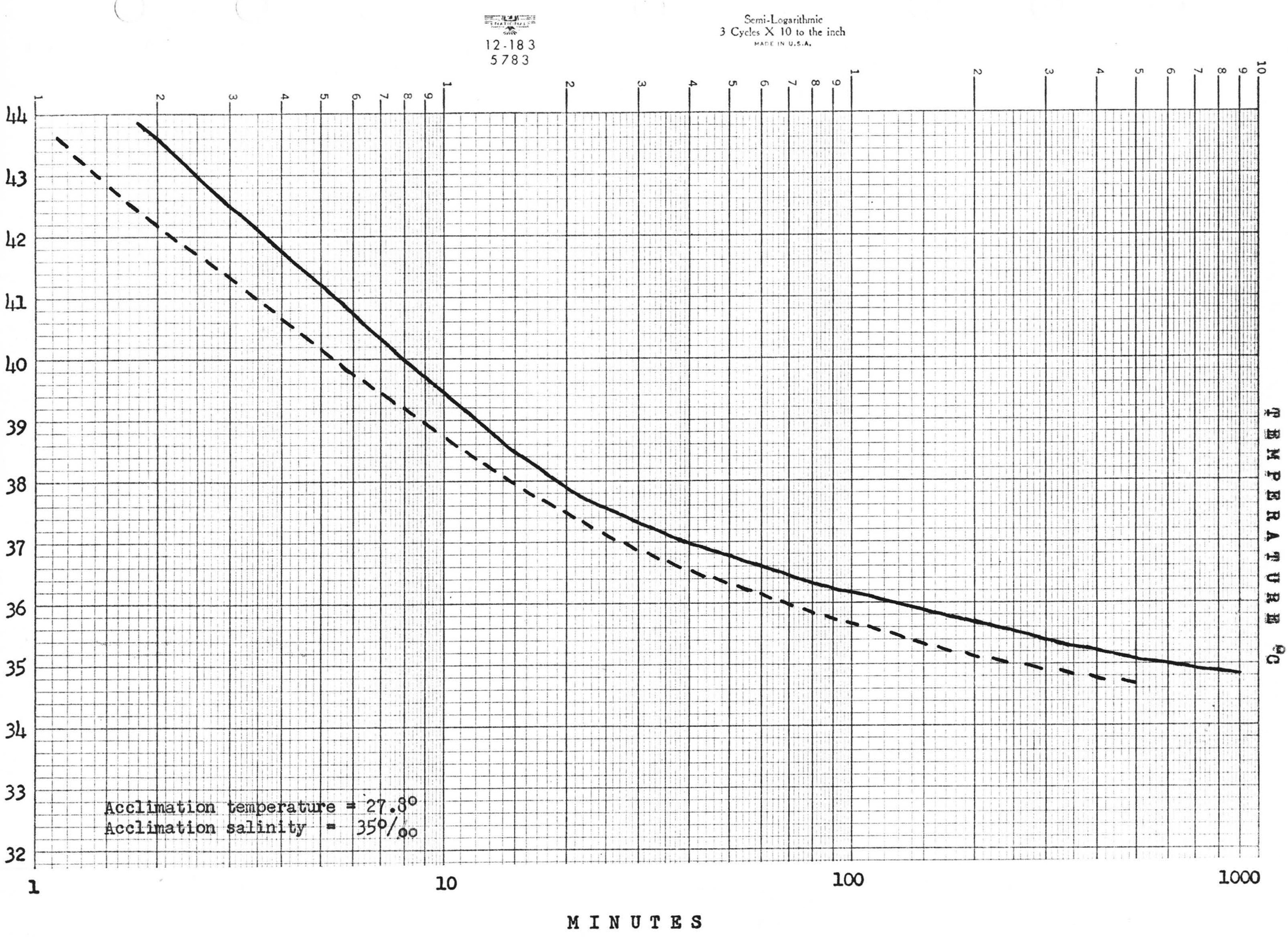
Acclimation temperature = 30°

Acclimation salinity = 30°/oo

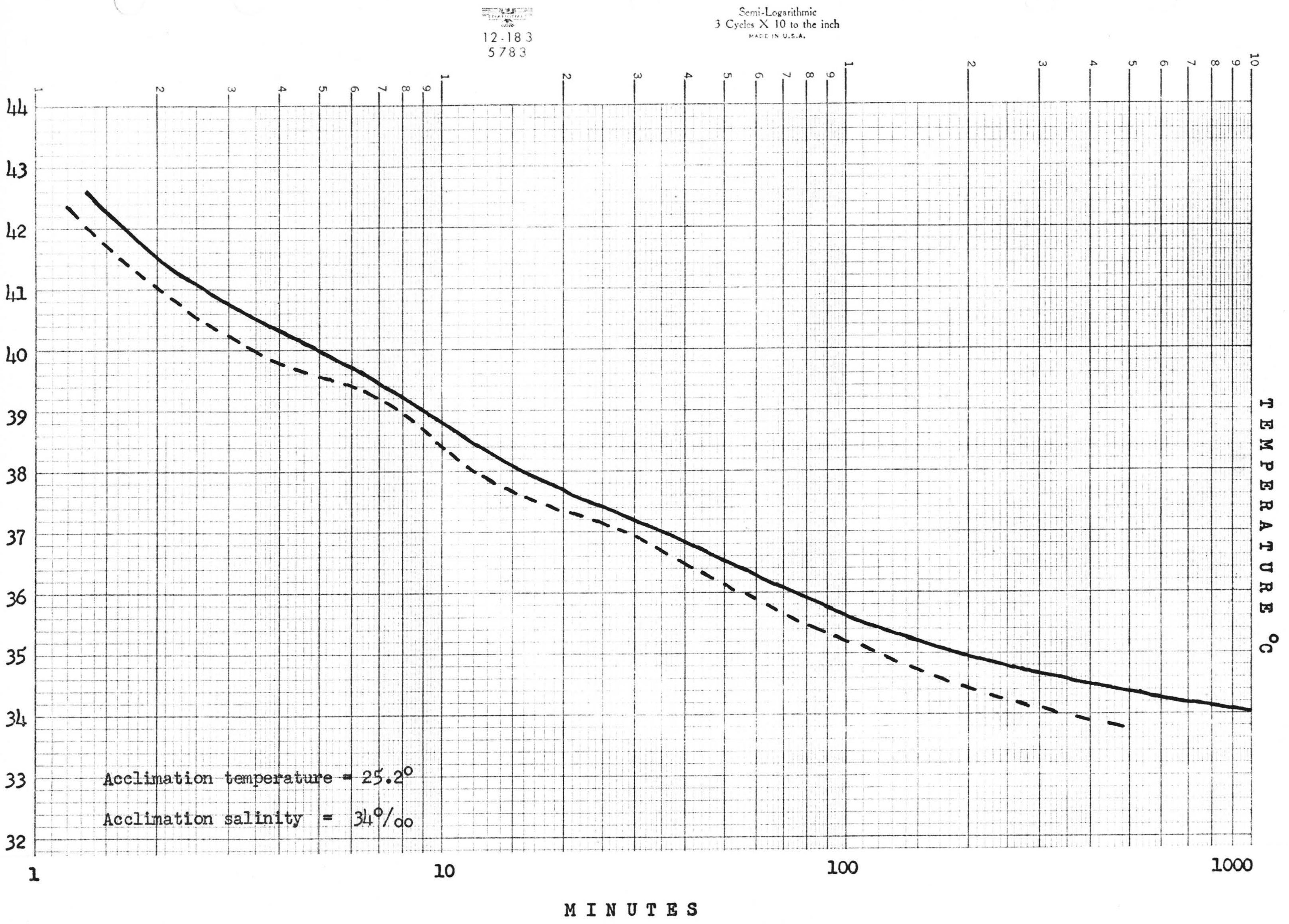


Acclimation temperature = 28.5°

Acclimation salinity = 48.6°/oo

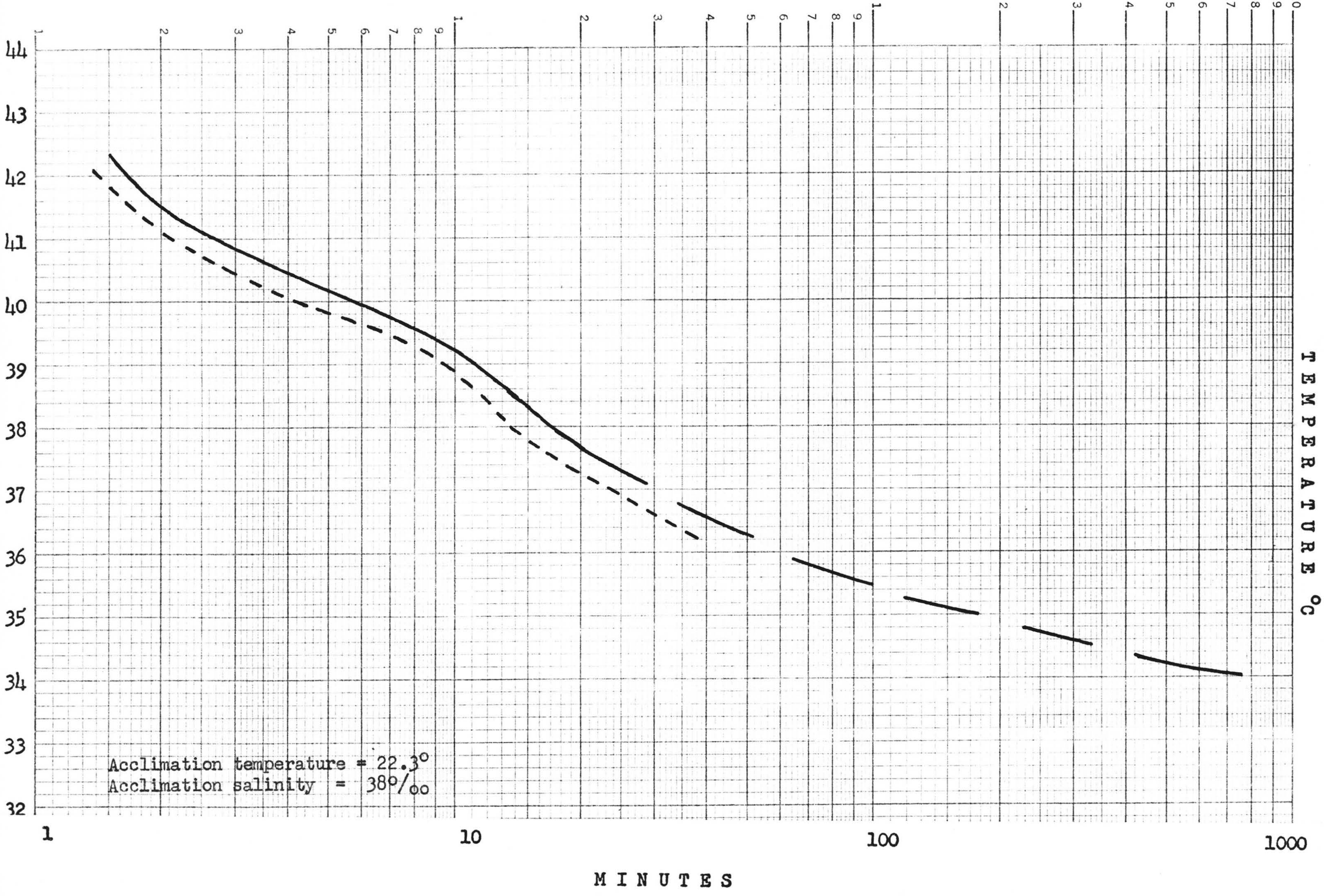


Acclimation temperature = 27.8°
Acclimation salinity = 35°/oo



Acclimation temperature = 25.2°

Acclimation salinity = 34‰


44
43
42
41
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39
38
37
36
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34
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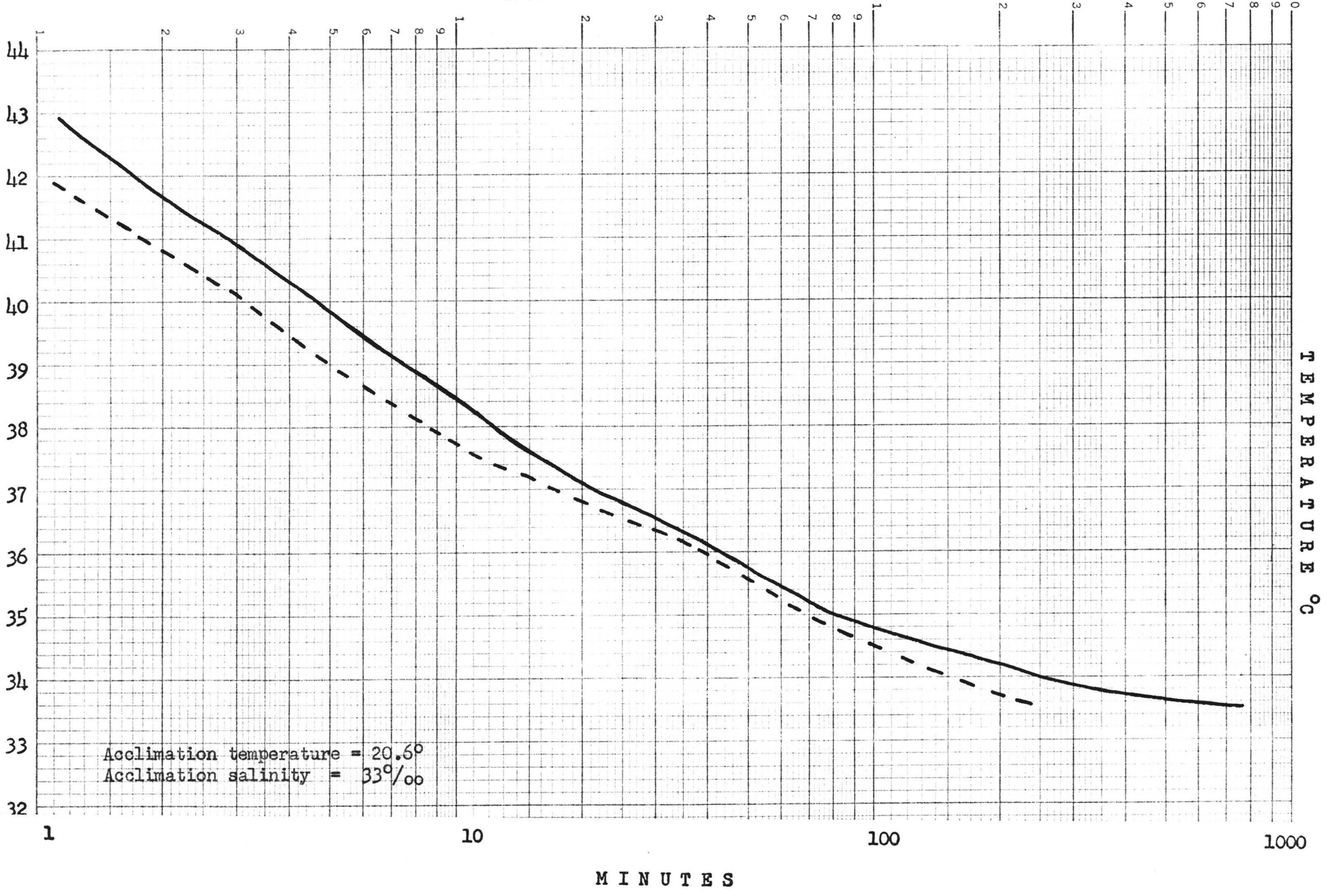
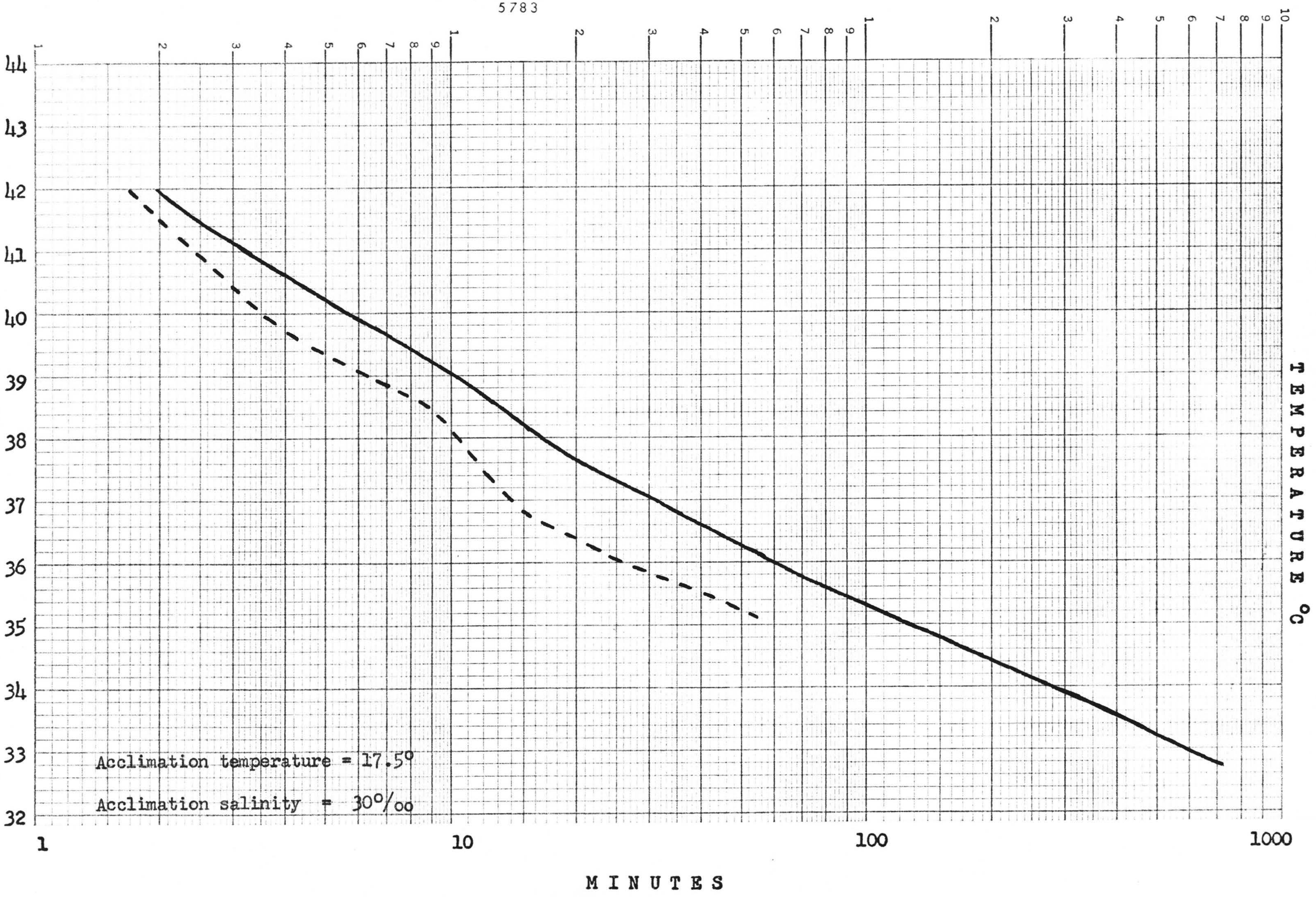
1
10
100
1000
MINUTES
TEMPERATURE °C
Acclimation temperature = 22.3°
Acclimation salinity = 38°/oo

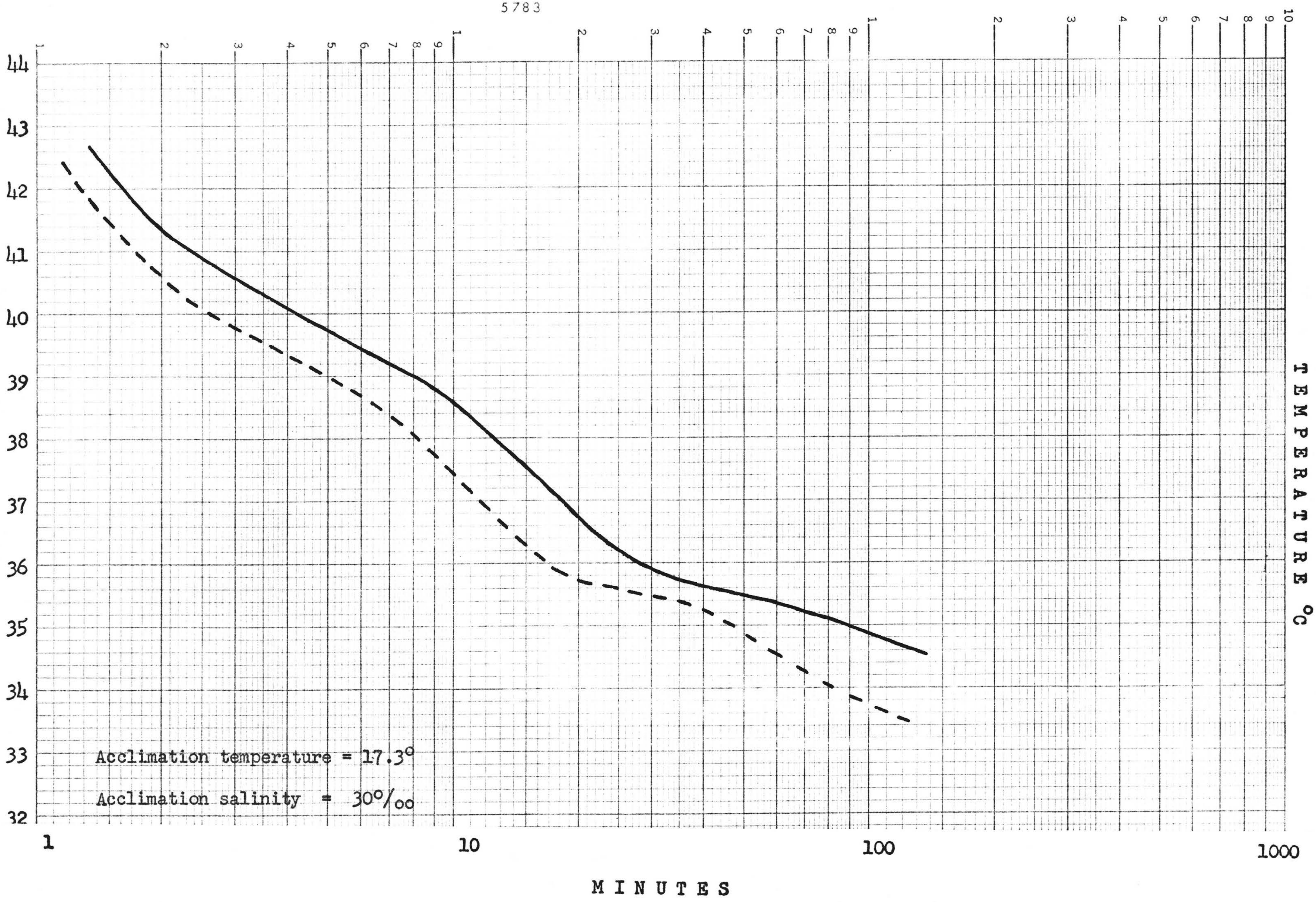


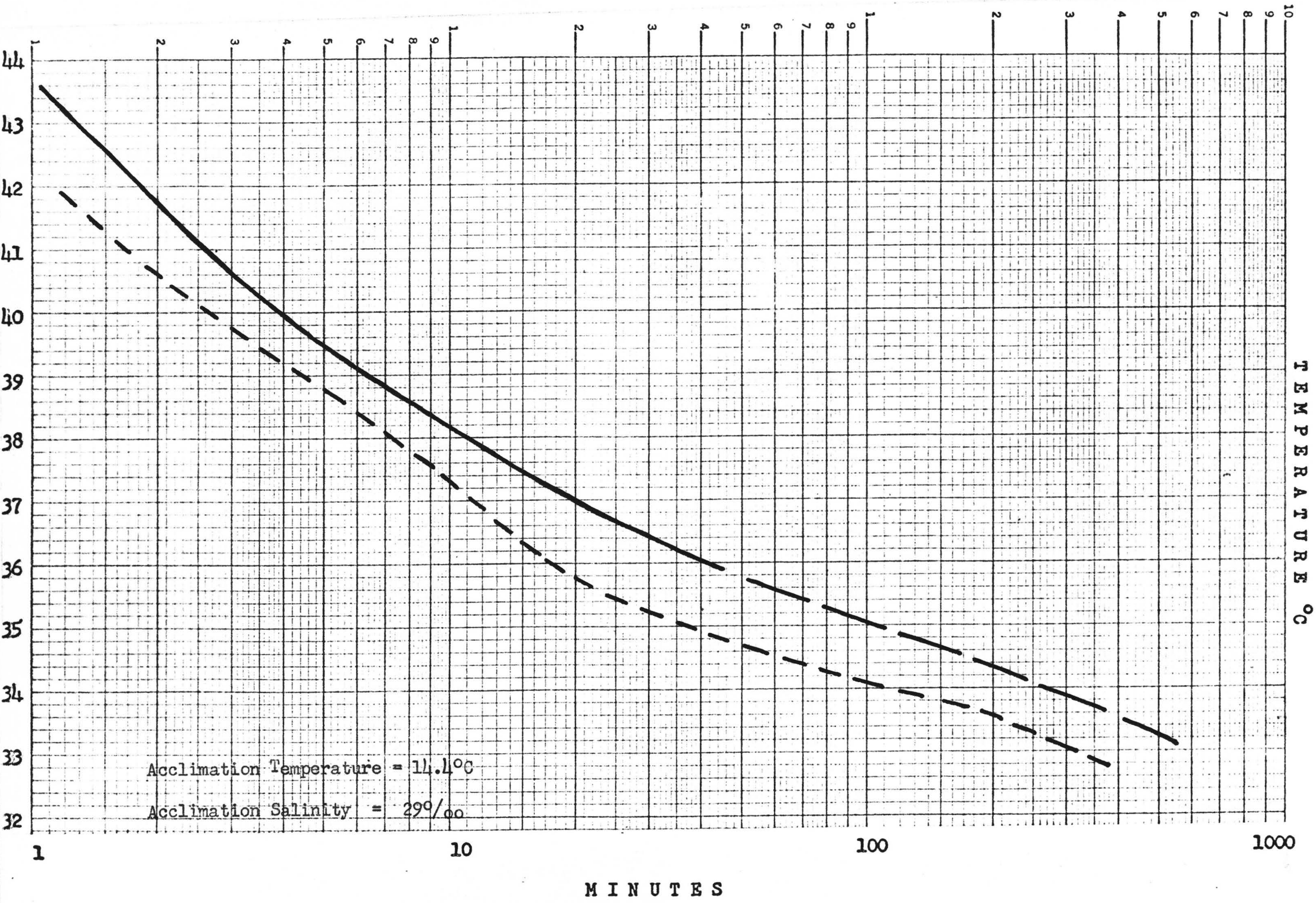
Acclimation temperature = 20.6°
Acclimation salinity = 33°/oo



Acclimation temperature = 17.5°

Acclimation salinity = 30‰


44
43
42
41
40
39
38
37
36
35
34
33
32
1
10
100
1000
MINUTES
TEMPERATURE °C
Acclimation temperature = 17.3°
Acclimation salinity = 30°/oo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1
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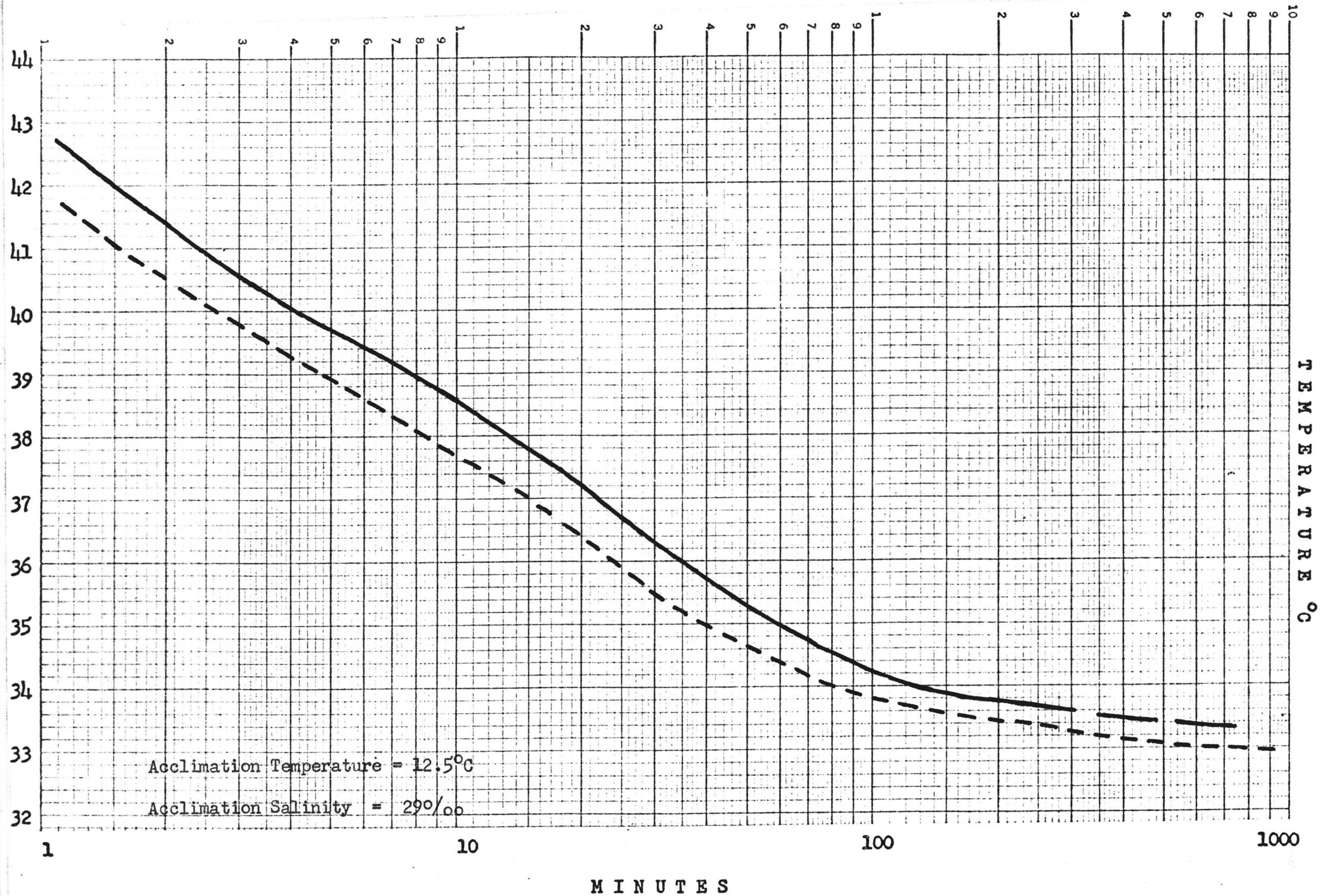
MINUTES
TEMPERATURE °C
Acclimation Temperature = 14.4°C
Acclimation Salinity = 29‰


44
43
42
41
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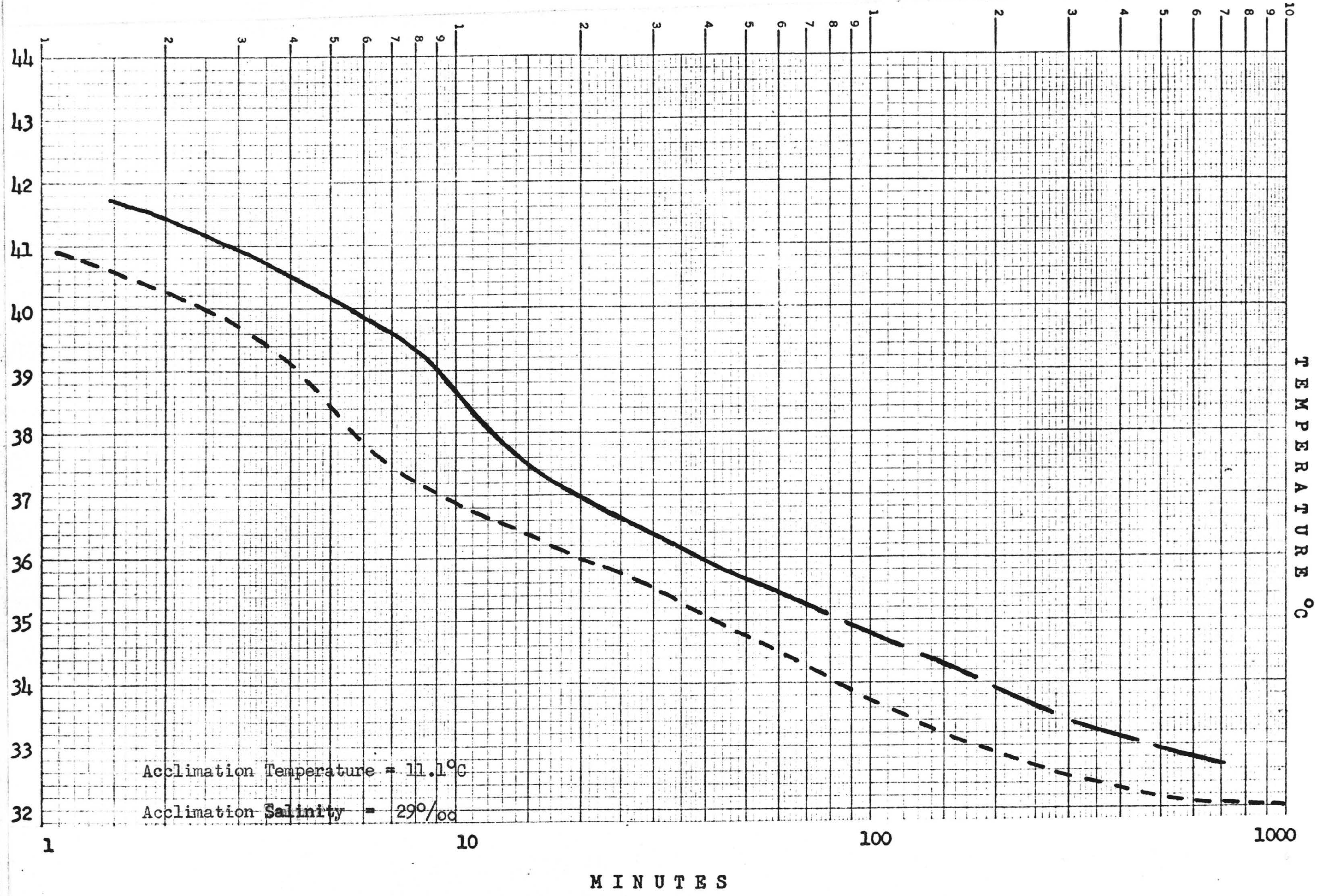
39
38
37
36
35
34
33
32
1
10
100
1000
MINUTES
TEMPERATURE °C
Acclimation Temperature = 12.5°C
Acclimation Salinity = 29°/oo


44
43
42
41
40
39
38
37
36
35
34
33
32
1
10
100
1000
MINUTES
TEMPERATURE °C
Acclimation Temperature = 11.1°C
Acclimation ~~Salinity~~ = 29°/oo