

spawning had occurred in July and August, ovogenesis and growth of oocytes began immediately and proceeded rapidly through October and November and into December. Proliferation of the follicles through the connective tissue of the visceral mass occurs at this time. Thus, animals collected in January have initiated or may already have completed the development of many of the gametes that would normally be spawned the following August.

In Southampton Water, the condition (per cent flesh content) of clams declines more or less continuously following spawning and any renewed gametogenesis and growth of gametes in the autumn can only be occurring at the expense of stored food reserves. The proliferation and major growth of the gonad does not occur until the following spring. Thus, animals collected in Southampton Water in January (as were those in experiment 2) have still to undergo the main period of gonad proliferation and may be expected, after conditioning at this time, to release fewer eggs than Long Island Sound clams collected in January, or Southampton Water clams collected in June after the spring increase in condition has occurred (as were those in experiment 1).

These results are important in indicating the dependence of egg production on plankton abundance over the clam beds at some time previous to the spawning season. In Long Island Sound this may be the previous autumn, in Southampton Water the previous spring. To what extent the number of eggs produced also depends on con-

ditions existing during the 2–2.5 months over which spawning may take place is not known, nor is it known whether in fact new oocytes are produced and matured during this period to be spawned along with those that developed earlier. If this is the case, then the total egg production of clams in nature could considerably exceed the figures given here and by Davis and Chanley (1956), especially at sites where conditions remain suitable for oocyte production and maturation for an extended period during the summer months.

ALAN D. ANSELL<sup>1</sup>

*Department of Zoology and Plankton  
Laboratory,  
University of Southampton, England.*

#### REFERENCES

- ANSELL, A. D. 1963. *Venus mercenaria* L. in Southampton Water. *Ecology*, **44**: 396–397.
- , F. A. LOOSMORE, AND K. F. LANDER. 1964. Studies on the hard-shell clam, *Venus mercenaria*, in British waters II. Seasonal cycle in condition and biochemical composition. *J. Appl. Ecol.*, **1**: 83–95.
- DAVIS, H. C., AND P. E. CHANLEY. 1956. Spawning and egg production of oysters and clams. *Biol. Bull.*, **110**: 117–128.
- HEPPELL, D. 1961. The naturalisation in Europe of the quahog, *Mercenaria mercenaria* (L.). *J. Conch.*, **25**: 21–34.
- LOOSANOFF, V. L. 1937. Seasonal gonadal changes of adult clams, *Venus mercenaria* (L.). *Biol. Bull.*, **72**: 406–416.
- , AND H. C. DAVIS. 1950. Conditioning *V. mercenaria* for spawning in winter and breeding its larvae in the laboratory. *Biol. Bull.*, **98**: 60–65.

<sup>1</sup> Present address: The Marine Station, Millport, Isle of Cumbrae, Scotland.

### PREPARATION OF ARTIFICIAL SEAWATER<sup>1</sup>

During some physicochemical studies of seawater, we used artificial rather than

natural seawater to minimize biological effects and to provide a reproducible solution of known composition. Little attention has been given to the technique for preparing artificial seawater. We have developed a method that gives reproducible and satisfactory results. We also have revised the composition of artificial seawater to agree

<sup>1</sup> This work was supported by National Science Foundation Grants GP-3582 and GA-301. We would like to express our appreciation to Drs. P. K. Weyl and K. S. Deffeyes for their suggestions and encouragement during this work. We are grateful for the suggestions of Mr. K. L. Russell.

TABLE 1. Comparison of the composition of natural and artificial seawaters

Ion	Formula wt*	Artificial seawater† (g/kg)	Natural seawater‡ (g/kg)	% difference§	Artificial seawater   (g/kg)
Cl <sup>-</sup>	35.453	19.353	19.353	0.0	19.353
Na <sup>+</sup>	22.9898	10.764	10.76	0.0	10.765
SO <sub>4</sub> <sup>2-</sup>	96.06	2.701	2.712	-0.4	2.711
Mg <sup>2+</sup>	24.312	1.297	1.294	+0.2	1.295
Ca <sup>2+</sup>	40.08	0.406	0.413	-1.7	0.414
K <sup>+</sup>	39.102	0.387	0.387	0.0	0.387
HCO <sub>3</sub> <sup>-</sup>	61.01	0.142	0.142	0.0	0.142
Br <sup>-</sup>	79.91	0.066	0.067	-1.5	0.066
Sr <sup>2+</sup>	87.62	0.014	0.008	+75	0.008
H <sub>3</sub> BO <sub>3</sub>	61.83	0.026	0.026	0.0	0.026
F <sup>-</sup>	19.00	0.001	0.001	0.0	0.001

\* From Weast (1965).

† Salinity 35.00‰, Lyman and Fleming (1940).

‡ Salinity 35.00‰, Culkin (1965).

§ % difference = († - ‡) / ‡ × 100.

|| Salinity 35.00‰, this work.

with recent determinations of the composition of natural seawater.

The formula of Lyman and Fleming (1940) has been one of the most widely used recipes for artificial seawater (Harvey 1960; Riley and Skirrow 1965). The composition of artificial seawater prepared by this formula was compared with recent analyses of natural seawater as reviewed by Culkin (1965). The mass of each major constituent per kilogram of solution was calculated for artificial seawater of salinity 35.00‰ using recent values of atomic and molecular weights (Weast 1965). These masses were compared with those given by Culkin (1965, Table I) and are shown in Table 1. If weighings in the preparation of artificial seawater are made to 1 mg of salt/kg of solution, the differences between the artificial seawater recommended by Lyman and Fleming and natural seawater of the same salinity are significant for SO<sub>4</sub><sup>2-</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, and Sr<sup>2+</sup>. Early determinations of the Sr<sup>2+</sup> content of seawater indicated a value of 14 mg/kg, but determinations since 1951 give a value of 8 mg/kg (Culkin 1965). This accounts for the discrepancy in the Sr<sup>2+</sup> content of artificial seawater. Lyman and Fleming adjusted the early Ca<sup>2+</sup> determinations for 14 mg/kg of Sr<sup>2+</sup> which partially accounts for the low Ca<sup>2+</sup> content of artificial seawater.

TABLE 2. Formula for 1 kg of 35.00‰ artificial seawater

A. Gravimetric salts					
Salt	Molecular wt			G/kg of solution	
NaCl	58.44			23.926	
Na <sub>2</sub> SO <sub>4</sub>	142.04			4.008	
KCl	74.56			0.677	
NaHCO <sub>3</sub>	84.00			0.196	
KBr	119.01			0.098	
H <sub>3</sub> BO <sub>3</sub>	61.83			0.026	
NaF	41.99			0.003	
B. Volumetric salts					
Salt	Molecular wt	Moles/kg of solution	Stock solution Conc'n	solution Density (23C)	
MgCl <sub>2</sub> ·6H <sub>2</sub> O	203.33	0.05327	1.0 M	1.071 g/ml	
CaCl <sub>2</sub> ·2H <sub>2</sub> O	147.03	0.01033	1.0 M	1.085 g/ml	
SrCl <sub>2</sub> ·6H <sub>2</sub> O	266.64	0.00009	0.1 M	1.013 g/ml	
C. Distilled water to 1,000.000 g					

The Lyman and Fleming formula for artificial seawater was revised to bring the composition of artificial seawater to within 1 mg/kg of natural seawater for all the major constituents. The revised formula for salinity 35.00‰ is given in Table 2.

Impurities in the reagent grade salts used in Table 2 do not change the composition of artificial seawater by more than 1 mg/kg for the major constituents. However, impurities in these salts are important with regard to the minor constituents of seawater. If reagent grade NaCl contains the maximum PO<sub>4</sub><sup>3-</sup> and Fe impurities (American Chemical Society 1955), the artificial seawater will contain ten times the average amount of PO<sub>4</sub><sup>3-</sup> and four times the normal amount of Fe in natural seawater.

Two factors must be considered in preparing artificial seawater: the reagents used must be weighable and of known composition (or they must be standardized against primary standards) and the salts must be added so as to avoid precipitation of insoluble compounds.

The following salts were dried and weighed in anhydrous form: NaCl, Na<sub>2</sub>SO<sub>4</sub>, KCl, KBr, and NaF. NaHCO<sub>3</sub> and H<sub>3</sub>BO<sub>3</sub> were weighed without drying due to uncertainty in the composition of the dried

TABLE 3. Salinity and pH data for artificial seawater based on triplicate determinations with the average deviation from the mean taken as the uncertainty of each measurement

Batch	Chlorinity (‰)	Salinity		(b) - (a)	pH
		(a) from chlorinity (‰)	(b) from conductivity (‰)		
1	16.674 ± 0.023	30.127 ± 0.042	30.136 ± 0.004	+0.009	8.26
2	16.695 ± 0.008	30.164 ± 0.015	30.132*	-0.032	8.12
3	19.070 ± 0.010	34.451 ± 0.018	34.459 ± 0.002	+0.008	8.23
4	22.225 ± 0.009	40.142 ± 0.040	40.073 ± 0.000	-0.069	8.26

\* Based on a single determination.

forms. Reagent grade salts of  $MgCl_2$ ,  $CaCl_2$ , and  $SrCl_2$  contain water of hydration which makes direct weighing unsatisfactory. Following the suggestion of Sverdrup, Johnson, and Fleming (1942), we added these salts volumetrically from concentrated solutions. One molar solutions of  $MgCl_2 \cdot 6H_2O$  and  $CaCl_2 \cdot 2H_2O$  and 0.1 molar  $SrCl_2 \cdot 6H_2O$  were prepared and their chloride concentrations determined by the Mohr method (Blaedel and Meloche 1957). The  $MgCl_2$  solution contained some insoluble material that was removed by filtration before the chloride determination. To account for the amount of water added with these solutions, their density was determined by weighing a known volume (Table 2).

To avoid precipitation of  $CaCO_3$ ,  $CaSO_4$ ,  $SrCO_3$ , or  $SrSO_4$  while combining the constituents of the artificial seawater, we prepared the artificial seawater in two separate containers and then combined the two portions after adding all the water. In one container we prepared a solution of the gravimetric salts (Table 2) using about two-thirds of the total required amount of water. In the other container the desired amounts of  $MgCl_2$ ,  $CaCl_2$ , and  $SrCl_2$  solutions were diluted with the remaining one-third of the water. The water was added volumetrically; its mass was calculated from its density which is given as a function of temperature (Weast 1965). After the two solutions were thoroughly mixed, they were combined while stirring.

We measured the chlorinity and electrical conductivity of the artificial seawater. There were no significant differences between the salinities based on these two measurements

(Table 3). The artificial seawater was aerated by drawing laboratory air through the solution until the pH did not change by more than 0.02 units over a 2-hr period. This tended to equilibrate the artificial seawater with atmospheric gases and removed the excess  $CO_2$  resulting from the conversion of  $HCO_3^-$  to  $CO_3^{2-}$ . The pH after aeration was about 8.2 (Table 3).

After four months, the pH of the artificial seawater, which had been sealed off from the atmosphere, had dropped from 8.26 to 8.03. A visible growth had accumulated at the air-solution interface, indicating that the artificial seawater was capable of supporting bacterial growth. These growths did not appear in artificial seawater preserved with a few drops of chloroform.

DANA R. KESTER  
IVER W. DUEDALL<sup>2</sup>  
DONALD N. CONNORS  
RICARDO M. PYTKOWICZ

Department of Oceanography,  
Oregon State University,  
Corvallis 97331.

#### REFERENCES

- AMERICAN CHEMICAL SOCIETY. 1955. Committee on Analytical Reagents. Reagent chemicals A. C. S. specifications 1955. Am. Chem. Soc., Washington, D.C. 428. p.
- BLAEDEL, W. J., AND V. W. MELOCHE. 1957. Elementary quantitative analysis: Theory and practice. Row, Peterson, Evanston, Illinois. 826 p.
- CULKIN, F. 1965. The major constituents of seawater, p. 121-161. In J. P. Riley and G.

<sup>2</sup> Present address: Fisheries Research Board of Canada, Atlantic Oceanographic Group, Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

- Skirrow [eds.], *Chemical oceanography*, v. 1. Academic, London. 712 p.
- HARVEY, H. W. 1960. *The chemistry and fertility of seawaters*. University Press, Cambridge. 240 p.
- LYMAN, J., AND R. H. FLEMING. 1940. Composition of seawater. *J. Marine Res.*, **3**: 134-146.
- RILEY, J. P., AND G. SKIRROW. 1965. *Chemical oceanography*, v. 1. Academic, London. 712 p.
- SVERDRUP, H. U., M. W. JOHNSON, AND R. H. FLEMING. 1942. *The oceans*. Prentice-Hall, Englewood Cliffs, New Jersey. 1087 p.
- WEAST, R. C. [Ed.]. 1965. *Handbook of chemistry and physics*, 46th edition. Chemical Rubber Co., Cleveland, Ohio.

### MIDGET BENTZEL CURRENT SPEED TUBE FOR ECOLOGICAL INVESTIGATIONS<sup>1</sup>

Field studies on the behavior of juvenile chinook salmon and steelhead conducted by the Idaho Cooperative Fishery Unit have resulted in development of a miniaturized

Bentzel current speed tube that can be used wholly submerged (Fig. 1). The original Bentzel tube described by Welch (1948) is 1.3 m long, weighs about 2 kg, and is designed to measure velocities ranging from 0.1-1.2 m/sec in depths of 0.8 m or less. This instrument consists basically of a U-shaped metal tube which has the

<sup>1</sup> I thank Mr. David A. Ward, Hydrologic Laboratory, Washington State University, who helped secure suitable components for construction of these devices.

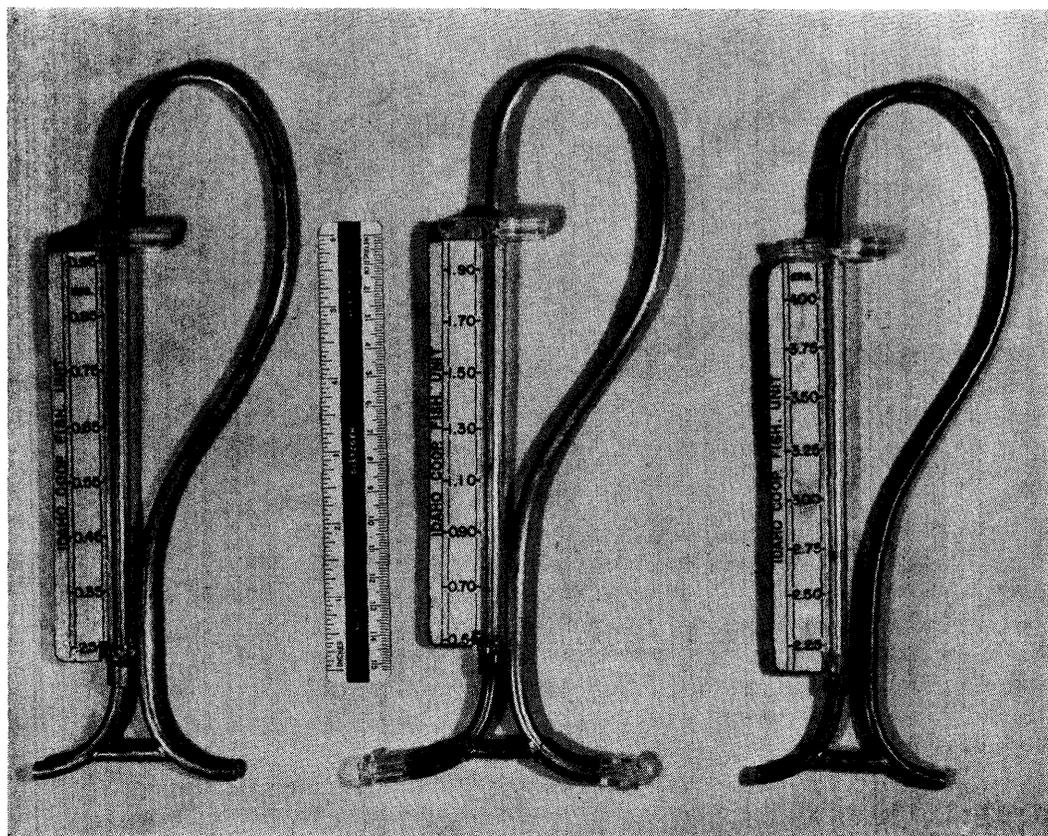


FIG. 1. Set of three midget Bentzel current speed tubes capable of measuring speeds from 0.1 to 1.2 m/sec.