THE AGE AND GROWTH OF THE PACIFIC COCKLE (*CARDIUM CORBIS*, MARTYN) [1]

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INTRODUCTION

Cardium corbis, commonly known as the "cockle," is the most abundant and important species of *Cardium* found on the Pacific coast. It is widely distributed along the Pacific coast from southern California to the Pribilof Islands, Alaska, and as far south as Japan on the Asiatic shore. (Dall, 1916.) In the north it is found on tide flats in the bays, where it may be seen lying on top of the sand or barely beneath the surface. In the south it is found both in the bays and on the exposed beaches of coarse sand. The optimum locality for the species would appear to be in the Strait of Georgia, southern British Columbia, where they occur in great numbers. (Thompson, 1912; Weymouth, 1920.)

Although the cockle is very abundant in many localities and is an excellent food mollusk, it has never attained commercial importance because of its poor keeping qualities and small edible content. The local markets absorb small quantities, and many are used by the crab fishermen for bait. Attempts have been made to can the cockle, but have not met with notable success.

The data upon which this paper is based were incidentally collected by Dr. F. W. Weymouth, H. C. McMillin, and H. B. Holmes during the studies of the Pacific razor clam. Although the amount of material was relatively small, the homogeneity of the samples and the uniformity of clam growth have made it excellent material for growth studies.

AGE DETERMINATION

A quantitative analysis of growth data requires the knowledge of two variables—time and size. The absence of direct observation has required the use of the "annual rings" as measures of the time variable or age. The method is that which has long

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been used to determine the age of trees that in their structure show evidence of seasonal growth. Observers have established the presence of annual marks on the scales and otoliths of fish. Weymouth (1923) has shown in the Pismo clam and Weymouth, McMillin, and Holmes (1925) in the Pacific razor clam that there is a very definite relation existing between seasonal growth and the structure and external appearance of the shell. Rings are formed only once each year at the time of slow or suspended growth in the winter. Evidence of this cyclic growth in the Pismo clam has been presented by Weymouth (1923), and a retardation of growth during the winter months has been shown to occur in the razor clam by McMillin (1923), in the limpet (*Patella vulgata*) by Orton (1928), and in *Tellina tenuis* by Stephen (1929). By marking and holding Atlantic cockles (*Cardium edule*), Orton (1927) affirmed the validity of the rings as measures of age.

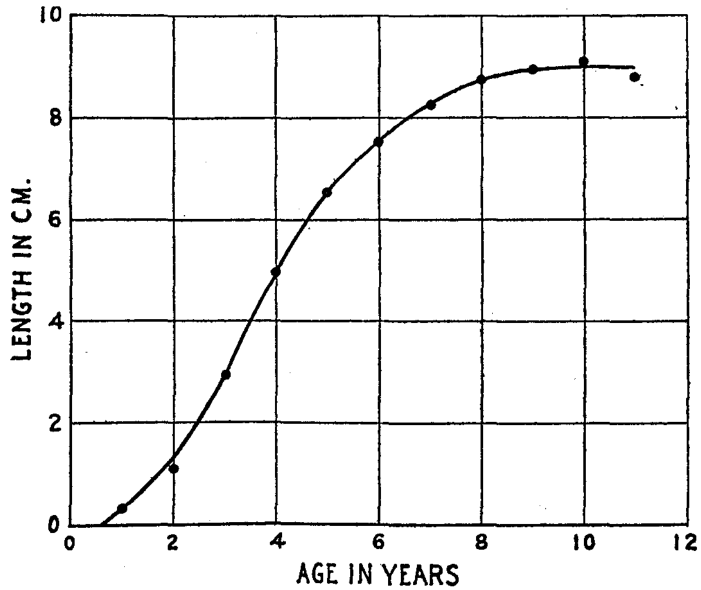

FIGURE 2.—Course of growth of *Cardium corbis* at Snug Harbor

GROWTH

In determining the size at the different ages the shells were measured radially from the umbo along the longest rib by means of calipers reading to tenths of millimeters. This rib, in *Cardium corbis*, is located near the posterior end of the shell. The annual rings to which the measurements were made are very definite and readily noted in the cockles from northern waters. The determination of the annual rings is more difficult on those from southern beaches, where winter growth is less retarded.

From measurements made in this manner the secular trend of the growth has been determined. The growth may be graphically represented by two methods, direct and logarithmic, and each type of curve has its particular value in the presentation of data. Figure 2 is an example of the direct presentation of growth and the curve is of the type most commonly used. This type of curve is constructed from the median length at each age, and is convenient for comparing the growth of closely related forms. (Brody, 1927.)

The life of this clam is sufficiently long to permit satisfactory trends of growth to be determined and to eliminate the effect of chance succession of favorable or un-

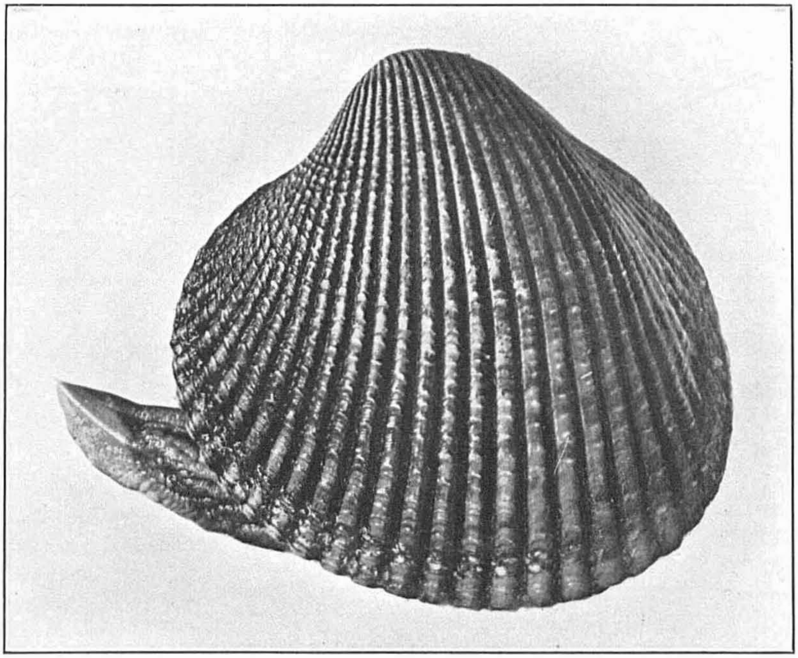

FIGURE 1.—*Cardium corbis*, Martyn

favorable years. The unusual uniformity of the data, due to the high correlation of the growth from year to year in the same individual, has resulted in very smooth growth curves. Figure 3 shows the uniform course of growth of two large individuals taken at Kukak Bay and at Port Moller, respectively.

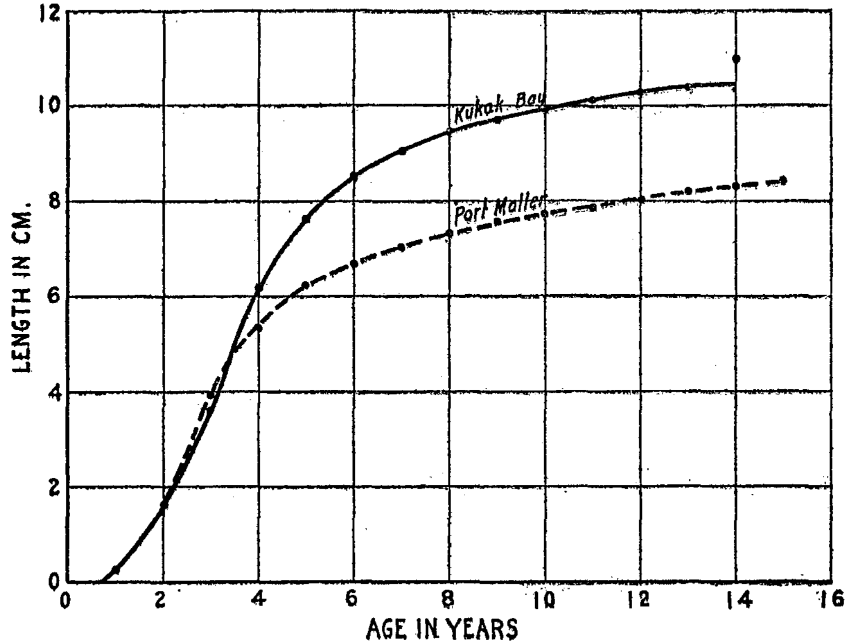

FIGURE 3.—Individual growth of *Cardium corbis* at Kukak Bay and at Port Moller

The same data may be further analyzed, and the differential of the first curve or the absolute annual increments may be plotted as in Figure 4 V. This curve shows

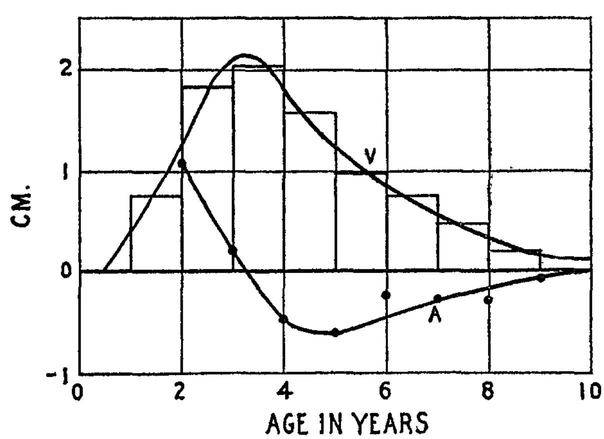

FIGURE 4.—The velocity (V) and (A) of the absolute growth of *Cardium corbis* at Snug Harbor

the velocity or time rate of growth and is useful to make conspicuous relatively slight variations in the curve, such as the presence of growth cycles.

The differential of this velocity curve—that is, the second differential of the original growth curve—represents the acceleration of the growth. Most growth data are

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so irregular as to make it impossible to use this curve, but the clam data are sufficiently uniform to give fairly smooth acceleration curves, as seen in Figure 4 A.

Since one can not readily see from the velocity curve the relative changes with time—the gain per unit of size—it becomes necessary to plot the ratio diagram of growth as in Figure 5. Minot (1908) emphasized the importance of relative growth. He says: "It is evident that the increase in weight depends upon two factors—first,

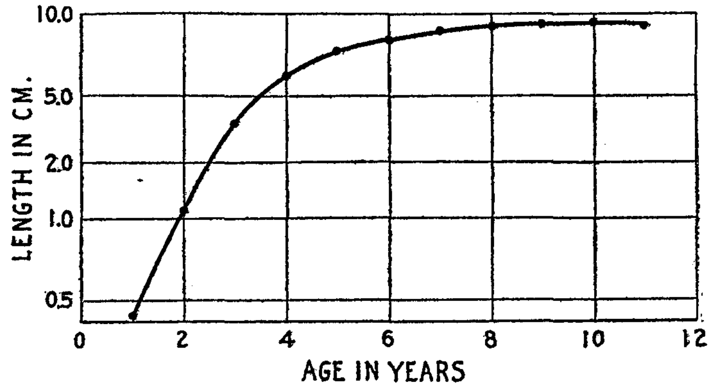

FIGURE 5.—Ratio diagram of the growth of *Cardium corbis* at Snug Harbor

upon the amount of body substance, or, in other words, of growing material present at a given time; second, upon the rapidity with which that amount increases itself." The "intensity" of growth can be shown only by the relative method. To do this the logarithms of the lengths have been plotted on the age. As a result, equal vertical distances represent equal relative changes, and equal slopes mean equal relative rates.

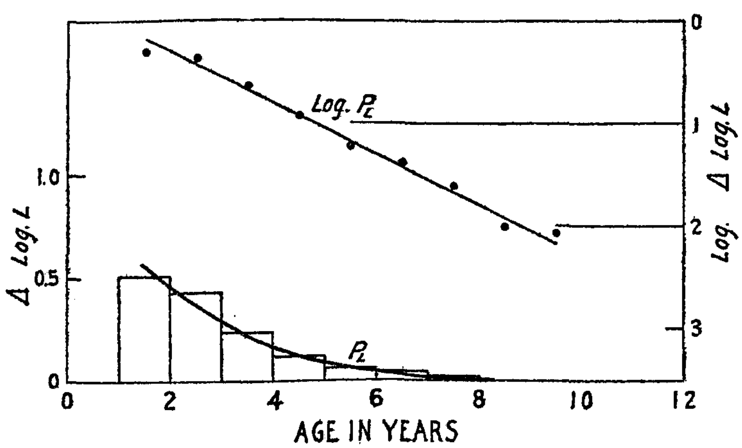

FIGURE 6.—Relative growth rate (P_L) $\left(\frac{\Delta \log L}{\Delta t}\right.$ from Figure 5) and logarithms of relative growth (log P_L) of *Cardium corbis* at Snug Harbor

Early growth is emphasized and late growth is minimized as a natural result of the relative aspect.

The differentials of the logarithmic lengths may be derived and plotted just as in the case of the absolute lengths. The first differential, in Figure 6, shows the declining relative growth rate so much emphasized by Minot. The decline of relative growth is an orderly process and may be fitted mathematically to some function of time. As shown by Weymouth, McMillin, and Rich (1931) and by Weymouth and McMillin (1931), this decline closely approximates an exponential series, so that the log of the relative growth rates plotted on age gives a straight line.

If relative growth rate $=\frac{d \log L}{dt}=P_L$, then

$$\log P_L = a - kt$$
$$P_L = e^{a-kt}$$
$$P_L = Ae^{-kt}$$

where $A = e^a$

$$\frac{d \log L}{dt} = Ae^{-kt}$$

$$\log L = \frac{-A}{K} e^{-kt} + b$$

$$\log L = b - ce^{-kt}$$

where $c = \frac{A}{K}$

$$L = e^{b-ce^{-kt}}$$
$$L = Be^{-ce^{-kt}}$$

where $B = e^b$

Table 1 is a comparison of the observed lengths of *Cardium corbis* with the lengths calculated by the formula $L = Be^{-ce^{-kt}}$, developed by Weymouth, McMillin, and Rich (1930), and Weymouth and McMillin (1930).

TABLE 1.—*Comparison of observed and calculated lengths of Cardium corbis*

SNUG HARBOR

Year	N	L_o	L_c	L_o-L_c	$P.E._o$	Year	N	L_o	L_c	L_o-L_c	$P.E._o$
1	1	0.34	0.363	−0.023	----------	6	6	7.52	7.599	−0.079	0.2135
2	7	1.09	1.280	−.190	0.5018	7	6	8.27	8.289	−.019	.2164
3	7	2.92	3.040	−.120	.2394	8	6	8.75	8.705	.045	.4340
4	6	4.96	4.949	.011	.5281	9	3	8.95	8.949	.001	----------
5	6	6.54	6.511	.029	.2972	10	2	9.09	9.089	.001	----------

NOTE.—N = number of individuals; L_o = observed lengths; $P.E._o$ = probable error of observed lengths; and L_c = calculated lengths: $L=Be^{-ce^{-kt}}$, $L=0.27228e^{-0.247345e^{-.574421t}}$.

GROWTH IN DIFFERENT LOCALITIES

The three curves presented in Figure 7 show the marked variation in the growth of the species in different localities. These have been constructed from measurements of clams taken on the beds of Copalis, Wash., and Kake and Kukak Bay, Alaska. In general, it may be said that *Cardium corbis*, in the southern part of its range, makes a tremendous early growth, with which is associated a short life and a small size. The northern forms show a low initial growth rate, a long life, and a larger size than that attained by the southern forms. Insufficient growth data for the more southern forms have made it impossible to plot the course of their growth. However, where data have been obtained the growth resembles that of the Copalis cockle.

The growth of *Cardium corbis* is an interesting confirmation of the conclusions reached by Weymouth, McMillin, and Rich (1930) in regard to the growth of the

Pacific razor clam. In their work the relative growth rate, as initial rate and rate at two years, was correlated with geographical position, age, and length. The factors involved in geographical position are numerous and largely unknown, but include all of the physical and chemical features of the environment.

Geographical position was given a numerical value for correlation by counting the distance along the coast from Pismo, Calif., the most southern beach from which statistically valuable data were gathered. The sign of the correlation, then, is entirely arbitrary.

In order to compare the variations of growth in different localities, as observed in the cockle, with that mentioned above for the razor clam, similar constants were

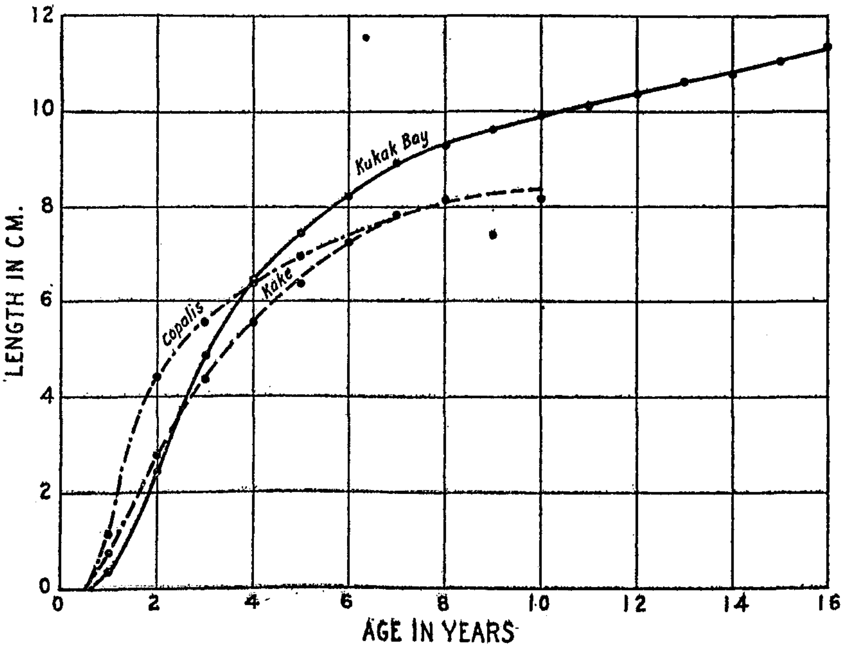

FIGURE 7.—Growth curves of *Cardium corbis* from three localities

calculated for each locality. The values for geographical position were determined as in the razor clam, the distance being measured from Tillamook. Maximum age and maximum length were obtained as follows: On a survival curve for each locality the age was located at which 5 per cent of the clams passing through the first winter were still alive. This was taken as the maximum age. Owing to the small numbers of cockles available for some localities, this value is only a rough approximation, but the errors involved are much less than the differences in length of life. The maximum length is that length read from the absolute growth curve at the maximum age as just defined.

The relative growth rate and acceleration were derived from the natural logarithms of the length as discussed earlier in the paper. These five constants for the eight localities are given in Table 2. It should be mentioned that Constantine Harbor and Port Moller do not represent normal habitats for *Cardium*. The beach at the former place is of coarse gravel, and Port Moller is near the northern limit of the species.

TABLE 2.—*Growth constants for different localities*

Locality	Distance, miles	Maximum age, years [1]	Maximum length, centimeters	P_L[2]	Acceleration [3]	Locality	Distance, miles	Maximum age, years [1]	Maximum length, centimeters	P_L[2]	Acceleration [3]
Tillamook	0	7.5	8.15	0.515	−0.497	Constantine Harbor	1,500	11.4	7.30	1.051	−1.342
Copalis	100	6.8	7.60	.515	−.986	Snug Harbor	1,800			1.076	−.603
Kake	1,000			.727	−.889	Kukak Bay	1,940	14.8	10.90	1.127	−1.285
Cordova	1,480	12.4	9.60	1.235	−1.207	Port Moller	2,240	15.2	7.40	.727	−1.363

[1] Actual ring number; to obtain age substract approximately one-half year.

[2] P_L=relative growth rate$=\frac{d \log L}{dt}$ at $t=2$.

[3] Acceleration$=\frac{dP_L}{dt}$.

Scatter diagrams prepared from these data show, in most cases, definite trends that agree with the correlations obtained for the razor clam. (Weymouth, McMillin, and Rich, 1930; Weymouth and McMillin, 1930.)

As in the razor clam, geographical position shows the highest correlation with maximum age. A lower correlation was obtained between length and age. Cockles from the northern beaches reach the greatest ages and largest sizes. The relative growth rate at two years shows a high positive correlation with age and with length. This agrees with the relation shown by razor-clam growth in which a high relative growth rate at two years is associated with great age and large size. The reverse correlations must exist between early growth rate, age, and length. Figure 7 clearly shows this relation to be true in the growth of the cockle. A high positive correlation between age and length is also shown. The cockles reaching the greatest age are the largest.

In the razor clam a confirmation of the relations observed between localities was obtained by comparing the growth of the sexes. (Weymouth, McMillin, and Rich, 1930.) In the case of *Cardium*, such a check is impossible, as the cockle is hermaphroditic. (Edmondson, 1920.)

CONCLUSIONS

In summarizing, it may be said that, although based on a relatively small amount of material incidentally collected, this study of *Cardium* presents several interesting features.

1. The ring method of age determination may be applied to this species as well as to others previously studied.

2. The growth of *Cardium* is characterized by great regularity, as shown by the individual growth curves presented.

3. The type of growth observed in the razor clam is found in the cockle. In this form the relative growth rate falls throughout postlarval life as first noted by Minot in the guinea pig. The decline is orderly and regular, and in most cases the growth curve can be accurately fitted from the formula $L=Be^{-ce^{-kt}}$, based on an exponential rate of decline of the relative growth rate.

4. A comparison of growth in different localities shows the same relations as observed in the razor clam. The northern forms, in contrast to the southern, show a slower initial but more sustained growth and reach the greater age and larger size.

TABLE 3.—*Average length of cockles*

[N=number of individuals; Mi=median length in centimeters; P. E.=probable error of median]

Ring No.	N	Mi	P. E.
TILLAMOOK			
1	23	2.02	0.031
2	17	4.65	.112
3	11	6.06	.281
4	10	7.13	0.264
5	4	7.25	--------
6	2	8.26	--------
7	1	8.10	--------
COPALIS			
1	47	1.14	.077
2	50	4.40	.040
3	22	5.52	.213
4	15	6.36	.104
5	7	6.97	.089
6	3	7.25	.058
7	3	7.85	.058
KAKE			
1	4	.73	--------
2	4	2.78	--------
3	4	4.35	--------
4	4	5.52	--------
5	4	6.37	--------
6	3	7.32	--------
7	3	7.81	--------
8	3	8.15	--------
9	2	7.37	--------
10	1	8.15	--------
CORDOVA			
1	16	.26	.017
2	32	1.80	.191
3	30	3.73	.062
4	30	5.83	.053
5	27	6.68	.140
6	23	7.43	.102
7	8	7.59	.237

Ring No.	N	Mi	P. E.
CORDOVA—con.			
8	7	8.11	0.147
9	7	8.42	.147
10	6	8.89	--------
11	4	9.21	--------
12	3	9.42	--------
13	2	9.82	--------
14	1	9.70	--------
15	1	9.81	--------
16	1	9.97	--------
17	1	10.03	--------
CONSTANTINE HARBOR			
1	34	.50	.039
2	107	1.80	.099
3	105	3.38	.036
4	81	4.59	.043
5	65	5.41	.055
6	44	5.89	.020
7	36	6.28	.051
8	22	6.60	.082
9	14	6.84	.126
10	11	6.93	.112
11	6	7.27	--------
12	5	7.44	--------
13	1	7.20	--------
SNUG HARBOR			
1	1	.34	--------
2	6	1.09	.502
3	6	2.92	.239
4	5	4.96	.528
5	5	6.54	.297
6	5	7.52	.214
7	5	8.27	.216
8	5	8.75	.434
9	3	8.95	--------
10	2	9.09	--------
11	1	8.80	--------

Ring No.	N	Mi	P. E.
KUKAK BAY			
1	72	0.34	0.015
2	92	2.44	.040
3	92	4.85	.081
4	81	6.44	.055
5	69	7.45	.093
6	47	8.23	.116
7	34	8.90	.098
8	29	9.31	.045
9	21	9.60	.062
10	14	9.90	.063
11	8	10.10	.063
12	7	10.35	.088
13	6	10.60	.032
14	5	10.75	.075
15	5	11.06	.199
16	4	11.35	.199
PORT MOLLER			
1	18	.39	.020
2	29	2.30	.364
3	20	3.47	.101
4	16	3.60	.135
5	14	5.50	.627
6	13	5.62	.304
7	11	5.75	.558
8	11	6.25	.558
9	9	6.19	.202
10	8	6.54	.237
11	5	6.77	--------
12	2	8.03	--------
13	2	8.21	--------
14	2	8.35	--------
15	2	8.46	--------
16	1	8.73	--------

BIBLIOGRAPHY

BRODY, SAMUEL.

1927. Growth and development, with special reference to domestic animals. III. Growth rates, their evaluation, and significance. Research Bulletin No. 97, University of Missouri Agricultural Experiment Station, January, 1927, 70 pp., 18 figs. Columbia, Mo.

DALL, WILLIAM HEALEY.

1916. Check list of the recent bivalve mollusks (Pelecypoda) of the northwest coast of America from the Polar Sea to San Diego, Calif. 1916, 44 pp. Los Angeles, Calif.

EDMONSON, CHARLES HOWARD.

1920. Edible mollusca of the Oregon coast. Occasional Papers of the Bishop Museum, Vol. VII, No. 9, 1920, pp. 179–291, Figs. I–VI. Honolulu.

MCMILLIN, H. C.

1923. Additional observations on razor clams. 34th Annual Report, Supervisor of Fisheries, State of Washington, 1923–1925 (1925), pp. 15–17. Olympia, Wash.

MINOT, CHARLES S.

1908. The problem of age, growth, and death. 1908, 280 pp., 73 figs. New York and London.

ORTON, J. H.

1926. On the rate of growth of *Cardium eduli*. Part I. Experimental observations. Journal, Marine Biological Association, N. S., Vol. XIV, 1926–1927, No. 1, August, 1926, pp. 239–279, 11 figs. Plymouth.

1928. Observations on *Patella vulgata*. Part II. Rate of growth of shell. Journal, Marine Biological Association, N. S., Vol. XV, No. 3, November, 1928, pp. 863–874, 2 figs. Plymouth.

STEPHEN, A. C.
1929. Notes on the rate of growth of *Tellina tenuis* da Costa, in the Firth of Clyde. Journal, Marine Biological Association, N. S., Vol. XVI, No. 1, May, 1929, pp. 117–129, 5 figs. Plymouth.
THOMPSON, WILLIAM F.
1913. Report on the clam beds of British Columbia. Report, Commissioner of Fisheries of British Columbia, 1912 (1913), pp. 37–56, XIV Pls.
WEYMOUTH, FRANK W.
1920. The edible clams, mussels, and scallops of California. Fish Bulletin No. 4, State of California Fish and Game Commission, 1920, 74 pp., 26 figs, 19 pls. Sacramento.
1923. The life history and growth of the Pismo clam. Fish Bulletin No. 7, State of California Fish and Game Commission, 1923, 120 pp., 10 figs, 18 graphs. Sacramento.
WEYMOUTH, FRANK W., H. C. MCMILLIN, and H. B. HOLMES.
1925. Growth and age at maturity of the Pacific razor clam, *Siliqua patula* (Dixon). Bulletin, United States Bureau of Fisheries, Vol. XLI, 1925 (1926), pp. 201–236, 27 figs. Washington.
WEYMOUTH, FRANK W., and H. C. MCMILLIN.
1931. Relative growth and mortality of the Pacific razor clam (*Siliqua patula*, Dixon), and their bearing on the commercial fishery. Bulletin, United States Bureau of Fisheries, Vol. XLVI, 1930 (1931). In press. Washington.
WEYMOUTH, FRANK W., H. C. MCMILLIN, and W. H. RICH.
1931. Latitude and growth of the razor clam. Journal, Experimental Biology. In press.