which relates surface current speed (V_0) to wind speed (W) in terms of latitude (ϕ) and an empirical constant ($\lambda \doteq 10^{-2}$), we obtain an estimate of average wind-driven surface current velocity of 5.7 cm/s northward.

In light of the velocity estimates, it is apparent that locally wind-driven currents are significant for the northward transport of pelagic larvae east of the northern Bahamas only if the larvae spend most of their time near the sea surface. If, instead, they are scattered throughout the upper layer or undergo diurnal vertical migration, their northward progress will be much slower.

Another possible pathway of larval transport which should be considered, however, is the nearshore band of strong flow mentioned by R. Yager (pers. commun.). If such a band exists as a regular, steady feature of the current field east of the Bahama Banks, then it would be particularly informative to conduct seasonal ichthyoplankton surveys on a scale appropriate to determine the relative abundance of pelagic larvae in and near the current band.

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SALINITY ACCLIMATION IN THE SOFT-SHELL CLAM, *MYA ARENARIA*

A steady increase in sewage pollution followed by the closing of many productive shellfish growing areas has seriously affected the harvesting of the soft-shell clam, *Mya arenaria,* in the State of Maine. In areas where a large percentage of the population derives its income from harvesting soft-shell clams, these closings have caused severe economic hardships. Beginning in the mid-1950's the Maine Department of Marine Resources (then Maine Department of Sea and Shore Fisheries) accelerated research on clam depuration in an attempt to salvage moderately polluted clams of 70-700 most probable number of *Escherichia coli* bacteria per 100 g. Based upon the design and development of a pilot process (Goggins et al. 1964) five commercial depuration plants have been established. The first of these (Seafair, Inc.[1]), in Phippsburg, Maine, utilized clams dug from Parker Head, Maine. During routine operation of this plant, it was apparent that exposure of clams to certain salinity and temperature conditions increased the time required for depuration.

Former investigators have revealed that pumping activity and associated shell and ciliary movements are affected when bivalves other than soft-shell clams are immersed in water of a different salinity from that to which they are accustomed (Wells et al. 1940; Medcof 1944; Loosanoff[2]). In this paper, salinities lower than

[1]Reference to a commercial enterprise does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]Loosanoff, V. L. 1952. Behavior of oysters in water of low salinities. Conv. Address Proc. Natl. Shellfish. Assoc., Atlantic City.

the accustomed are called "dilutions," those above, "concentrations." The literature shows that the effects of dilution upon *Mya arenaria* are most noticeable when reduced to the stress point. The stress point for Massachusetts clams is approximately 15‰ (Matthiessen 1960), 22-24‰ for Medomac River, Maine, clams (Welch and Lewis[3]) and 5‰ for Chesapeake Bay clams (Schubel[4]).

Pumping activity and associated feeding and ciliary movements of many bivalves are also known to be directly affected by temperature changes (Nelson 1923; Gray 1924; Galtsoff 1928; Hopkins 1931, 1933; Elsey 1936; Loosanoff 1939, 1950, 1958; Harrigan 1956; Goggins et al. 1964; Feng[5]).

To our knowledge, only Loosanoff (see footnote 2) and Welch and Lewis (see footnote 3) have attempted to relate changes in bivalve behavior to changes in both salinity and temperature.

This investigation was undertaken to establish the relationship of temperature to acclimation time when *Mya* is immersed into dilutions and concentrations of seawater. The results are applicable to many real situations where *Mya* are harvested from an area with one set of environmental conditions and subjected to acclimation and depuration in an area of another.

Materials and Methods

Salinity Control Apparatus

The constant flow apparatus used in the following experiments was similar in principle to that used by Loosanoff and Smith (1950). The complete system consists of freshwater and saltwater constant head reservoirs and nine adjustable head units, four regulating the freshwater flow and five the seawater flow. Water from each adjustable head or pair of heads flowed through plastic tubing into the bottom of a large mixing tube and then into the test tank. In this manner, ambient salinity and four dilutions could be maintained simultaneously. Temperature differences between the freshwater and saltwater constant head reservoirs were eliminated by the installation of a temperature equalizer functioning on the heat exchanger principle.

Experimental Design

Clams were dug by commercial clam diggers (under Department of Marine Resources supervision) from moderately polluted clam flats at Parker Head, Maine, and transported to the laboratory shortly thereafter. Broken clams and clams under 50 mm were discarded, and the remaining clams were thoroughly washed and held in flowing control salinities until shell liquor salinities were the same as control salinities. The experimental temperatures desired were obtained over a 10-mo period using the natural range of ambient seawater temperature available. Approximately 1 bushel of clams was used in each set of dilution and concentration experiments testing salinity acclimation rates at ambient water temperature. Clams were acclimated to control salinities of 30.54-31.80‰ (dilution experiments) and 16.26-17.14‰ (concentration experiments) and then roughly divided into five groups; one group remained in the control salinity and the other four groups were immersed into tanks set at other dilutions and concentrations of seawater.

Changes in shell liquor salinity were chosen as the criteria for the measurement of acclimation because shell liquor was easily obtained from each group of six clams by inserting a knife into the region of the foot opening and draining the contents into a paper cup. Five milliliters of this total and a sample of tank water were analyzed for salinity by the Knudsen Method. Acclimation had occurred when shell liquor salinities were the same as tank salinities. The oxygen content of the water flowing into and out of each test tank was measured by the Azide Modification of the Iodometric Method (American Public Health Association 1967). We attempted to regulate the flow rate in each tank at approximately 1,000-1,100 ml/min. All temperature measurements were made with a calibrated glass thermometer. Measurements of salinity, temperature, and flow rate were recorded as the mean$\pm$1 SE. Appropriate curves were fit where necessary.

Results

The dissolved oxygen content of the water used

[3]Welch, W. R., and R. D. Lewis. 1965. Shell movements of *Mya arenaria*. Unpubl. manuscr., [U.S.] Bur. Commer. Fish. Biol. Lab., West Boothbay Harbor, Maine.

[4]Schubel, J. 1973. Report on the Maryland State Department of Health and Mental Hygiene cooperative study to determine cause and extent of high bacteria counts found in *Mya arenaria* in 1973. Md. Dep. Health Ment. Hyg., 57 p.

[5]Feng, S. Y. 1963. Activity of the hard clam *Mercenaria mercenaria*. Talk at Rutgers, the State University of New Jersey and NAS Meeting July (Furfari 1966).

in dilution and concentration experiments varied between 5.91 and 12.58 mg/liter depending largely upon the ambient range of temperature and salinity conditions encountered (Table 1). It is evident in Table 1 that no significant differences exist between flow rates at the beginning and end of a given group of experiments.

The results of one typical set of dilution and concentration experiments are presented in Figure 1. A comparison of this set of experiments reveals that *Mya* acclimates faster to high salinity from 17‰ than to 17‰ from high salinity. Similar observations were noted for all ambient temperature ranges used. The approximate number of hours required to acclimate to each dilution from the control was recorded for each

TABLE 1.—Parameters recorded during dilution (D) and concentration (C) experiments with *Mya arenaria* at ambient temperature ranges.

Experiment	Tank salinity (‰)	Water temp (°C)	Flow rate (ml/min) Beginning	End
2.9°-3.2°C:				
D	[1]31.36±0.04			
	27.37±0.08	2.9±0.2	1,132± 94	1,184±104
	22.48±0.04			
	16.88±0.05			
	11.49±0.06			
C	31.16±0.06			
	27.41±0.10	3.2±0.2	1,170±106	1,156±115
	22.07±0.04			
	[1]16.58±0.03			
	11.58±0.12			
6.4°-6.9°C:				
D	[1]31.80±0.15			
	27.16±0.17	6.9±0.3	1,152± 71	1,156± 45
	22.35±0.07			
	16.93±0.08			
	11.91±0.13			
C	31.43±0.05			
	28.04±0.06	6.4±0.2	1,100± 66	1,064± 70
	22.65±0.12			
	[1]17.14±0.07			
	11.89±0.03			
10.0°-10.7°C:				
D	[1]30.54±0.06			
	27.15±0.11	10.0±0.2	1,109±122	1,111±112
	21.66±0.08			
	16.82±0.06			
	11.71±0.03			
C	31.18±0.07			
	28.09±0.03	10.7±0.1	1,068±123	1,084±123
	21.82±0.07			
	[1]16.26±0.11			
	12.04±0.32			
15.4°-16.3°C:				
D	[1]31.01±0.07			
	27.55±0.15	16.3±0.1	938± 75	980± 62
	22.53±0.11			
	16.95±0.06			
	12.05±0.04			
C	30.89±0.09			
	27.57±0.07	15.4±0.1	1,028± 79	957± 78
	22.95±0.14			
	[1]17.11±0.09			
	11.78±0.03			

[1]Control.

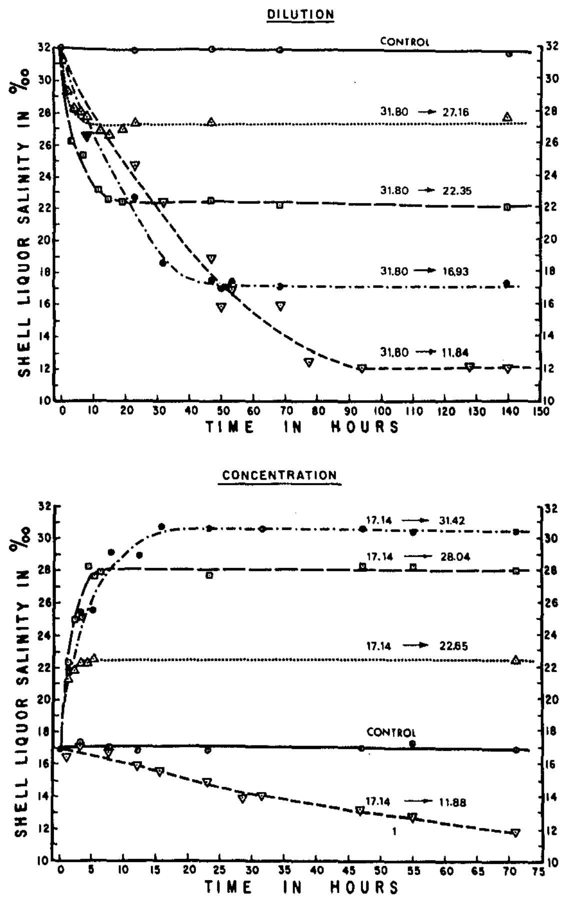

FIGURE 1.—Shell liquor salinity acclimation rates for *Mya arenaria* in dilutions and concentrations at 6.4°-6.9°C (lines fitted by eye).

ambient tempreature range used, plotted for each dilution in Figure 2, and the appropriate curve was fit. Hence at 8°C in Figure 2, 95 h are required for *Mya* to acclimate to 11.49-12.05‰ salinity from the control, 45 h to 16.82-16.95‰ from the control, 15 h to 21.66-22.53‰ from the control, and 10 h to 27.15-27.55‰ from the control. In Figure 2, a geometric relationship exists between temperature and acclimation time after immersion into various dilutions. The approximate time required to acclimate to each concentration from the control, at each ambient temperature range, was recorded in Table 2. Tested at 95% confidence intervals (±2 SE), Table 2 reveals that no significant differences exist between the mean numbers of hours required to acclimate to each concentration experiment at all temperature ranges combined. Table 2 also reveals that no significant differences exist between the mean

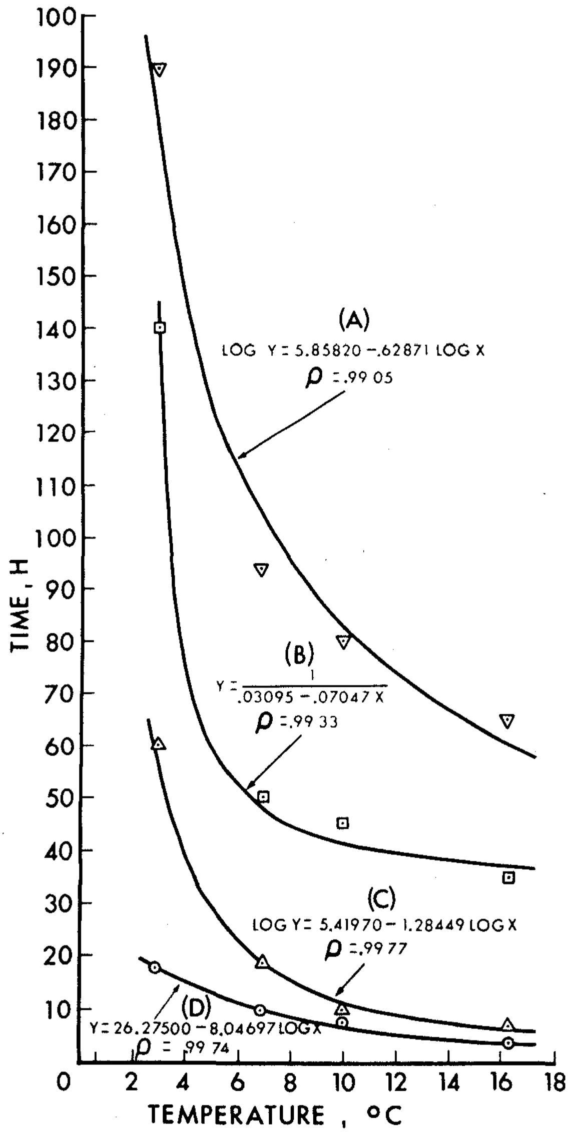

FIGURE 2.—The relationship between temperature and time required to acclimate *Mya arenaria* from the control salinity (30.54-31.80‰) to the following dilutions: (A) 11.49-12.05‰; (B) 16.82-16.95‰; (C) 21.66-22.53‰; (D) 27.15-27.55‰.

acclimation time (±2 SE) for all concentration experiments combined at each temperature range.

Discussion

A constant flow apparatus is ideally suited to shellfish studies. Continuous exchange of water assures a rapid elimination of metabolic waste products and more closely resembles natural conditions than does a standing water system

TABLE 2.—The relationship between temperature and the approximate number of hours required for *Mya arenaria* to acclimate to three concentrations from a control salinity of 16.26-17.14‰.

Temp (°C)	Control 30.89-31.43‰	Control 27.41-28.09‰	Control 21.82-22.95‰	$\bar{X}$±SE
3.2	about 10 h	about 10 h	about 7 h	9.0±1.0 h
6.4	about 20 h	about 7 h	about 5 h	10.7±4.7 h
10.7	about 8 h	about 5 h	about 4 h	5.7±1.2 h
15.4	about 8 h	about 8 h	about 6 h	7.3±0.7 h
$\bar{X}$±SE	11.5±2.9 h	7.5±1.0 h	5.5±0.6 h	

(Loosanoff and Smith 1950; Loosanoff see footnote 2).

Van Dam (1935) observed that oxygen utilization in *Mya* is independent of oxygen concentration down to about 2 cm^3/liter (2.8 mg/liter). There is therefore no reason to believe that the variations in dissolved oxygen encountered in these experiments altered the pumping activity of *Mya*.

In these studies, the exclusive use of adult *Mya* is consistent with Matthiessen's (1960) observation that adult and juvenile *Mya* have different tolerance levels to low salinity conditions.

The phenomenon of faster acclimation to concentrations than dilutions has not been previously reported for *Mya*. Loosanoff (see footnote 2), however, reported that oysters moved from 10‰ into 20-25‰ returned to normal pumping very quickly.

The relationship of pumping activity to shellfish depuration has been well documented (Furfari 1966). When shellfish are subjected to suitable salinity and temperature conditions, high pumping activity is maintained and efficient depuration results.

Furfari (1966) reported that pumping activity is reduced for a time when shellfish are subjected to salinity other than that to which they are accustomed in the harvest area. During this time, our data suggest that *Mya* periodically "samples" the water conditions and acclimates to them gradually. The length of time required is related to the magnitude of the dilution. Welch and Lewis (see footnote 3) have observed that this "sampling" behavior is performed by opening the siphons very slightly and then gently closing them, very little water having passed through the clam in the process.

Our studies indicate that water temperature directly influences the rate at which salinity acclimation occurs. The results are consistent with Harrigan (1956) who observed that the pumping rate of *Mya* increased up to a temperature of 16°-20°C and Goggins et al. (1964) who observed that *Mya* activity (measured by physical criteria: extension of siphon, response to tactile stimuli) increased in direct proportion to an increase in temperature. Other investigators have reported that *Mya arenaria* pumps as effectively at all temperatures (Belding 1930; Marston 1931; Arcisz and Kelly 1955). If this were true in our studies, *Mya* would be expected to acclimate to a dilution as quickly at 3°C as at 16°C. Clearly, in the case of Parker Head clams, our findings do not agree with these authors.

In the case of Seafair, Inc., it is apparent that depuration took longer because the Parker Head clams first had to acclimate to unaccustomed salinity before they could actively pump and cleanse themselves. Low water temperature would, of course, tend to lengthen this acclimation period. Our findings are consistent with Furfari's (1966) statements, "Time taken by shellfish to acclimate to the stress of a change in salinity, is time lost in depuration."

In addition to establishing the time required for *Mya* to acclimate to dilutions at ambient temperature ranges, this study demonstrates the need for appraising the response of clams from the harvest area to the environmental conditions existing at the depuration site. Acclimation times recorded in this paper are specific for Parker Head clams. *Mya* dug from other locations may respond differently.

Acknowledgments

We extend our appreciation to Philip L. Goggins and John W. Hurst, Jr. for their advice and assistance in various aspects of this research, and to James A. Rollins for photographic services.

This research was conducted by the Maine Department of Marine Resources Research Laboratory, West Boothbay Harbor, Maine, in cooperation with the U.S. Public Health Service, under Contract No. 86-64-78.

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