Growth and Mortality Rates of the Razor Clam (*Siliqua patula*) on Clatsop Beaches, Oregon

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GROWTH AND MORTALITY RATES OF THE RAZOR CLAM (Siliqua patula) ON CLATSOP BEACHES, OREGON

George Hirschhorn[1]

ABSTRACT

Clatsop Beaches, characterized by flat beach-face slope (1:70) and small sand-size (0.2 mm.), have supported commercial and recreational fisheries for the razor clam (*Siliqua patula*) for many years. Tracing the linear growth of two year classes through more than one year following set led to a validation of the ring method of age determination in the population studied. Annual ring lengths based on the means of samples from all subareas were fitted by von Bertalanffy equations. Increases in total length, wet weight, and relative width showed patterns of seasonal variation. Death rates of the Seaside Beach population were estimated from recoveries of 3,379 serially marked razor clams. Mortality coefficients obtained were: 2.52 for total mortality, based on the difference between estimated population sizes in 1952 and 1953 of year classes fully recruited at the beginning of the census; 1.78 for the estimated removals by actual harvesting; and 0.74 for other losses to which fishery-connected wastage was believed to have contributed, in addition to true natural mortality. The weight yield per 1,000 recruits, as function of age at first capture, was examined at three hypothetical levels of wastage indicating that potential increases in yield at each level could be realized by deferring the exploitation of a year class until its second year of age, regardless of whether the fisheries are continuous or seasonal.

INTRODUCTION

The areas most productive of the Pacific razor clam (*Siliqua patula*) in Oregon are Clatsop Beaches. They have supported commercial and recreational clam fisheries for many years under regulations which provided until 1954 for a minimum size limit of 3.5 inches in commercial catches and a limit of 36 clams by recreational diggers.[2] Neither fishery has been subject to seasonal restrictions at any time, nor to quota limitations.

In the present study a description of this fishery is attempted by estimating the rates of growth and mortality essential to the determination of optimum yields. Following validation of the ring method of age determination for Clatsop stocks, the seasonal variation in weight and linear growth is examined as well as variations in linear growth of clams between beaches. Mortality rates are estimated from a census on one of the smaller Clatsop Beaches in 1952 and 1953 which included the use of serially marked clams. Finally, potential yield is examined as a function of age at first capture.

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[2] In 1955 the commercial minimum size was changed to 4¼ inches and the possession limit for recreational diggers to 24 clams.

PHYSICAL FEATURES OF CLATSOP BEACHES

Clatsop Beaches are about 20 miles in length, extending from a point south of Seaside, Oregon (lat. 45° 57′ N, long. 123° 57′ W) to the South Jetty of the Columbia River (lat. 46° 12′ N, long. 124° W). As shown in Figures 1 and 2, they are open and fully exposed to wind and wave action from the west at all points. They are discontinuous only at the mouth of the Necanicum River which separates the southernmost portion (Sea-

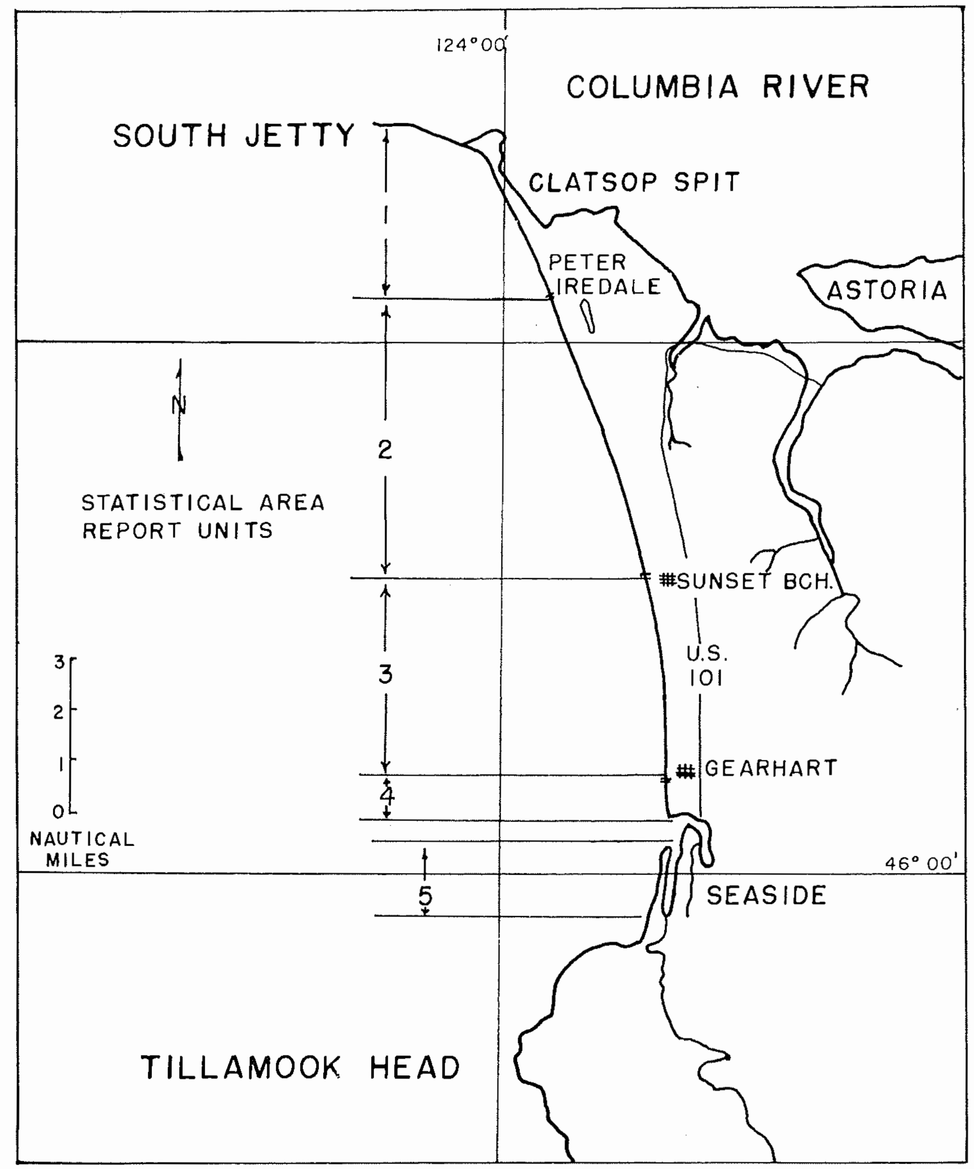

FIGURE 1. A MAP OF CLATSOP BEACHES, OREGON, SHOWING LOCATION OF STATISTICAL AREA REPORT UNITS.

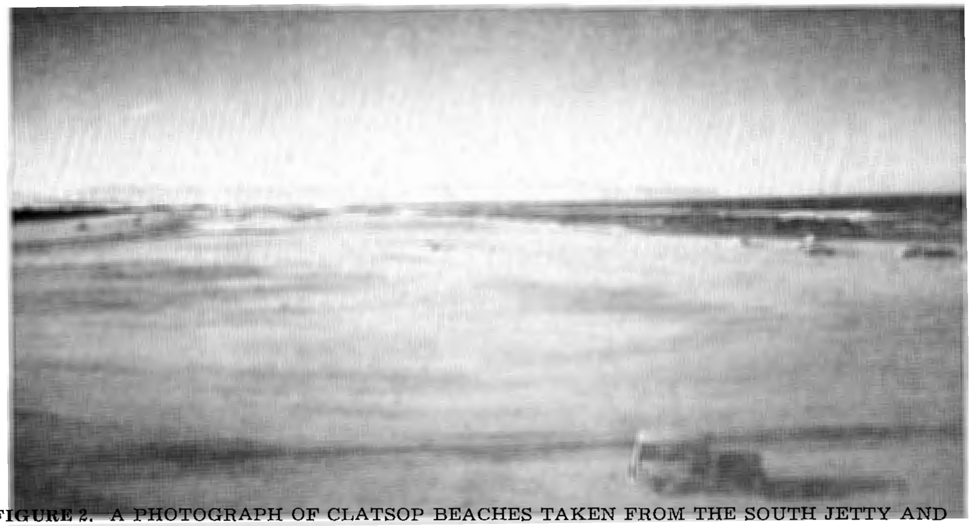

FIGURE 2. A PHOTOGRAPH OF CLATSOP BEACHES TAKEN FROM THE SOUTH JETTY AND SHOWING TILLAMOOK HEAD IN THE DISTANCE.

side Beach) from the others. Aerial photographs indicate the presence of erosional matter in the ocean, transported from the Columbia River in a southerly direction as far as Tillamook Head. An eddy exists in the southernmost portion of Clatsop Beaches. In this area, protected to the south by Tillamook Head, the sand is marked by greater variation in grain size and coloration and the presence of more debris than in beaches to the north. Photographs taken near the beginning of the century indicate that the amount of sand accumulated on Seaside Beach was considerably smaller than at present. Then the upper reaches of Seaside Beach were covered with cobble stones which are still visible near the southern extremity, especially during the winter when erosion has taken place.

The northern extremity of Clatsop Beaches was altered in 1895 by the construction of the South Jetty at the mouth of the Columbia River and led to shoaling of the area 1.5-2.0 miles south of the jetty. A chart prepared by Captain Sir Edward Belcher, *H. M. S. Sulphur*, in 1839, shows the northern terminus of Clatsop spit at this location. The intervening area was then occupied by Queens Channel and the jetty area itself was called Middle Ground. Today this area, as well as the southernmost extremity of the beach, produces razor clams.

According to Bascom (1951), extensive surveys of some 40 beaches along the Pacific Coast under the sponsorship of the Office of Naval Research and the Beach Erosion Board of the Corps of Engineers in 1944-48 indicated that Clatsop Beaches were characterized by flat slopes (1:70) of the beach face and small median diameter values of sand (0.2 mm.) Other productive razor clam beaches included in these surveys had even smaller values of slope and grain size. The association of beach erosion with high waves, and shoreward sand movement in the presence of small waves, was studied by Shepard (1950a) and led to the description of annual beach cycles.

The set of young razor clams on Clatsop Beaches is generally observed near the onset of fall and winter storms (i.e., shortly before and after the period of maximum beach buildup). Because of their small size at that time, the clams are unable to withdraw rapidly from the top layers of sand and hence their movement is likely to be governed largely by that of the upper sand layers. During the erosional phase of the annual beach cycle, these layers of sand appear to move in an offshore direction and are a ready vehicle for the redistribution of small razor clams. According to Shepard (1950b), bar and trough development takes place in the breaker zone. Live adult razor clams have been found by crab fishermen in pots fished just outside of that zone. Whether they are part of a self-contained population has not been determined, but it appears that their original placement in the breaker zone could have been the result of involuntary seaward transport due to wave conditions prevailing at the time of set.

METHODS AND OBJECTIVES OF SAMPLING

For the study of linear growth in juvenile razor clams, several beach transects 1 meter wide were sampled periodically. Samples were obtained by screening standard amounts of sand until members of the new "set" had grown large enough to avoid capture in this manner by withdrawing to deeper layers. At this stage, detection by eye is possible, however, and samples could be obtained with a clam shovel. Occasional digs were made by biologists on all parts of Clatsop Beaches to produce additional length-frequency samples.

For age and growth studies on adult clams, the most productive source of samples was the commercial catch delivered to local processing plants. In May 1952 the industry agreed to add to obligatory records the origin of catches by beach area. This reduced the need for samples dug by biologists and provided more material for determination of age composition and growth, and for conversion factors between numbers and pounds of clams. However, area reporting was voluntary and only about 90 per cent complete, so that adjustments were necessary in estimating the total catch from a given area. During the 1952-53 census of Seaside Beach, clam processing plants provided the most practical source of mark recoveries in commercial catches. The reportability of commercial mark recoveries was estimated in a subsidiary experiment and applied to the reported recoveries for the calculation of exploitation rates.

Since no catch records are required of recreational diggers, all information relating to their harvest depends on sampling. Accordingly, estimates were made from periodic digger counts and average values of catch-per-man-tide. In the census area, the questionnaire method of obtaining information was also used to facilitate the reporting of marked clams; however, the returns proved unsuitable for estimating the catch of unmarked clams since there was a tendency to use questionnaires only for reporting marks. Even if this bias had not existed and an accurate determination of the catch had been possible, such values would not reflect the destruction of clams which are not retained because of their small size, or could not be captured due to lack of skill.

That these sample sources can produce substantially different length-frequency distributions in nearly simultaneous catches from the same area is illustrated by Figure 3. The biologists' sample, intended to be non-selective as to length, produced a mode at 75-80 mm. The 100 mm. mode in the sport sample reflected the preference by recreational diggers for large clams. The virtual absence of clams below 90 mm. in the commercial sample was, of course, a consequence of the 3.5-inch minimum size limit then in effect. Figure 3 suggests that these sample sources produce length-frequency distributions which differ in modal length and therefore are not comparable. In the study of first-year growth, biologist-dug clams were used since they were believed to be less affected by size selectivity than clams from the other sources.

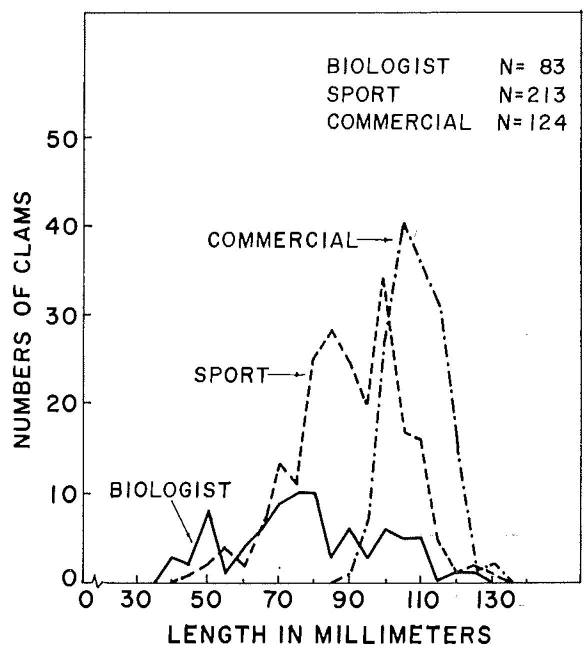

FIGURE 3. COMPARISON OF LENGTH-FREQUENCY DISTRIBUTIONS OF BIOLOGIST, SPORT, AND COMMERCIAL CATCH SAMPLES (SEASIDE, MAY 31, 1954).

LENGTH-WEIGHT MEASUREMENTS

Monthly length-weight data of freshly dug clams were collected in 1950 and 1951. Most of these were based on commercial catches but some biologist-dug samples were also used to extend the size range below the 3.5-inch commercial minimum, or to supply study material for off-season periods. The weights of clams are "wet weights"; i.e., those on which the purchase price of commercial digs is based. Inaccuracies in weight values may be due to variations in time between catch and weighing, amount of adhering sand, and mode of transportation. Weights of biologist samples were recorded to the nearest gram, without reference to sex, since the work of Weymouth and McMillin (1931) indicated that sexual characteristics made no appreciable difference in the growth and proportional measurements of razor clams from a particular habitat.

A seasonal description of the length-weight relationship was attempted by grouping the data in ⅛-year intervals. Each interval includes about 3 successive series of low tides, centered on the nominal dates shown in Table 1. This table shows the regression constants for each interval and the sample sizes associated with each regression. Minimal slope values are indicated for February 15 and July 1; the maximum value appeared in the April 1 sample. These and other features of the length-weight relationship are more apparent from Figure 4, which shows the calculated weight changes for clam lengths in 10 mm. intervals. The February reduction in weight for clams of similar length appears to be associated with annual temperature minima. The generally sharp weight increase between February and May is largely due to development of sex products, while the ensuing drop signifies the passing of the spawning season usually in late May or early June. This is followed by the restoration of weight to pre-spawning levels and greater. Between August and the end of the year some weight loss is apparent at all levels of length, reflecting the relatively unfavorable environmental conditions. Figure 4 shows that the weight of the 80 and 90 mm. groups (representing clams of lower age, higher growth rate, and lower fecundity) is less affected by these factors than are larger clams; and that a single formula cannot take into account all the variations encountered within a year. The seasonal regressions shown in Table 1 have been used in the construction of an age-weight table and in yield calculations presented in later sections.

TABLE 1. SUMMARY OF REGRESSIONS OF WET WEIGHT ON LENGTH FOR RAZOR CLAMS FROM CLATSOP BEACHES, GROUPED BY ⅛-YEAR INTERVALS.

Nominal Date	Dates Sampled	Range of Sample (mm.)	Number of Clams in Sample	Formula log weight (g.) = a + b log length (mm.) a	b
Jan. 1	Jan. 6–9, 1950	90–140	48	–4.82335	3.29260
Feb. 15	Feb. 4–27, 1950	90–135	49	–4.53636	3.14825
Apr. 1	Mar. 30–Apr. 4, 1950	85–130	777	–5.21421	3.49275
May 15	May 19, 1950–May 31, 1951	75–150	299	–4.77645	3.28877
July 1	June 26–30, 1950	68–143	233	–4.54678	3.16515
Aug. 15	July 28–Aug. 29, 1950	65–150	128	–4.35280	3.09239
Oct. 1	Sept. 14–15, 1950	75–140	177	–4.70492	3.24554
Nov. 15	Nov. 10–19, 1950	60–140	191	–4.69260	3.23627

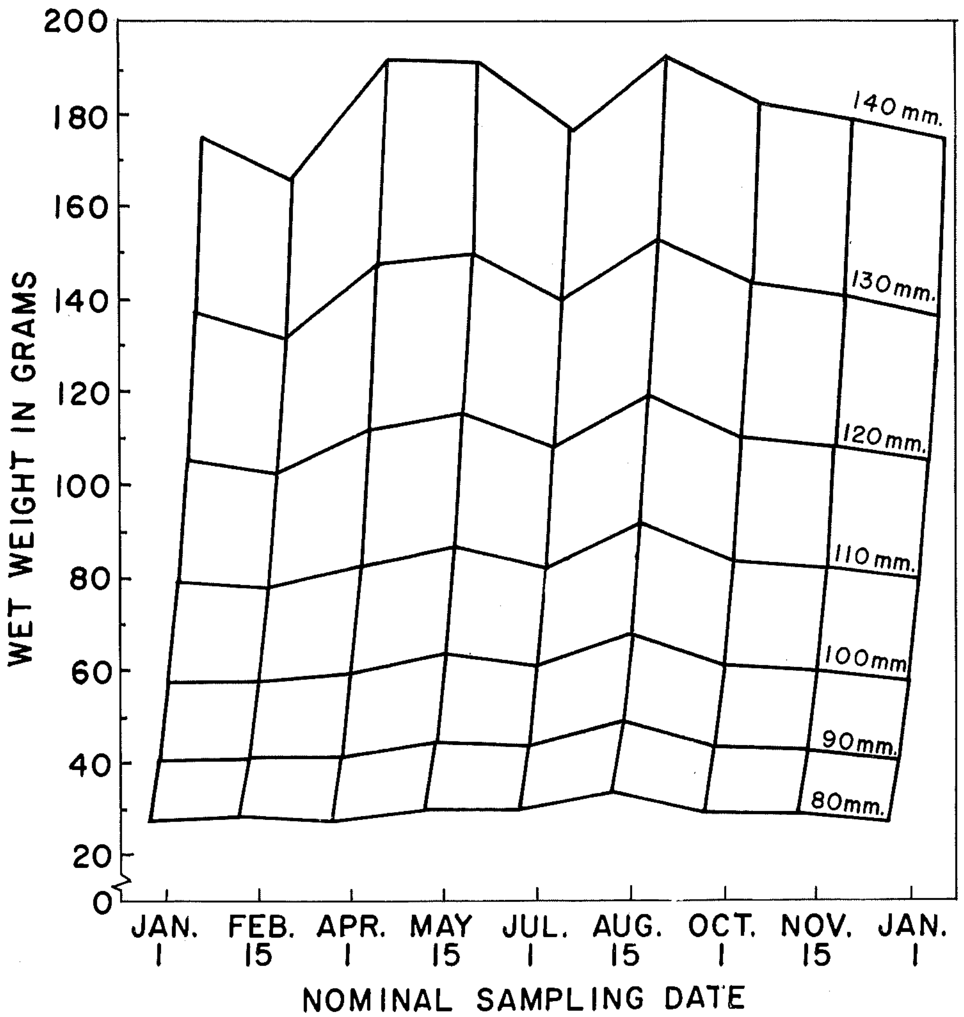

FIGURE 4. SEASONAL VARIATION IN WET WEIGHT OF RAZOR CLAMS AT SEVEN LEVELS OF TOTAL LENGTH.

AGE DETERMINATION

The ring method of age determination in shellfish has long been recognized and applied to razor clams. In this study, the method of validating rings as age structures is essentially that employed by Weymouth (1923) on the Pismo clam and by Weymouth, McMillin, and Holmes (1925) on the Pacific razor clam. The latter work describes growth of clams in Washington and Alaska populations but not specifically Oregon stocks.

A ring is considered here as a continuous and concentric shell structure bounded by relatively wide, lighter-colored bands on both sides, and frequently marked by visible and palpable changes in shell curvature. Ring length represents the distance between the central portions of the darker ring band along its major axis (Figure 5) rather than between the interior or exterior ring margins; measurement was by means of calipers and recorded to the nearest millimeter. Another quantity derived from length measurements but not shown in Figure 5 is the marginal increment (i.e., the difference between total length and last-formed ring).

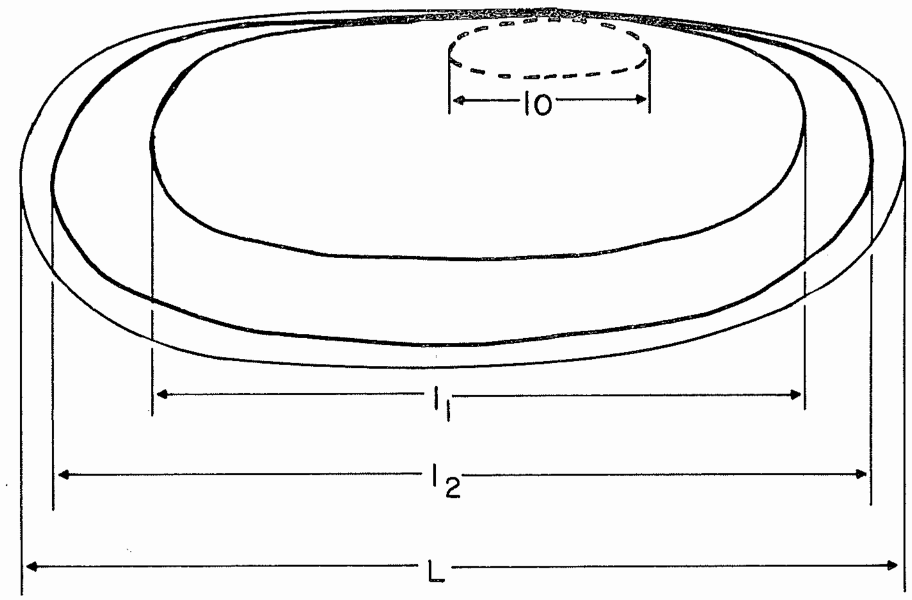

FIGURE 5. SCHEMATIC SKETCH OF RAZOR CLAM SHOWING MEASUREMENTS OF TOTAL LENGTH (L) AND RING LENGTH (l) ALONG THE MAJOR AXIS.

Following the appearance of a new set of razor clams on Clatsop Beaches in late September 1949, growth studies were made from their length-frequency distributions in periodic samples. These clams were collected until February 1950 with a 16-mesh-per-inch sand screening box and thereafter by shovel. To produce as continuous a time series as possible, samples were taken from all beach areas. The length-frequency distributions of the October 1949-December 1950 series is depicted in Figure 6. Although a substantial increase in shell length was apparent throughout the first winter, there were too few samples to provide continuous frequency distributions. Relatively rapid gains in the March-June samples were followed by a noticeable reduction in growth in July. Between July and August a further increase in total length was indicated, with modal size groups reaching or exceeding the commercial minimum of 3.5 inches or 89 mm. From September through December 1950 the modal position varied between 95 and 100 mm. without further progression; the length increases were the smallest observed since the appearance of the 1949 set. The beginning of ring formation on the shell margin during this period was noted in some individuals sampled.

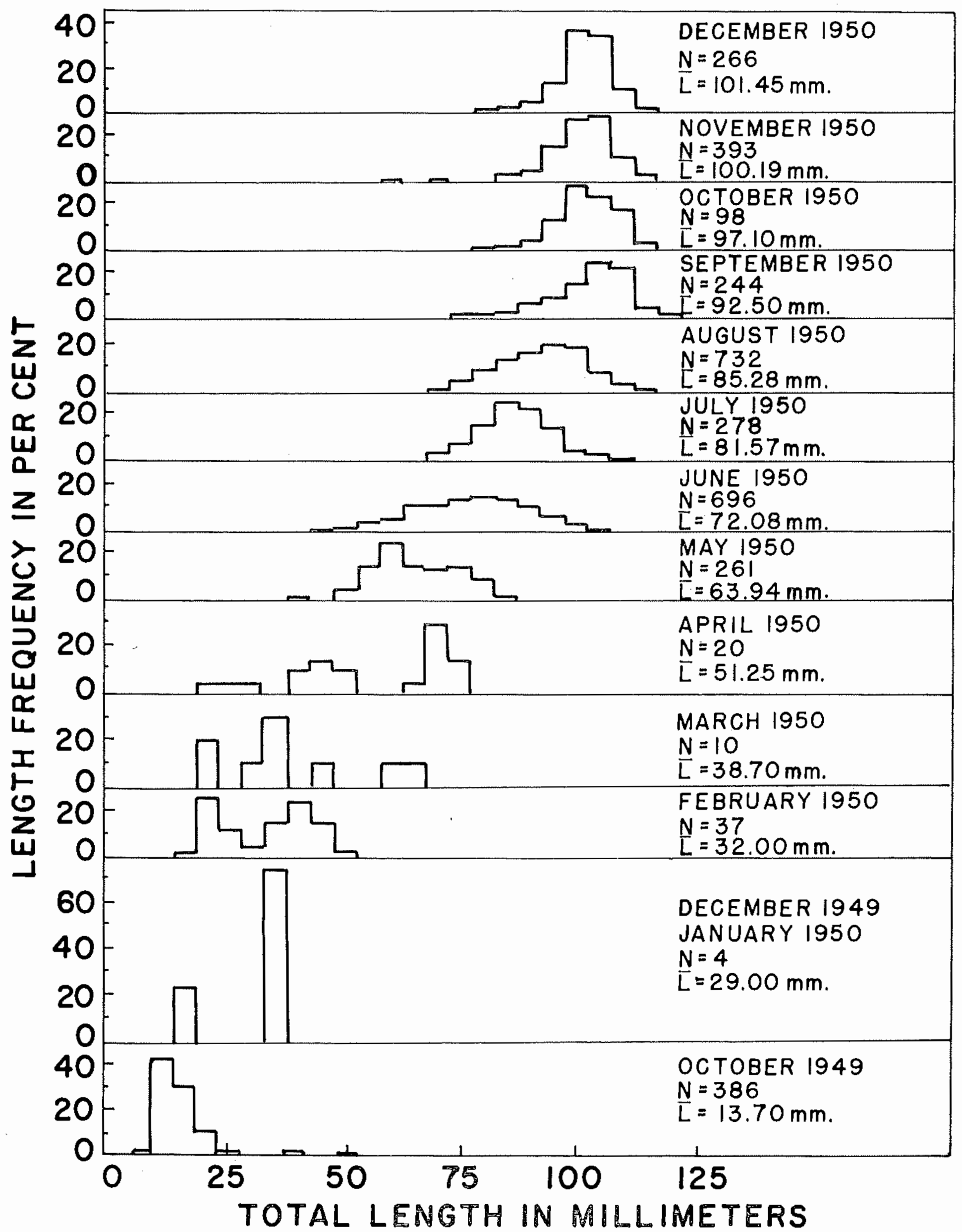

FIGURE 6. PER CENT LENGTH-FREQUENCY DISTRIBUTIONS OF THE 1949 YEAR CLASS, OCTOBER 1949—DECEMBER 1950.

Growth during the second calendar year following the 1949 set is shown in Figure 7. The histograms which represent total length (L) in January and February 1951 show distributions similar to those of samples collected in November-December 1950. The sharpest increase in modal length, as shown by the histogram peaks, appeared between

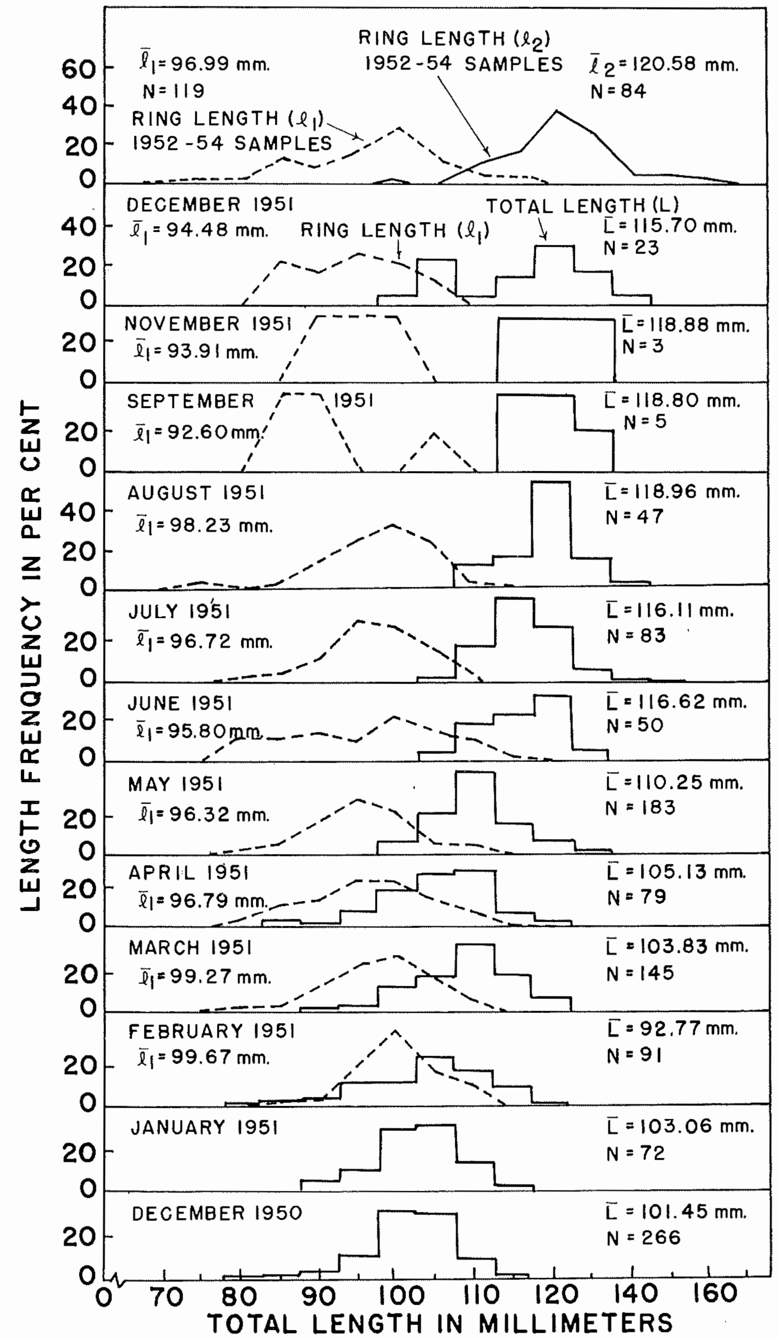

FIGURE 7. FREQUENCY POLYGONS OF 1949-YEAR CLASS RING LENGTHS (l_1 and l_2) AND HISTOGRAMS OF TOTAL LENGTH (L), DECEMBER 1950—FEBRUARY 1954.

May and June 1951. The slight increase between July and August was followed by no further advances in the primary mode during fall and early winter, indicating—as in 1950—that growth during this period was subject to prolonged retardation. Again, the beginning of the formation of a second ring along the shell margin was observed in some instances.

The dashed frequency polygons in Figure 7 represent the ring lengths where ring formation was completed. Only 57 out of 91 clams were so classified in the February 1951 sample; by March, all but 3 of the 145 clams sampled had acquired additional, measurable growth beyond the exterior margin of the ring. In general, the frequency distributions of ring length were similar in all months shown to those of total length in the fall of 1950. Therefore, the length of the 1950 ring was considered to indicate the total length of clams in this year class at or near the end of their first year in the fall of 1950. It was accordingly labeled l_1. Members of the 1949 year class continued to appear sporadically in shell samples obtained in 1952, 1953, and 1954, totalling 119, of which 84 showed completed second-year rings. The top panel of Figure 7 contains the composite freqency distributions of the first- and second-year ring lengths of these samples. They show no major differences from distributions of total length in the 1949 year class during the period of retarded growth (October-December) in 1950 and 1951, respectively.

Figure 8 summarizes the total length growth and ring measurements pertaining to the 1949 year class. The top panel shows that total length had increased during the first year of life from 14 mm. shortly after set to about 100 mm. by December 1950. During the second year (1951) of life, additional growth was noted in measurements of the marginal increment (i.e., the difference between total length and the 1-ring which had formed during the winter of 1950). The sample means of these differences are plotted in the center panel of Figure 8. Their largest values were attained toward the end of 1951, indicating that maximal growth beyond the first ring amounted to 21 to 26 mm. The bottom panel of Figure 8 shows the sample means of ring lengths obtained for 1-ring (in 1951-54) and 2-ring (in 1952-54) clams of the 1949 year class. Although substantial variations between the sample means of each ring are apparent, the mean difference between them approximates that of the largest marginal increment (L-l_1) shown in the central portion of the figure; the difference between the ring length means was about 24 mm., comparable to the marginal increment values observed near the end of the second year. The similarity between total length at the end of the first year and the length of the first ring indicates that ring formation occurs in winter. The similarity of the marginal increment (about one year following l_1 formation) and the distance between successive ring lengths l_1 and l_2, indicates that ring formation occurs annually.

Rings are recognizable by changes in growth rate before and after ring formation. Recognition is impaired if a ring is not preceded by relatively fast growth or followed by relatively slow growth. If one of the margins is indistinct, accurate measurement is difficult. In many, if not most, of the shells examined in this study the measurement referred to by Weymouth, McMillin, and Holmes (1925) as that of the first ring was not

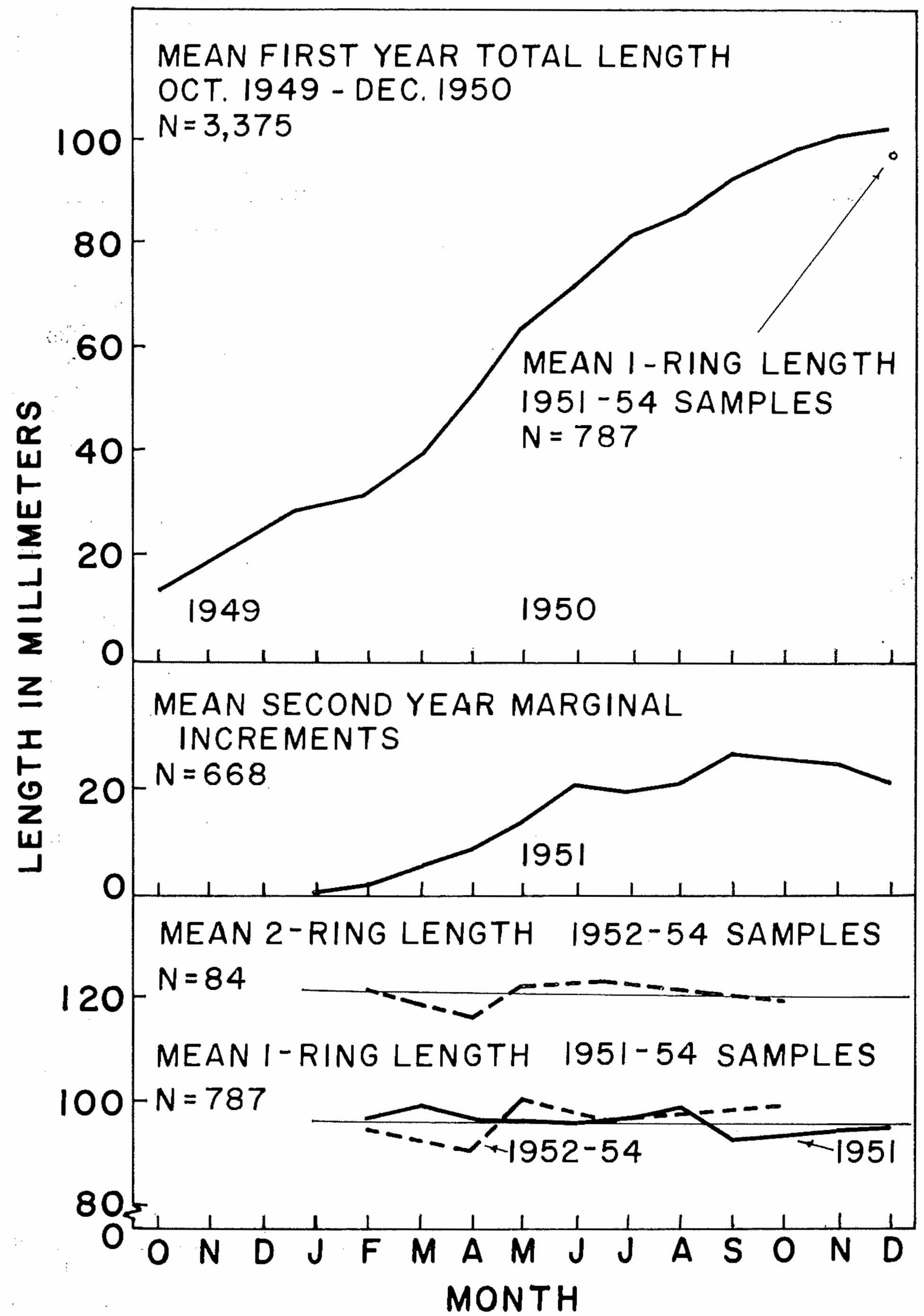

FIGURE 8. SAMPLE MEANS OF FIRST-YEAR TOTAL LENGTH, SECOND-YEAR MARGINAL INCREMENTS, AND MEASUREMENTS OF THE FIRST AND SECOND ANNUAL RINGS IN CLATSOP BEACH RAZOR CLAMS OF THE 1949 YEAR CLASS.

preceded by a marked change in shell coloration. (In Figure 5 the approximate location of this ring was labeled l_0 since it presumably indicates total length during the winter preceding the first full calendar year of growth.) The absence of contrast was expected in view of the dates—in 1949, for example—on which new sets were first observed. Although clams in the 10-30 mm. size range have been observed on Clatsop Beaches at other times of year, the largest concentrations—encountered nearly simultaneously in all areas—usually occurred during the fall months. This would account for the common appearance of umbonic shell areas which showed a distinct exterior margin, but lacked a similar margin on the inside of the l_0 ring. The latter was not measured in all samples collected but only when the criteria described earlier were met.

Erosion of the periostracum was observed primarily in older clams and in a few cases affected the measurability of rings. The close spacing of the higher-numbered rings in older clams undoubtedly reduced measurement accuracy but the superimposition of successive rings was infrequent. Disturbance checks were often encountered. However, they were accompanied as a rule by other shell imperfections and hence readily recognized.

VARIATIONS IN LINEAR GROWTH

In the preceding section the samples obtained from the 1949 year class were used as a basis for validating the ring method of age determination. Sampling of the 1950 year class provided information on (1) unequal dates of set, (2) selective removal of clams by size, (3) the effect of beach level on growth, and (4) short-term differences in frequency distribution of total length during the first year within and between

FIGURE 9. BIOLOGIST SCREENING FOR NEWLY-SET RAZOR CLAMS NEAR THE WRECK OF THE *PETER IREDALE*.

areas. Seasonal changes in marginal increments were also studied in several age groups throughout the year. These changes were found to be associated with seasonal variations in relative shell width, water temperature, and total weight.

Although a sample of 58 juvenile clams was obtained as early as April 28, 1950 by screening on Seaside Beach, there was no evidence that a similar set had occurred on other beaches. In July and August 1950 negative results were obtained from 20 screenings covering all areas. The general occurrence of a new set was first noted in late August but, with the exception of the northernmost quarter of Clatsop Beaches, substantial numbers were not encountered in all areas until October. A particularly productive area was located 1.3 miles north of the *Peter Iredale* wreck (Figure 1) in late August, initiating a 15-month sequence of sampling. Identified by landmarks and staked out in an east-west direction, this area continued to produce samples from a strip one meter wide until August 1951. It was then extended by one meter to the north and south and sampled until October 1951. Figures 9 and 10 show the screening operation.

FIGURE 10. JUVENILE RAZOR CLAMS REMAINING IN THE SCREENING BOX AFTER THE SAND HAS BEEN WASHED AWAY.

Figure 11 traces growth of the 1950 year class at the *Peter Iredale* strip from August 1950 through October 1951. The two earliest samples (August and September 1950) show a sharp modal increase in length, indicating that growth had taken place. The small September sample was due partly to the inaccessibility of the more seaward segments of the strip which had produced 58 per cent of the previous month's sample.

At comparable beach levels, the number of clams per square meter screened was about half as large in September as in August. In October 1950 the number of clams increased again, producing a sample with bimodal distribution. The primary mode at 10 mm. suggested the occurrence of a set that was absent during the previous month while the secondary mode at 25 mm. could reflect growth of survivors from earlier sets. In November a further increase was noted in the number of clams screened. Since no displacement of the mode was apparent from its position at 10 mm. one and three months earlier, it was assumed that the bulk of the November sample represented clams which first appeared that month. At the same time, the size range began to extend to 40 mm. total length and beyond, suggesting the continued presence and growth of survivors from earlier sets. No quantitative importance was attached to their incidence since 40 mm. clams are capable of avoiding capture during the screening of sand. Slight increases in modal and average length were noted in December 1950 and January 1951, coupled with a progressive reduction in the proportion of 5- and 10-mm. clams. The February and March 1951 samples indicated no shift in modal position and only slight increases in mean total length.

Thus the tracing of growth of clams at the *Peter Iredale* location through the fall of 1950 and winter of 1951 suggested that seeding occurred intermittently between August and December rather than in a single tide series, and created a relatively wide variation in size in a single year class during the first few months.

Figure 11 shows that by April 1951 the modal size had increased by 15 mm. over the preceding 3 months. This sample—the last obtained by screening—was compared with one dug by shovel near the seaward end of the *Peter Iredale* strip (shown by dashed line). The latter group had a mean total length and frequency distribution generally to the right of that obtained by screening. This was considered due either to superior growth offshore or to selectivity in favor of larger clams when digging with a shovel, or both.

Continued rapid growth was apparent from the dug samples in May 1951 and to a lesser extent those of the ensuing 3 months. A gain in modal length was observed in the size distribution of clams taken from comparable beach levels in August and September (not shown by beach level in Figure 11). The October 1951 sample, more nearly normal for the beach levels studied, indicated that further growth had taken place, producing a mode at 80 mm. As shown in Figure 11, this strip-dig group was accompanied by a random sample obtained outside the area previously sampled. The modal difference between the two was 10 mm., possibly due to relatively heavy previous digging in that area which had consistently harvested the faster growing and more readily detectable clams. Another factor contributing to the size difference between the October 1951 samples may have been the disturbance by diggers (mostly biologists) and consequent reduction of growth of clams in the strip area proper.

A comparison of first-year growth of the 1949 and 1950 year classes (Figures 6 and 11) shows that, although initial modal sizes in recent sets were similar (10 mm.) and followed a parallel course of seasonal

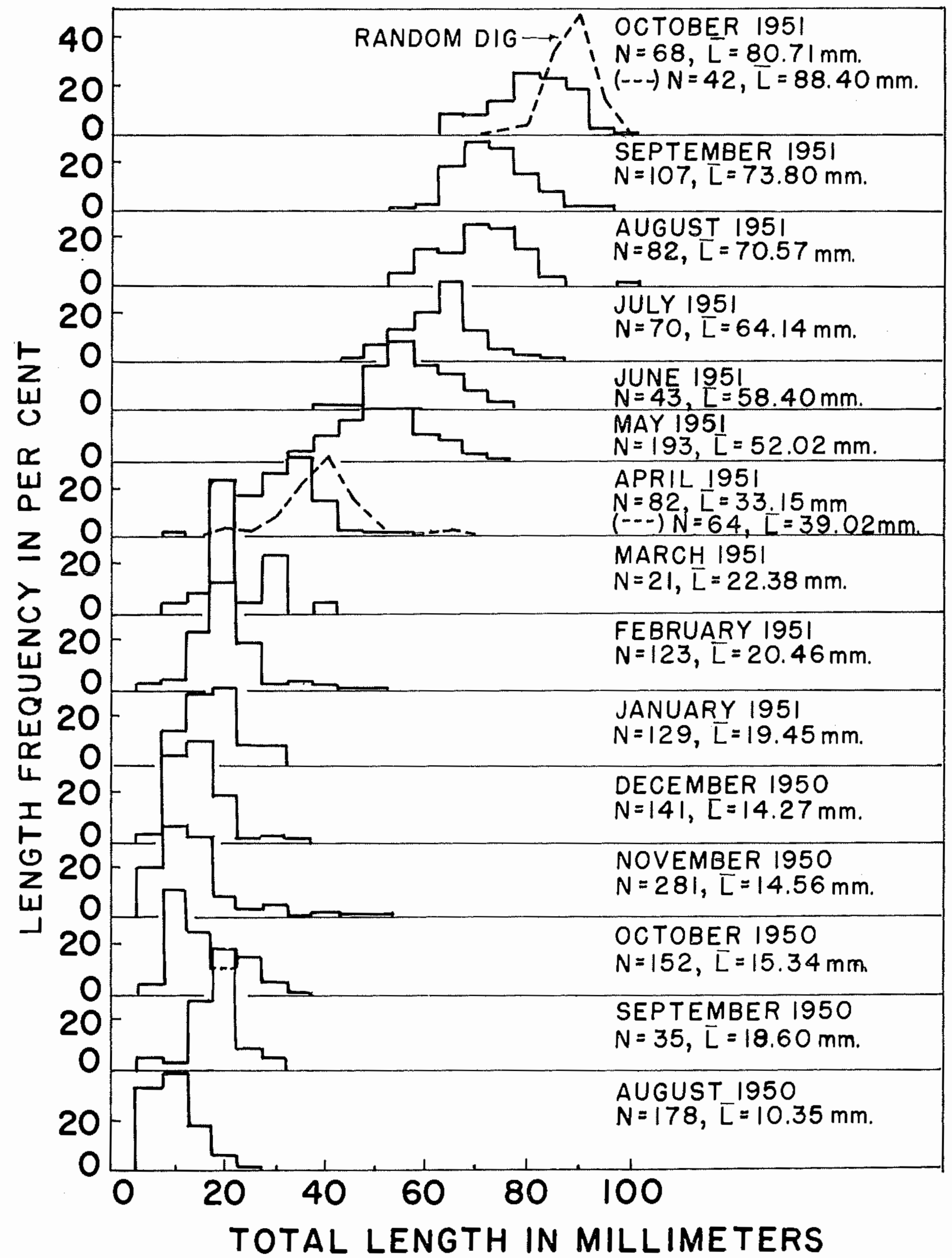

FIGURE 11. GROWTH OF THE 1950 YEAR CLASS, AUGUST 1950—OCTOBER 1951, FROM CLAM SAMPLES ORIGINATING 1.3 MILES NORTH OF THE *PETER IREDALE*.

growth throughout the first full calendar year of life, the 1949 year class had considerably larger modal values of total length (100-105 mm.) than the strip-dig samples of the 1950 year classes (75-85 mm.). It will be recalled that the sequence representing first-year growth of the 1949 year class consisted of samples obtained from all areas rather than a single one. It was presumably less affected by selective digging of specific size groups than the 1950 year-class sequence. Therefore it was considered the more representative with respect to first-year linear growth.

Growth of clams by beach level was studied from strip-dig samples obtained 1.3 miles north of the *Peter Iredale* between June and October 1951. Figure 12 shows the length-frequency distributions of clams from successive 10-meter sections west of a reference stake on the low-tide terrace. During this period all sections were not equally accessible, due to changes in beach contour and tidal conditions. Such samples as were obtained indicated a tendency toward larger shell size at lower beach levels but slopes of regression failed to reach statistically significant probability levels (less than 5 per cent) in June and October. The apparent association of better growth with distance offshore could have been due to the strip digs themselves since fast-growing animals would be more frequently exposed at upper levels and therefore more apt to be removed by diggers. The regression of total length on distance offshore failed to show statistical significance in most strip-dig samples from other areas. It should be mentioned that bars, often located considerably west of these strips and accessible to clam diggers, were not examined in this regard.

A variety of material was obtained to study differences in size composition among clams from different beaches. Extensive sampling of sport catches during two successive series of low tides in August 1954 provided the length-frequency distributions shown in Figure 13. The primary modal groups represent members of the 1953 year class in each case, illustrating the numerical importance of first-year clams to the recreational fishery. Gearhart Beach, located between Sunset Beach and Seaside, produced samples with superior growth in both tide series; their mode was 5 mm. larger than in samples from Sunset Beach and 10 mm. larger than those from Seaside. Similar differences were also apparent from samples obtained by biologists in these areas during the tide series of August 26-28, 1954. The consistently larger modal values of the sport sample, as well as a general displacement to the right of biologist-dug samples, show the emphasis on harvesting the largest clams available. A single day's sport sample (not shown in Figure 13) was obtained from the northernmost Clatsop Beach on August 13, 1954. Its modal length, 75 mm., was the smallest encountered anywhere. This further indicates that the size of first-year clams tended to decrease toward the northerly and southerly limits of Clatsop Beaches.

A similar pattern was noted in size distributions of the strip-dig samples obtained from June 7 to July 5, 1951 (Figure 14). Separation of first-year clams of the 1950 year class from older age groups is easily recognized by the discontinuity of frequency distributions near the 95 mm. interval. As with the 1953 year class, the smallest modal values were obtained in samples from Areas 1 and 5, and the largest from Area 3, while Area 2 values were intermediate. Area 4 samples displayed a pronounced bimodality in first-year clams. The smaller modal group was associated primarily with lower beach levels and the larger mainly with

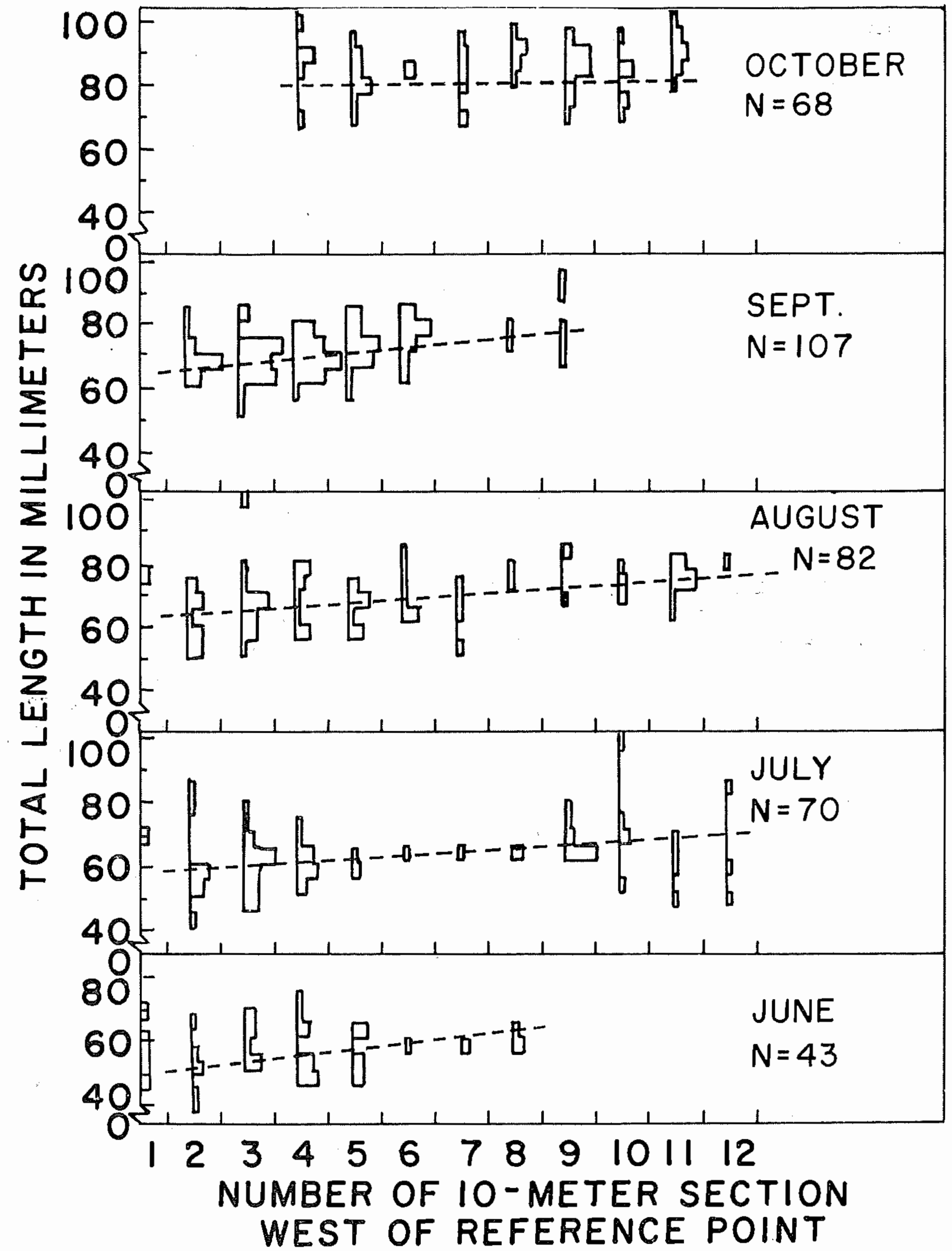

FIGURE 12. RELATIONSHIP BETWEEN FREQUENCY DISTRIBUTION OF CLAM TOTAL LENGTH AND BEACH LEVEL, JUNE-OCTOBER 1951, FROM SAMPLES DUG 1.3 MILES NORTH OF THE *PETER IREDALE*.

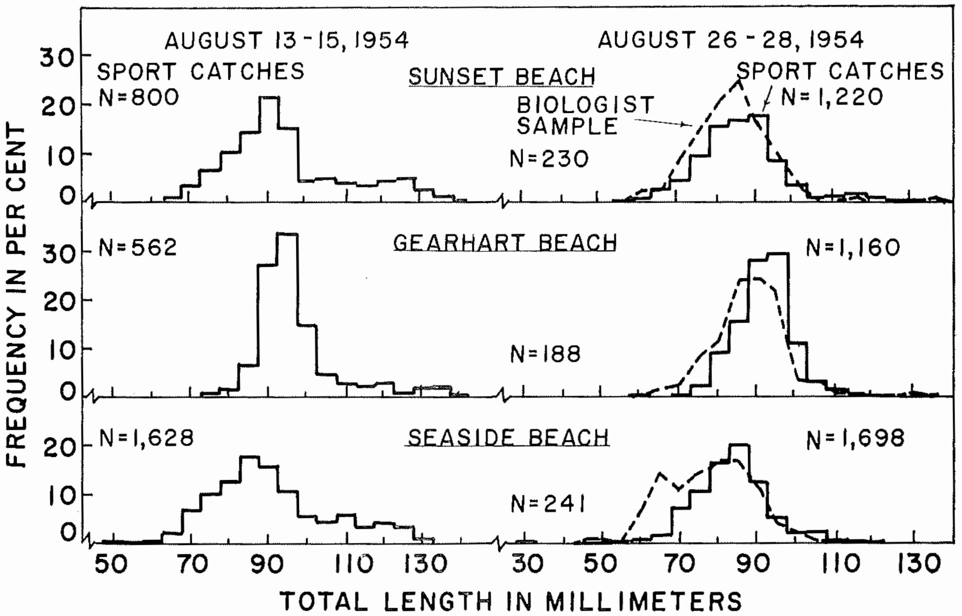

FIGURE 13. COMPARISON OF THE SIZE COMPOSITION OF RAZOR CLAM SPORT CATCHES AND BIOLOGIST SAMPLES DURING TWO SUCCESSIVE TIDE SERIES (AUGUST 1954) AT SUNSET, GEARHART, AND SEASIDE BEACHES.

inshore sections of the strip. This stratification suggested that size differences were due to unequal dates of set. The samples shown in Figure 14 indicate that first-year clams began to reach 89 mm. or 3.5 inches as early as June of the year following set.

Superior growth was also noted in commercial shell samples of second-year clams from Area 3, collected in June 1953. Areas 1 and 5 again produced the lowest mean and modal values of total length (no sample from Area 4 was available). The variation in size of second-year clams on 5 consecutive days (June 9-13) at Seaside Beach was examined in commercial shell samples. Although the daily means of total length varied by only 3 mm., two modal shifts between 105 and 110 mm. occurred, and statistical tests indicated significant differences between days.

The growth differences between areas are of particular interest in connection with the recreational fishery for first-year clams, most of which are discarded because they are too small to be handled. Measurable discarded clams were found to be predominantly less than 3 inches. Holes dug in areas frequented almost exclusively by recreational diggers showed that up to 40 per cent contained dead clams, or parts thereof. Although wastage is sometimes attributable to lack of skill, small clams are often discarded after having been retrieved from the sand. From this standpoint, wastage may be less critical in areas of relatively fast first-year growth since here first-year clams remain small for a shorter period than in areas of slow growth. The commercial catches were also subject to sorting by size since the 3.5-inch minimum size rendered many clams vulnerable to this fishery by August of their first year of age. However,

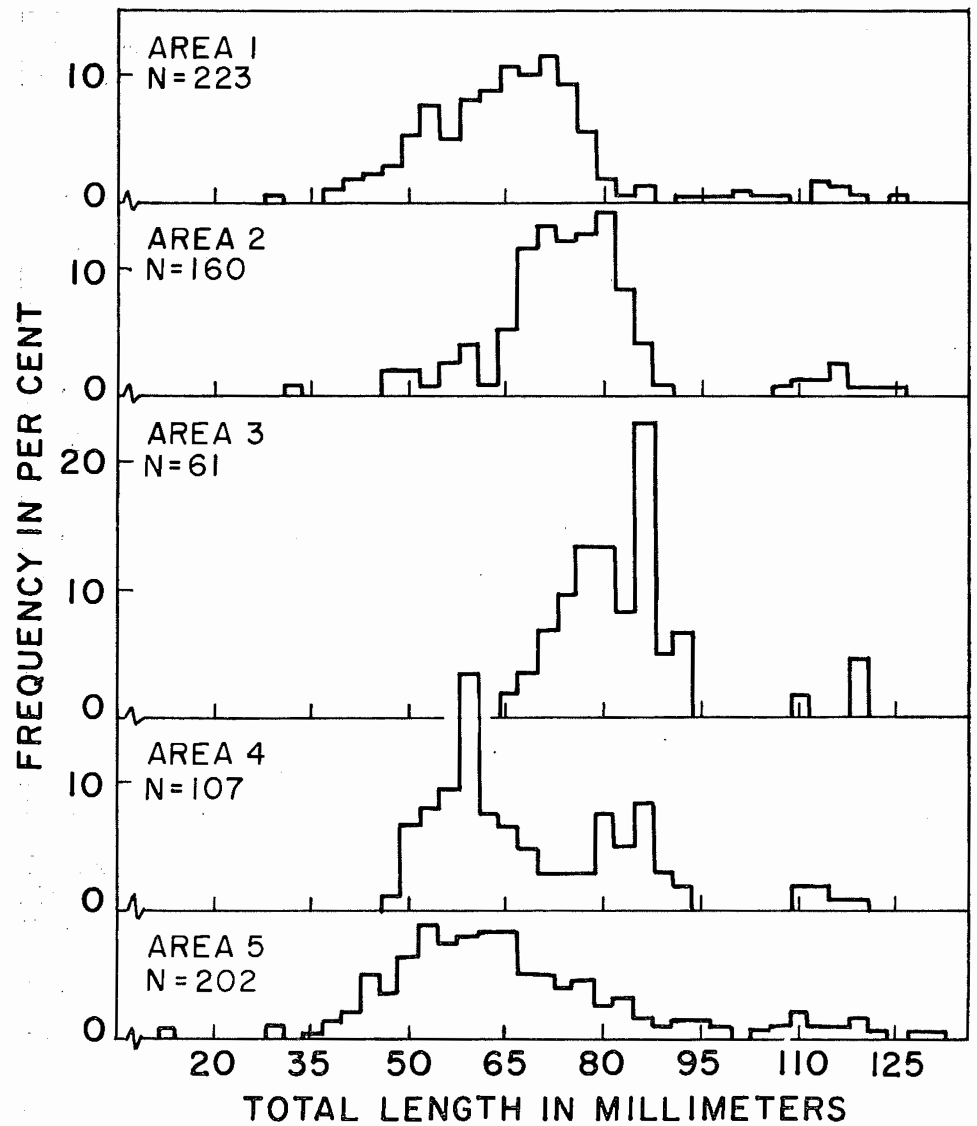

FIGURE 14. COMPARISON OF SIZE COMPOSITION OF RAZOR CLAMS FROM STRIP DIGS (JUNE 17—JULY 5, 1951) IN FIVE SUBAREAS OF CLATSOP BEACHES.

the peak months of commercial clamming are usually April and May. During this period commercial diggers avoid areas in which undersized, first-year clams predominate. They often replace undersized clams in the sand after sorting. Because of the diggers' skill, fewer shells are broken and the chances for survival improved.

Area differences were also studied from ring lengths. For this purpose, all commercial shell samples identifiable as to the area of origin were used. Table 2 shows length data for rings 0 to 5 in Clatsop Beach clams from Areas 1 to 5 for 1945-52 year classes combined. No single area produced differences consistent for all ring lengths, although Area 3 indicated higher values for the higher-numbered rings than did the others. However, this difference was obtained from rather small samples. The first- and second-ring values obtained for Area 5 were generally lower than for Areas 1-4 based on a comparison of 979 and 512 ring measurements, respectively. In general, the variation of mean ring lengths between areas seemed too irregular and too small to warrant treating each area separately.

The ring length measurements on which area comparisons were based were rearranged by year class in Table 3. No consistent differences were apparent between year classes. The standard deviations associated with the mean lengths of the 0-ring substantially exceeded those of higher-numbered rings, both in absolute value and as fractions of mean ring length. The lack of definition in the 0-ring and method of selection with respect to established criteria have been described earlier. This ring was therefore excluded from formal age-length descriptions. The last two columns of Table 3 show the ring lengths (l_1 to l_5) and their differences, as calculated according to the growth equation of von Bertalanffy (1951). The calculated values of the four ring lengths following l_1 differ but little from the actual ring length means and suggest that deceleration of linear growth is fairly constant after completion of the first full calendar year of life.

A back-calculation to estimate total length one year prior to l_1 formation by the von Bertalanffy formula resulted in a value nearly double that observed for l_0, and the time at which the calculated length equals zero would have preceded that of l_1 formation by two years. Both of these values were contrary to experience. First-year growth as observed on Clatsop Beaches was much more rapid than predicted by the von Bertalanffy equation.

The very pronounced gains in total length in the spring following the set of the 1949 and 1950 year classes (Figures 8 and 11) suggest that a point of inflection in linear growth had been reached prior to l_1 formation. The presence of such a point has been amply demonstrated by Weymouth and McMillin (1931) for Alaskan clam populations but was not noted in their studies of early growth of clams on Washington beaches. Length-on-age relationships containing a point of inflection were considered as a distinct growth type by von Bertalanffy (1951), characteristic of isometrically growing animal species whose growth pattern is neither mass-dependent nor surface-dependent but intermediate between the two.

Ring lengths by year class were also examined with respect to variation of the sample means (Table 4). Comparing the corresponding values of standard deviation in Tables 3 and 4, those of the sample means appear to be much larger than expected under conditions of statistical homogeneity. As a result, sample means of ring length appeared to be preferable to arithmetic means; the unweighted row means in Table 4 were considered the most appropriate description of ring length in the presence of variations which, it is believed, were largely independent of sample size and unassessable within the scope of this study. The von Bertalanffy parameter K (= 0.59) was estimated from the regression of $\bar{\bar{l}}_{t+1}$ on $\bar{\bar{l}}_t$ (Walford, 1946), with values of $\bar{\bar{l}}_0$ excluded.

TABLE 2. **RING LENGTH DATA FOR CLATSOP BEACH RAZOR CLAMS BY AREA, YEAR CLASSES 1945-52 COMBINED.**

Ring	*AREA* 1	2	3	4	5	*Area Unknown*	*Total Sample*
0–Ring							
M.L.[1] (mm.)	....	....	37.14	....	....	28.64	28.70
s[2] (mm.)	....	....	16.08	....	....	12.59	12.63
n[3]	....	....	7	....	....	952	959
1–Ring							
M.L. (mm.)	98.19	95.06	95.78	90.67	92.72	95.01	94.63
s (mm.)	9.06	4.38	8.59	9.46	7.66	10.27	9.53
n	108	54	271	89	457	1,351	2,330
2–Ring							
M.L. (mm.)	115.83	120.50	117.74	115.91	112.71	115.99	115.89
s (mm.)	4.28	1.50	6.13	4.85	4.97	6.55	6.12
n	108	4	222	32	146	428	940
3–Ring							
M.L. (mm.)	125.79	....	130.40	127.00	128.00	128.84	128.03
s (mm.)	3.89	....	5.05	....	4.32	6.23	5.78
n	42	....	53	1	7	157	260
4–Ring							
M.L. (mm.)	131.58	....	137.48	134.00	132.25	132.80	133.93
s (mm.)	4.01	....	3.83	....	2.24	4.11	4.48
n	12	....	21	1	4	35	73
5–Ring							
M.L. (mm.)	....	....	142.50	138.00	....	139.86	140.20
s (mm.)	....	....	0.70	....	....	4.74	4.11
n	....	....	2	1	....	7	10

[1] Mean length.
[2] Standard deviation.
[3] Number of clams measured.

TABLE 3. **DATA ON RING LENGTHS OF CLATSOP BEACH RAZOR CLAMS FOR YEAR CLASSES 1945 TO 1952, AREAS COMBINED.**

Ring	*YEAR CLASS* 1945	1946	1947	1948	1949	1950	1951	1952	*Total*	*Calculated Ring Length*[1]	*Calculated Annual Growth*
0–Ring											
M.L.[2] (mm.)	—	—	—	32.88	30.26	23.88	30.50	—	28.70	—	—
s[3] (mm.)	—	—	—	14.03	12.58	10.96	11.02	—	12.63	—	—
n[4]	—	—	—	91	574	272	22	—	959	—	—
1–Ring											
M.L. (mm.)	90.0	89.29	92.78	91.79	96.78	95.17	96.08	88.89	94.63	(94.63)	20.85
s (mm.)	6.22	5.60	7.68	9.19	3.49	6.78	8.96	7.29	9.53	—	—
n	17	97	109	206	799	392	491	219	2,330	—	—
2–Ring											
M.L. (mm.)	113.41	109.86	113.95	118.26	120.88	119.20	113.82	118.00	115.89	115.48	12.40
s (mm.)	4.14	5.28	4.77	6.31	6.29	4.49	5.27	5.60	6.12	—	—
n	17	97	62	169	107	150	334	4	940	—	—
3–Ring											
M.L. (mm.)	123.82	124.34	126.64	128.70	131.46	126.44	127.59	—	128.03	127.88	7.37
s (mm.)	3.00	4.57	4.15	3.57	6.85	4.01	3.98	—	5.78	—	—
n	17	32	39	27	87	41	17	—	260	—	—
4–Ring											
M.L. (mm.)	135.00	132.59	136.00	137.40	131.58	135.22	—	—	133.93	135.25	4.39
s (mm.)	2.65	4.19	1.41	3.87	4.01	4.58	—	—	4.48	—	—
n	3	32	2	15	12	9	—	—	73	—	—
5–Ring											
M.L. (mm.)	141.00	139.00	142.50	138.00	—	—	—	—	140.20	139.64	—
s (mm.)	2.00	2.00	0.70	—	—	—	—	—	4.11	—	—
n	3	4	2	1	—	—	—	—	10	—	—

[1] By the von Bertalanffy equation: $l_t = 146.06 - (146.06 - 94.63)e^{-0.52t}$
[2] Mean length.
[3] Standard deviation.
[4] Number of clams measured.

TABLE 4. **DATA ON RING LENGTH SAMPLE MEANS OF CLATSOP BEACH RAZOR CLAMS FOR YEAR CLASSES 1945 TO 1952, AREAS COMBINED.**

Ring	*YEAR CLASS* 1945	1946	1947	1948	1949	1950	1951	1952	*Unweighted Row Means*	*Calculated Ring Lengths* ①	*Differences Calculated Between Ring Lengths*
$\bar{\bar{l}}_0$ ②	....	....	....	33.50	30.38	26.04	30.50	....	30.11	....	....
s③	....	....	....	4.70	3.26	9.87	....	....	....	....	....
n④	....	....	....	8	10	8	1	....	....	....	....
$\bar{\bar{l}}_1$	86.73	89.20	93.17	92.87	95.48	95.02	94.57	89.56	92.09	(92.09)	....
s	5.73	3.08	5.72	3.88	2.85	2.56	4.90	7.14	....	....	....
n	6	12	12	15	17	15	12	5	....	....	23.24
$\bar{\bar{l}}_2$	111.88	110.08	113.53	118.56	120.57	118.26	114.03	117.50	115.55	115.32	....
s	2.49	3.66	4.25	1.81	2.39	2.21	2.50	6.71	....	....	....
n	6	12	8	14	8	10	9	3	....	....	12.88
$\bar{\bar{l}}_3$	124.16	125.84	126.03	128.34	130.59	128.01	127.59	....	127.22	128.20	....
s	1.95	2.67	3.58	1.87	3.50	2.19	....	....	....	....	....
n	6	8	7	5	5	6	1	....	....	....	7.14
$\bar{\bar{l}}_4$	135.00	133.25	136.00	136.60	131.58	134.93	....	....	134.56	135.34	....
s	2.65	3.14	....	2.43	....	3.74	....	....	....	....	....
n	3	8	1	3	1	2	....	....	....	....	3.96
$\bar{\bar{l}}_5$	141.00	139.00	142.50	138.00	....	....	....	....	140.13	139.30	....
s	2.00	....	....	....	....	....	....	....	....	....	....
n	3	1	1	1	....	....	....	....	....	....	....

① Calculated from $l_t = 144.22 - (144.22 - 92.09)e^{-0.59t}$
② Mean of sample means of ring length in mm.
③ Standard deviation in mm.
④ Number of samples.

Seasonal variations in growth were noted earlier with respect to weight at constant levels of shell length (Figure 4) and also in linear growth of the 1949 and 1950 year classes from monthly samples. A general description of seasonal growth involving first-year total length measurements was considered undesirable because both methods of obtaining clams (screening and digging) were probably selective within the size range of first-year clams. Marginal increments seemed to hold more promise, and were measured in 79 separate samples containing 2,420 shells of clams in their second, third, and fourth calendar year of life. Increments based on the 0-ring were excluded for reasons discussed earlier.

Table 5 contains the means of the marginal increments of 1-, 2-, and 3-ring razor clams from Clatsop Beaches, expressed in millimeters. In the upper part of the table these are weighted by the total number of individuals measured ($\overline{\text{M. I.}}$), while averages of sample means are given in the lower part ($\overline{\overline{\text{M. I.}}}$). The measurements were grouped into 1.5-month intervals to permit comparisons on a uniform basis. The variation of means throughout the year followed a pattern similar to that of total length in first-year clams in that the largest increase was observed during the spring months, and reductions of growth rate were apparent both in mid-summer and the last 3 months of the year. A comparison of corresponding weighted and unweighted mean values in Table 5 shows fair agreement, but as in an earlier comparison of estimates of ring length, the variability of the unweighted means is relatively large. In expressing seasonal growth as fractions of total annual growth, the latter is represented here (separately for each age group) by the differences between the means of successive ring lengths as calculated by the von Bertalanffy formula and included in Table 5. The growth gains attained on similar dates are sufficiently alike in the three ring groups to be practically described by average values given in the last two rows of Table 5. The lowest line of the table contains the relative marginal increments used in the estimation of yields of clams—the subject of a later section.

RELATIVE WIDTH

The general relationship between width and length in razor clams was described by Weymouth and McMillin (1931) from shell collections in California, Washington, and Alaska. Width was shown to be variably allometric with respect to length, the width-to-length ratio falling rapidly to a minimum of 0.358 when total length reaches 40 mm. and increasing thereafter until at near-maximal sizes it reaches 0.435. A gradual change from negative to positive allometry of width was noted as the near-maximal values of length were approached. In the present study, the ratio of width to length was examined and, as indicated by Weymouth and McMillin (1931), found highly variable at all levels of length. In clams of similar total length, the mean of this ratio was found to increase in all groups examined (80-140 mm., at 10 mm. levels) between April 1 and July 1. A similar result was obtained when size was not held constant but chosen

TABLE 5. **ARITHMETIC AND SAMPLE MEANS OF THE MARGINAL INCREMENT OF ONE-, TWO-, AND THREE-RING RAZOR CLAMS FROM CLATSOP BEACHES, EXPRESSED IN MILLIMETERS AND AS PER CENT OF CALCULATED ANNUAL GROWTH.**

Difference Between Total Length and		*1.5-Month Interval Midpoints*								*Calculated Differences Between Means of Successive Ring Lengths*	
		Feb. 15	*Apr. 1*	*May 15*	*July 1*	*Aug. 15*	*Oct. 1*	*Nov. 15*	*Jan. 1*	$\bar{l}_t - \bar{l}_{t-1}$ ①	$\bar{\bar{l}}_t - \bar{\bar{l}}_{t-1}$ ②
1–Ring ($\bar{l}_1$):	$\overline{\text{M.I.}}$③	2.21	7.37	13.77	18.62	16.38	20.55	22.13	22.70	20.96	....
	Standard Deviation (mm.)	2.94	2.68	3.80	4.17	5.06	7.22	6.69	9.15	....	....
	Number Measured	150	400	455	233	248	31	30	23	....	....
2–Ring ($\bar{l}_2$):	$\overline{\text{M.I.}}$	0.15	3.77	6.52	8.67	8.97	10.91	11.85	12.47	12.43	....
	Standard Deviation (mm.)	0.71	2.31	2.17	2.22	2.55	2.09	3.18	1.00	....	....
	Number Measured	97	106	268	24	73	32	26	16	....	....
3–Ring ($\bar{l}_3$):	$\overline{\text{M.I.}}$	0.57	1.90	3.81	5.00	5.15	5.81	5.86	6.67	7.37	....
	Standard Deviation (mm.)	1.10	1.33	1.15	0.00	1.50	1.69	1.94	1.52	....	....
	Number Measured	73	42	32	3	20	21	22	3	....	....
1–Ring ($\bar{\bar{l}}_1$):	$\overline{\overline{\text{M.I.}}}$	3.24	7.49	13.75	18.50	17.54	21.88	23.59	23.94	....	23.19
	Standard Deviation (mm.)	3.51	1.64	1.23	2.30	2.76	4.98	4.24	8.11	....	....
	Number of Samples	3	4	6	4	4	3	4	2	....	....
2–Ring ($\bar{\bar{l}}_2$):	$\overline{\overline{\text{M.I.}}}$	1.28	4.14	6.63	8.75	8.98	11.77	11.68	11.59	....	12.87
	Standard Deviation (mm.)	1.22	0.75	0.77	0.84	1.18	2.45	0.63	2.30	....	....
	Number of Samples	4	4	7	2	4	2	2	3	....	....
3–Ring ($\bar{\bar{l}}_3$):	$\overline{\overline{\text{M.I.}}}$	0.82	2.00	2.88	5.00	5.23	5.94	6.13	6.67	....	7.15
	Standard Deviation (mm.)	1.24	0.22	0.85	....	0.14	0.77	0.81	1.52	....	....
	Number of Samples	3	3	4	1	2	2	3	3	....	....
M.I. as Per Cent Total Annual Growth:											
Based on Arithmetic Means		6.5	30.5	56.8	75.7	73.6	88.5	93.7	100.0	....	....
Based on Sample Means		11.8④	30.8	50.3	72.5	72.8	89.6	92.7	95.4	....	....

① $\bar{l}_t = 146.06 - (146.06 - 94.63)e^{-0.52t}$ of Table 3.

② $\bar{\bar{l}}_t = 144.22 - (146.22 - 92.08)e^{-0.59t}$ of Table 4.

③ M.I. = Marginal increment in millimeters.

④ $11.8\% = \frac{1}{3}\left[\frac{3.24}{23.24} + \frac{1.28}{12.88} + \frac{0.82}{7.14}\right] \times 100$

so as to represent growth at successive ⅓-year intervals of age (Table 6). Figure 15 contains the means (smoothed by 3's) of this ratio obtained from 442 shells during the time intervals and ages indicated. Comparing the absolute values of the ratio on similar nominal sampling dates, an increase with age and length is noted in nearly all cases. Fifth-year data (not shown in Figure 15 but included in Table 6) were similar to those of the fourth-year group. All age groups showed an increase in relative width between April 1 and July 1 and a decrease between November 15 and February 15, suggesting the occurrence of seasonal changes in relative width, superimposed as it were on the general pattern of width-on-length variation described in the work of Weymouth and McMillin (1931).

A comparison of relative width and linear growth—as expressed by the per cent marginal increment in Figure 15—shows that the largest seasonal increases in both quantities occurred between March and July. Favorable environmental conditions during this period were indicated by maximal increases of water temperature as recorded at the Seaside Aquarium. Unfavorable conditions, as reflected by low water temperatures, on the other hand were associated with changes in length and relative width which proceeded in essentially opposite directions. This negative association appeared to be most pronounced between November and February, coinciding with the annual ring formation discussed in a previous section.① The midsummer retardation of length gains, noticeable in all age groups, was accompanied by comparative stability in relative width and, as shown in Figure 4, by the restoration of earlier weight loss due to spawning. No evidence of ring formation was found during this period, although the reduction of linear growth in July and August appeared to be rather distinct; nor did the positive association between growth in length and relative width between March and July appear to be affected by the spawning activities. Thus, formation of rings seems to coincide with negatively allometric changes in width as well as with reduction in linear growth and annual temperature minima.

AGE-LENGTH AND AGE-WEIGHT

As shown in Table 4, the von Bertalanffy formula $l_t = 144.22 - (144.22-92.09)e^{-0.59t}$ provided a close approximation of shell length means during successive periods of annual ring formation, beginning with that of the winter ending the first full calendar year of growth. However, seasonal variations during the remainder of the year were considered too large to be adequately described by interpolations based on this formula. Consequently, the observed seasonal pattern was incorporated in the description of length on age by adding the appropriate calculated

① The extreme elongation of the shell following the set of juvenile clams, as shown by Weymouth and McMillin (1931), may have survival value since vertical movement is facilitated by the narrowness of the shell (Yonge, 1952). Consequently the ability of juvenile clams to withdraw from the top layers of sand is likely to be enhanced by the negative allometry of shell width during the critical period of beach erosion.

TABLE 6. **SEASONAL VARIATIONS IN LENGTH AND RELATIVE SHELL WIDTH OF CLATSOP BEACH RAZOR CLAMS AT SUCCESSIVE ⅛-YEAR INTERVALS OF AGE.**

Nominal Date (i)	Calculated Length at Age i (mm.)	Length Range of Sample (mm.)	Number of Clams Measured	Ratio of Width to Length: Mean	Ratio of Width to Length: Range	Ratio of Width to Length: Standard Deviation	Means Smoothed by 3's
Year 1							
Aug. 15	82.0	81–83	22	.385	.341–.422	.018	....
Oct. 1	89.6	88–91	14	.381	.353–.398	.012	.382
Nov. 15	91.6	90–93	17	.381	.323–.419	.021	.387
Year 2							
Jan. 1	92.1	89–95	7	.398	.379–.433	.019	.390
Feb. 15	94.8	93–97	11	.390	.366–.404	.011	.391
Apr. 1	99.2	98–100	21	.385	.367–.410	.012	.389
May 15	104.8	104–106	15	.392	.381–.410	.009	.393
July 1	108.9	108–110	12	.408	.382–.426	.015	.401
Aug. 15	109.0	108–110	14	.403	.373–.427	.016	.404
Oct. 1	112.9	111–115	5	.400	.378–.426	.023	.402
Nov. 15	113.6	112–115	22	.402	.366–.429	.017	.404
Year 3							
Jan. 1	115.3	113–117	7	.411	.388–.444	.021	.401
Feb. 15	116.8	115–119	10	.391	.353–.427	.025	.400
Apr. 1	119.3	117–121	10	.398	.381–.415	.010	.400
May 15	122.4	122–123	26	.410	.382–.431	.013	.407
July 1	124.6	125–126	11	.412	.384–.432	.015	.414
Aug. 15	124.7	124–126	9	.420	.392–.440	.018	.416
Oct. 1	126.8	125–129	11	.416	.395–.452	.015	.416
Nov. 15	127.2	126–128	19	.412	.365–.449	.019	.416
Year 4							
Jan. 1	128.1	126–130	7	.420	.409–.438	.011	.414
Feb. 15	128.9	127–131	9	.410	.395–.426	.010	.411
Apr. 1	130.3	128–132	6	.404	.379–.419	.015	.410
May 15	132.0	131–133	17	.417	.379–.447	.018	.416
July 1	133.3	132–135	17	.426	.396–.452	.017	.421
Aug. 15	133.3	131–135	5	.419	.405–.435	.014	.421
Oct. 1	134.5	133–136	7	.417	.397–.441	.016	.418
Nov. 15	134.7	132–137	22	.418	.385–.449	.018	.415
Year 5							
Jan. 1	135.3	133-137	11	.411	.364–.438	.025	.411
Feb. 15	135.8	134–138	5	.405	.382–.449	.027	.406
Apr. 1	136.5	134–139	8	.403	.385–.424	.011	.406
May 15	137.5	136–139	14	.410	.391–.428	.011	.414
July 1	138.2	136–140	21	.429	.388–.457	.017	.424
Aug. 15	138.2	138–139	2	.434	.432–.435	.002	.425
Oct. 1	138.9	137–141	7	.411	.383–.441	.020	.422
Nov. 15	139.0	137–141	10	.422	.409–.438	.010	.412
Jan. 1	139.3	137–141	4	.403	.380–.426	.019	....

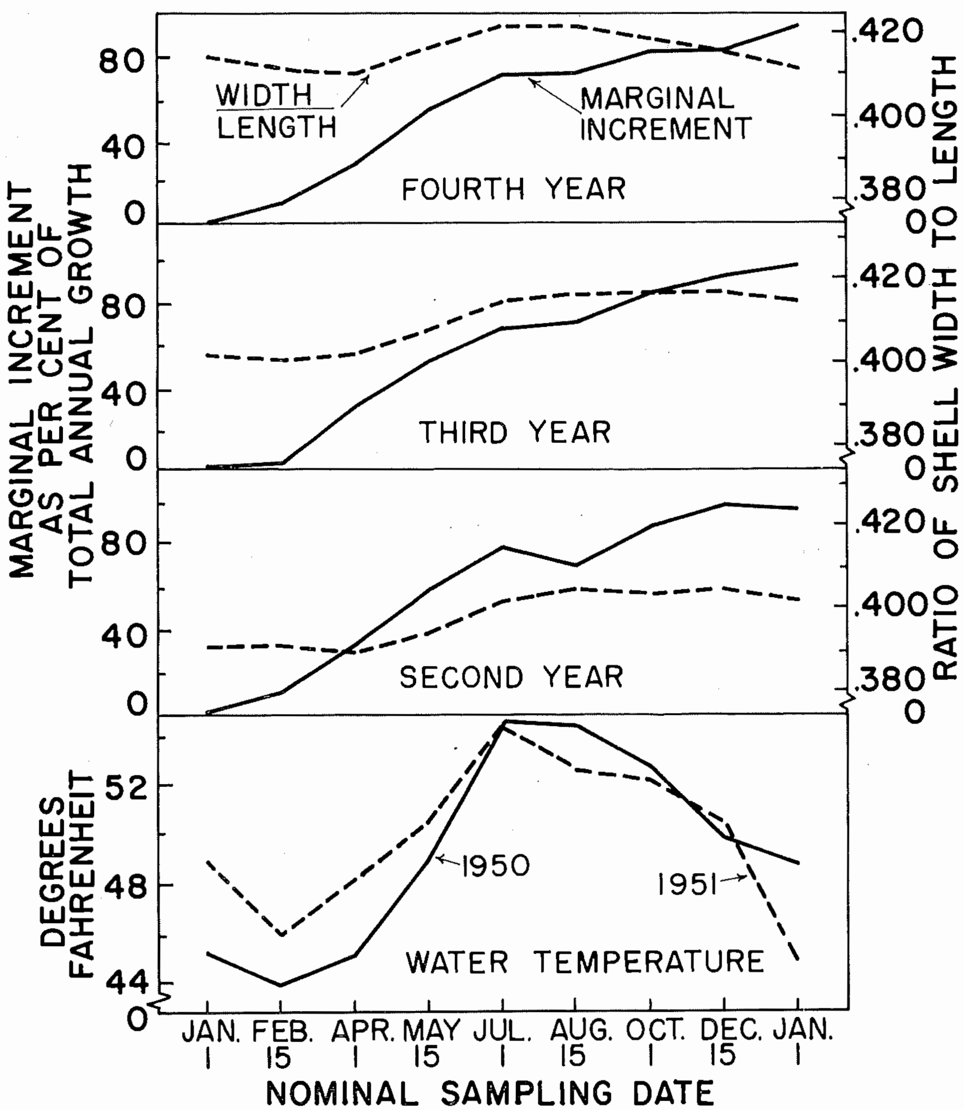

FIGURE 15. SEASONAL VARIATIONS OF WATER TEMPERATURE, LINEAR GROWTH, AND RELATIVE SHELL WIDTH OF CLATSOP BEACH RAZOR CLAMS.

values of marginal increment to those of ring length as obtained by the von Bertalanffy formula.[1]

Table 7, which contains the calculated values of length (in millimeters) and weight (in grams) of razor clams from Clatsop Beaches, includes estimates obtained without reference to the von Bertalanffy formula for the latter half of the first year. These are means of total length obtained from samples dug by biologists during the 1.5-month intervals

[1] These values were used in Table 6, to show the variation of width on "representative" lengths at successive ⅛-year intervals of age.

TABLE 7. **ESTIMATED TOTAL LENGTH AND WEIGHT ON AGE FOR RAZOR CLAM POPULATION OF CLATSOP BEACHES.**

Completed Calendar Years of Age (i)	*Nominal Date*	*Ring Length (mm.)*	*Calculated Total Length (mm.)*	*Calculated Weight (grams)*
0	July 1		75.9①	25.3
	Aug. 15		82.0①	36.8
	Oct. 1		89.6①	42.8
	Nov. 15		91.6①	42.2
1	Jan. 1	92.1	92.1	44.1
	Feb. 15		94.8	48.1
	April 1		99.2	57.4
	May 15		104.8	73.8
	July 1		108.9	79.4
	Aug. 15		109.0	88.6
	Oct. 1		112.9	90.6
	Nov. 15		113.6	91.0
2	Jan. 1	115.3	115.3	92.4
	Feb. 15		116.8	93.9
	April 1		119.3	109.3
	May 15		122.4	123.0
	July 1		124.6	121.6
	Aug. 15		124.7	134.4
	Oct. 1		126.8	132.1
	Nov. 15		127.2	131.3
3	Jan. 1	128.1	128.1	130.6
	Feb. 15		128.9	128.0
	April 1		130.3	148.9
	May 15		132.0	157.6
	July 1		133.3	150.6
	Aug. 15		133.3	165.1
	Oct. 1		134.5	160.0
	Nov. 15		134.7	158.0
4	Jan. 1	135.3	135.3	156.4
	Feb. 15		135.8	150.9
	April 1		136.5	175.1
	May 15		137.5	180.3
	July 1		138.2	168.8
	Aug. 15		138.2	184.7
	Oct. 1		138.9	177.6
	Nov. 15		139.0	174.9
5	Jan. 1	139.3	139.3	172.1

① Total length means of samples dug by biologists.

indicated. Several difficulties prevented a complete description of first-year growth. The zero ring, formed in the winter of the year of set, was too variable and in many cases too indistinct to estimate seasonal changes of total length from marginal increments based on this ring. (As shown in Table 4, the mean of the zero rings measured was 30.11 mm.) Also, both of the available methods of capture, i.e., screening and digging, were probably size-selective on clams between 30 and 60 mm.

The weights shown in Table 7 were calculated from the seasonal length-weight regressions presented earlier (Table 1). January 1 estimates by the von Bertalanffy formula resulted in parameters $K = 0.58$ and $W_{\infty} = 193.4$ grams ($w_0 = 44.1$ grams), K being similar in value to that based on the sample means of ring length (Table 4). It is apparent from the magnitudes of l_0 and w_0 that these parameters leave a substantial part of the growth curve undescribed. However, use of the von Bertalanffy expression seems acceptable where it provides a satisfactory fit of observed data, as pointed out by Ricker (1958).

The fact that first-year clams average less than 3 inches, or 76 mm., prior to July (Table 7) suggests that the abundance of any year class is reduced by wastage during most of its first calendar year since the recreational fishery displays a marked preference for clams over 3 inches in length. Before autumn, the mean length of this age group was still smaller than 3.5 inches (89 mm.), but even during the latter part of the year substantial proportions of first-year clams remained liable to wasteful selection because of the large size range of clams in their first year.

Table 7 also indicates a 3-fold increase in weight between July 1 of the first and second years of age (25.3 to 79.4 grams). The larger weight was considered satisfactory by both the recreational and commercial fishery. This weight increase appeared so large that only high natural mortality rates could prevent a gain in total harvestable weight by deferring for one year the digging of first-year clams. Consequently, the estimation of mortality rates was the subject of additional studies.

MORTALITY RATES

Digger counts on all parts of Clatsop Beaches in 1949, 1950, and 1951 indicated that Seaside Beach was the most heavily frequented; nearly half of the 22,000 diggers observed on all beaches were in this area which comprises only one-tenth of the total beach length. Although no distinction could be made between commercial and recreational diggers, counts strongly suggested that Seaside Beach was the most productive area, and potentially best suited for estimating mortality rates by the marking method. Only 2 miles long, this beach allowed close monitoring of both fisheries while the proximity of the Seaside Aquarium facilitated the marking, holding, and speedy liberation of relatively large numbers of clams at one time.

The marking program included the serial numbering of 3,379 razor clams between May 10, 1952 and August 26, 1953, and their liberation in 9 series of plants. Over the census period, the number of commercially harvested members, marked and unmarked, of the 1950 and older year classes was estimated from extensive catch sampling. The number of marks recovered by recreational diggers was estimated primarily from questionnaire returns since personal interviews were too time consuming. The reportability of marks was examined in both fisheries, leading to adjustments of the actual numbers of marks reported. The reduction in abundance of the 1950 and earlier year classes during the 1952 and 1953 seasons was estimated from the differences between population estimates obtained from commercial catch sample data and corrected for incomplete reporting of marked recoveries.

The selection of clams for marking was based on the physical condition and total length (over 3.5 inches) of commercially harvested clams shortly after they had been dug. The clams were marked serially on both shells with a conical carborundum tip driven by a small, portable electric power tool. Most marked clams were in their second year of age and measured 105-115 mm. Below this size, the thinner shells were more easily injured during the marking process, while larger individuals were only infrequently encountered. Following the engraving of serial numbers, the clams were held at the Seaside Aquarium for 1-3 days prior to release. They were placed in a wooden live box (measuring about 5 x 2.5 x 3 feet) containing an 18-inch layer of sand over which filtered sea water, pumped once daily and recirculated through the entire aquarium, was passed. Water entering the live box was aerated by jets attached to the intake and returned to the aquarium supply through an overflow pipe. Detritus on top of the sand layer was frequently siphoned off and the sand itself agitated between holding periods. This method of holding clams was adopted after confinement in the intertidal zone had been attempted in wire cages and lined crab pots and resulted in near total mortality.

Most clams were planted 1 day after marking, but at times of short supply they were accumulated for 2 or 3 days. Marked clams removed in lots of 20 from the live box in acceptable condition were placed in small wooden boxes lined and covered with wet burlap. These were taken to Seaside Beach and transferred to the planting teams. The planter placed the marked clams in holes 6-8 inches deep, observing each marked clam until it withdrew from sight. The recorder noted the condition of each marked clam and its serial number in the same sequence as that of release. The starting and finishing positions, identified by permanent reference stakes or other landmarks, as well as number of steps between release points, were predetermined so that the distribution of planted marks was fairly uniform over the length of the beach. The width of the area, being naturally variable, could not be considered in a similar manner. However, the choice of days with minima or near-minima of lower low water made it generally possible to include the lowest accessible levels of the beach face in the planting area. Plants always followed the water line, beginning at the time of lower low water and ending when the shoreward limit of the digging area was reached. The location of this limit was known from experience.

The effect of the marking process was evaluated from the difference in survival between marked and unmarked lots of 15 clams each held at Seaside Aquarium for 125 days. Table 8 shows that 11 unmarked and 10 marked clams survived at the conclusion of the experiment. The total mortality (9 out of 30) was considered to be due primarily to complete removal of both lots on 8 occasions following the marking of the test lot. The low mortality (1 out of 30) observed on the second day after marking suggested that the marking process itself, including handling, would not materially alter the natural survival of marked clams in actual releases.

TABLE 8. **SURVIVAL OF MARKED AND UNMARKED RAZOR CLAMS HELD AT SEASIDE AQUARIUM, JULY 5–NOVEMBER 7, 1952.**

No. of Days Held	*No. of Unmarked Clams*		*No. of Marked Clams*		*Total Clams*	
	Alive	*Dead*	*Alive*	*Dead*	*Alive*	*Dead*
0	15	0	15	0	30	0
2	14	1	15	0	29	1
6	13	2	14	1	27	3
18	12	3	14	1	26	4
33	12	3	12	3	24	6
65	12	3	11	4	23	7
80	12	3	10	5	22	8
88	11	4	10	5	21	9
125	11	4	10	5	21	9

The effect of condition at release on the survival of marked clams was tested by comparing the proportions of marks recovered according to the following classification at time of release:

1—No visible defects
2—Shell chipped at the margin
3—Adnation of shell and mantle partially severed
4—2 and 3 combined

Marked clams showing other types of damage were not released. Table 9 shows that in all but 1 of the releases, the proportions recovered were not demonstrably different (at the 5 per cent level) by condition of release. It was observed that in recovered marks with broken shells a layer of nacre had formed over the broken area internally, often covering impurities such as grains of sand; the nacre was present even in clams at liberty only a few days. Areas of severed adnation did not heal and were considered a more critical impairment than minor shell fractures.

The pattern of mark distribution in relation to beach length is shown in Table 10 for each of the 9 groups of mark releases. The number of marks planted per tenth-mile indicates that a degree of uniformity was achieved. Lack of uniformity was due to differences in pacing of planters or unintentional overlapping of plants. The northward extent of the plants varied according to the amount of clam digging observed. The most northerly quarter of Seaside Beach was frequented only sporadically, and by fewer people than the remainder.

Since lateral movement is not normal in razor clams, mixing, in the conventional sense, of marked and unmarked members of a population does not occur. It was therefore of interest to examine the distribution of fishing effort on the assumption that it was governed largely by the

TABLE 9. **NUMBER OF RECOVERIES OF MARKED RAZOR CLAMS AT SEASIDE BEACH, BY CONDITION AT RELEASE, 1952–53.**

Release Number	*Date*		*Condition at Release* 1	2	3	4	*Total*	*Degrees of Freedom*	*Chi-Square*	*Probability Greater Than*
52–0	May 11–14,	Recovered	79	9	2		90			
	1952	Not Recovered	189	42	5		236			
		Total	268	51	7		326	2	3.00	0.20
52–1	June 10–11,	Recovered	74	19	9	8	110			
	1952	Not Recovered	149	46	16	14	225			
		Total	223	65	25	22	335	3	0.63	0.80
52–2	July 8–10,	Recovered	109	39	3	6	157			
	1952	Not Recovered	163	101	18	9	291			
		Total	272	140	21	15	448①	3	10.34	0.01
52–3	Aug. 7–8,	Recovered	18	20	9	16	63			
	1952	Not Recovered	53	25	23	25	126			
		Total	71	49	32	41	189	3	5.52	0.10
52–4	Sept. 3,	Recovered	75	21	5	4	105			
	1952	Not Recovered	116	38	16	11	181			
		Total	191	59	21	15	286	3	2.72	0.30
53–0	Apr. 15–16,	Recovered	76	50	12	12	150			
	1953	Not Recovered	106	85	16	23	230			
		Total	182	135	28	35	380	3	1.26	0.70
53–1	May 14–15,	Recovered	86	68	17	16	187			
	1953	Not Recovered	122	101	26	53	302			
		Total	208	169	43	69	489	3	7.78	0.05
53–2	June 29–30,	Recovered	53	43	21	36	153			
	1953	Not Recovered	112	65	42	75	294			
		Total	165	108	63	111	447②	3	2.00	0.50
53–3	Aug. 24–26,	Recovered	118	38	7	4	167			
	1953	Not Recovered	186	79	22	14	301			
		Total	304	117	29	18	468	3	3.37	0.30

① Condition at release of 11 additional marks not known.
② Condition at release of 1 additional mark not known.

TABLE 10. **DISTRIBUTION OF MARKED RAZOR CLAMS BY 0.1 MILE OF BEACH LENGTH, SEASIDE BEACH, 1952–53.**

Release		*Tenth Mile Units of Beach Length*																		*Total Clams*
Number	*Date*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R–T*	
52–0	May 11-14, 1952	17	18	18	19	18	18	17	28	24	30	28	27	27	26	11	....	....	....	326
52–1	June 10-11, 1952	20	20	19	20	20	20	28	23	28	20	20	20	20	20	20	10	7	....	335
52–2	July 8-10, 1952	45	32	32	32	32	31	29	29	26	32	32	32	32	32	11	....	....	....	459
52–3	August 7-8, 1952	12	11	12	11	12	11	12	11	12	11	12	12	13	12	13	12	....	....	189
52–4	September 3, 1952 ..	19	19	19	19	19	19	19	19	19	19	21	22	20	24	9	....	....	....	286
53–0	April 15-16, 1953	21	26	27	22	17	17	18	18	23	19	20	21	23	27	21	21	18	21	380
53–1	May 14-15, 1953	26	28	26	28	26	28	26	22	28	25	29	29	29	28	48	36	27	....	489
53–2	June 29-30, 1953	26	25	26	26	27	25	25	25	23	18	17	25	25	23	24	23	26	39	448
53–3	August 24-26, 1953 ..	25	25	28	26	26	28	26	28	25	25	28	26	29	29	27	26	28	12	467
																				$\Sigma = 3{,}379$

appearance of harvestable clams. Table 11 shows the number of diggers per tenth-mile of beach length observed during 115 clam tides in 1952 and 1953 while the marking study was in progress. Counts were made with a hand tally and tenth-mile readings were taken from the speedometer of the vehicle used. Since Twohy (1949) had found the highest digger density to be shortly before low tide, the counts were timed accordingly. They began off Avenue T, Seaside, and terminated at the mouth of the Necanicum River which bounds Seaside Beach to the north. (Avenue T was designated as the southern boundary of the commercial digging area in 1935.)

An analysis of variance test was performed on the log transforms of the counts since means and standard deviations of digger counts were found to be correlated. Significant differences between subareas (as well as tide periods) were indicated in both years; however, by eliminating subareas P-T from the analysis, probability levels slightly above 1 per cent were obtained. Thus the digger distribution on the main part of Seaside Beach was not demonstrably heterogeneous with respect to subarea.

Because the diggers often covered several subareas during one clam tide, as well as offshore bars on occasion, and the counts did not differentiate between commercial and recreational diggers, the proportion of marked clams recovered, by fishery and subarea of release, was preferable to the study of effort distribution from digger counts (Table 12). Contingency chi-square tests indicated statistical differences at the 5 per cent level in 3 of the 9 releases (52-2, 53-1, and 53-3), and at the 1 per cent level in 1 release (53-3). These results suggested there was no consistent stratification of digging by successive tenth-mile sections.

The reportability of recoveries was incomplete in both fisheries. In the commercial fishery the degree of reporting was estimated from returns of 146 test marks introduced into Seaside catches sold to local clam processors. Approximately 64 per cent were reported in each year. Some marked clams were reported to biologists on the beach or in processing plants. These were noted, returned to the catches, and treated as test marks; they were considered as actual recoveries only if again reported by the dealer after processing.

To obtain an estimate of the proportion of recoveries reported by recreational diggers, a special release of 200 marked clams was made on August 3, 1952. In alternating quarters of the area planted, all recreational diggers observed during the following 2 days were given questionnaires, while checks were made by biologists of all sport catches originating in the other two quarters. In the supervised sections, the biologists found 25 marked clams among the 243 diggers checked, while the responses from the 111 diggers receiving questionnaires indicated the recovery of 5 marked clams. Since the total number released was the same

TABLE 11. **DISTRIBUTION OF RAZOR CLAM DIGGERS BY 0.1 MILE OF BEACH LENGTH, SEASIDE BEACH, 1952–53.**

Dates	*Census Tide Number*	*Number of Counts*	*Number of Diggers by 0.1 Mile of Beach Length* A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	*S*	*T*	*Total Diggers*
1952																							
May 22–30	1	5	18	7	9	31	20	25	21	26	26	27	22	26	30	23	5	24	24	12	12	2	390
June 7– 13	2	5	13	36	43	52	109	61	41	51	40	18	57	182	79	79	46	44	50	11	19	0	1,031
June 21–24	3	3	10	26	34	27	15	5	10	27	14	21	30	22	10	10	30	12	1	0	2	0	306
July 4–14	4	10	225	165	102	66	73	156	111	112	110	194	212	137	105	133	150	87	71	41	26	16	2,292
July 19–24	5	4	73	32	11	9	27	39	69	36	58	34	35	36	29	47	58	31	21	22	11	1	679
August 4–8	6	5	41	42	30	14	35	96	103	184	87	70	38	47	33	36	49	49	6	5	8	0	973
August 16–21	7	5	25	11	18	6	26	46	71	51	56	37	31	33	19	18	44	38	11	11	5	0	557
September 2–5	8	5	28	29	13	9	14	17	33	24	32	31	24	7	5	17	12	27	4	2	1	0	329
October 1–3	10	3	25	4	13	3	9	83	86	25	4	24	37	30	34	9	7	3	4	0	0	0	400
Total		45	458	352	273	217	328	528	545	536	427	456	486	520	344	372	401	315	192	104	84	19	6,957
1953																							
April 13–17	23	5	106	26	11	45	44	54	18	8	7	3	14	15	15	15	15	35	69	0	0	0	500
April 29–May 4	24	6	57	30	23	19	26	21	18	37	10	23	23	11	18	38	12	27	33	24	0	0	450
May 11–17	25	6	55	41	30	25	51	56	36	36	58	49	33	25	48	153	36	15	28	0	0	0	775
May 27–June 3	26	8	79	152	79	42	63	109	52	34	72	170	76	75	123	128	21	28	22	42	0	0	1,367
June 9–15	27	7	72	133	80	57	49	66	46	46	55	121	129	37	94	78	46	40	23	19	0	0	1,191
June 25–July 2	28	8	170	78	62	104	138	167	82	46	45	45	56	109	87	69	99	124	143	79	0	0	1,703
July 8–14	29	7	135	37	22	38	56	42	37	58	38	24	39	45	85	75	92	37	28	39	0	0	927
July 22–30	30	9	85	77	39	64	45	44	73	58	93	42	35	43	19	45	28	34	14	16	0	0	854
August 6–11	31	5	67	25	21	37	28	42	28	19	21	26	45	51	29	25	44	64	32	24	0	0	628
August 25–28	32	4	30	32	13	14	7	19	3	11	9	21	35	15	16	30	32	1	6	12	0	0	306
September 21–23	34	5	12	3	1	10	6	22	13	11	6	46	85	15	9	13	22	6	3	18	0	0	301
Total		70	868	634	381	455	513	642	406	364	414	570	570	441	543	669	447	411	401	273	0	0	9,002

TABLE 12. **REPORTED NUMBERS OF MARKED RAZOR CLAMS RECOVERED AND NUMBERS RELEASED AT SEASIDE BEACH BY FISHERY AND SUBAREA OF RELEASE.**

Release Number	*Recoveries*	*Numbers of Recoveries by 0.1 Mile of Beach Length*																		*Total Clams*
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R–T*	
52–0	Commercial	3	0	0	5	4	2	1	2	1	4	5	2	2	4	2	....	....	....	37
	Sport	2	2	1	1	3	4	6	5	1	2	4	4	11	2	4	....	....	....	52
	Not Reported	12	16	17	13	11	11	10	21	22	24	19	21	14	20	5	....	....	....	237
	Number Released	17	18	18	19	18	18	17	28	24	30	28	27	27	26	11	....	....	....	326
52–1	Commercial	2	3	0	3	7	3	7	1	2	2	5	1	7	2	6	2	2	....	55
	Sport	4	3	3	0	3	2	7	6	4	3	3	4	3	5	3	3	0	....	56
	Not Reported	14	14	16	17	10	15	14	16	22	15	12	15	10	13	11	5	5	....	224
	Number Released	20	20	19	20	20	20	28	23	28	20	20	20	20	20	20	10	7	....	335
52–2	Commercial	4	1	5	4	7	2	3	0	0	12	9	6	3	7	2	....	....	....	65
	Sport	15	4	3	1	4	4	8	9	10	5	4	10	6	9	0	....	....	....	92
	Not Reported	26	27	24	27	21	25	18	20	16	15	19	16	23	16	9	....	....	....	302
	Number Released	45	32	32	32	32	31	29	29	26	32	32	32	32	32	11	....	....	....	459
52–3	Commercial	4	1	3	2	4	2	5	1	3	4	2	5	3	1	2	1	....	....	43
	Sport	2	2	1	1	0	0	0	0	1	0	2	3	2	2	2	2	....	....	20
	Not Reported	6	8	8	8	8	9	7	10	8	7	8	4	8	9	9	9	....	....	126
	Number Released	12	11	12	11	12	11	12	11	12	11	12	12	13	12	13	12	....	....	189

52–4	Commercial	1	9	4	5	4	4	8	1	5	5	7	5	6	8	2	....	....	....	74
	Sport	2	0	0	0	5	2	1	5	2	3	0	2	2	6	2	....	....	....	32
	Not Reported	16	10	15	14	10	13	10	13	12	11	14	15	12	10	5	....	....	....	180
	Number Released	19	19	19	19	19	19	19	19	19	19	21	22	20	24	9	....	....	....	286
53–0	Commercial	2	4	6	5	3	6	5	3	4	6	5	0	7	3	3	2	4	0	68
	Sport	4	2	5	3	4	2	1	7	7	7	4	9	4	4	6	4	4	5	82
	Not Reported	15	20	16	14	10	9	12	8	12	6	11	12	12	20	12	15	10	16	230
	Number Released	21	26	27	22	17	17	18	18	23	19	20	21	23	27	21	21	18	21	380
53–1	Commercial	6	3	8	4	2	4	7	8	6	5	4	1	4	5	7	3	1	....	78
	Sport	8	3	6	5	3	8	5	9	5	2	5	11	3	7	14	6	8	....	108
	Not Reported	12	22	12	19	21	16	14	5	17	18	20	17	22	16	27	27	18	....	303
	Number Released	26	28	26	28	26	28	26	22	28	25	29	29	29	28	48	36	27	....	489
53–2	Commercial	1	5	3	2	2	2	5	5	9	3	4	4	1	4	2	5	2	4	63
	Sport	9	5	4	8	4	7	4	6	2	4	4	5	3	7	0	5	6	7	90
	Not Reported	16	15	19	16	21	16	16	14	12	11	9	16	21	12	22	13	18	28	295
	Number Released	26	25	26	26	27	25	25	25	23	18	17	25	25	23	24	23	26	39	448
53–3	Commercial	2	2	3	4	6	4	10	6	7	7	6	4	2	1	0	0	4	2	70
	Sport	6	7	5	3	5	0	4	5	5	6	10	6	7	7	4	6	7	3	96
	Not Reported	17	16	20	19	15	24	12	17	13	12	12	16	20	21	23	20	17	7	301
	Number Released	25	25	28	26	26	28	26	28	25	25	28	26	29	29	27	26	28	12	467

in the supervised and test areas, the expected number of marks reported by questionnaire was $\frac{111}{243} \times 25$, or 11.42 recoveries. Based on this expectation, the proportion of recoveries reported by questionnaire was $\frac{5}{11.42}$, or 43.78 per cent. This value was used to estimate the number of marks recovered in the recreational fishery. However, the normal coverage of this fishery by questionnaire was probably not as complete as during the two days of the experiment when all recreational diggers in the test areas were contacted. Hence the actual reportability may have been over-estimated by the value given.

The total decline of the 1950 year class over the census period may be judged without reference to marking results, by considering the changes in age composition shown in Table 13. They clearly demonstrate a sharp reduction in abundance of this and older year classes during this period. The 1950 year class was the most recent to be fully recruited to both fisheries at the beginning of the census in May 1952. As Table 13 shows, the incoming 1951 year class was predominant in the August 1952 catches, replacing the earlier year class from its position of dominance only 3 months earlier. The 1953 samples indicate that 2 year classes comprised the bulk of the commercial catch: that of 1951 (in its second year and fully recruited) and 1952 (in its first year and still incompletely recruited). The contribution of earlier year classes (1945-50) was insigificant by comparison and remained so during the census. Apparently, annual mortality of the population was sufficiently high during the census period, and earlier, that immature, first-year clams constituted large proportions of each year's harvest. Of the fully recruited year classes only the most recent contributed significantly to each year's catch.

The commercial catch per man tide indicates a similarly sharp decline. Figure 16 includes the values obtained during each period of mark release. Fitting a regression to their logarithms a decline of 95 per cent is indicated for a yearly period. During the months intervening between the two groups of mark releases, these year classes did not enter the catches with any regularity or in significant numbers. This was believed partly due to the inaccessibility of offshore areas.

The population estimates in Table 14 refer to the release dates shown. Since reliable marked-to-unmarked ratios for the recreational fishery could not be obtained, the estimates were based on commercial data only. These were divided by tide series and grouped so as to include no less than 5 actual recoveries. All such estimates were then averaged for each release, weighting each by the commercial catch, following a method suggested by D. G. Chapman (private communication). Data for the tide period of release were excluded in each case. The sharp decline in both groups (Figure 16) reflects the population reduction associated with the high fishing intensity of each season as well as availability effects which are also seasonal in nature. Comparing the means of population estimates of 1952 and 1953 gives an estimate of total annual mortality of 92 per cent or a total mortality coefficient of $Z = 2.52$. This value was used to obtain estimates of fishing and natural mortality.

TABLE 13. ESTIMATED AGE COMPOSITION OF THE COMMERCIAL RAZOR CLAM CATCH, BY TIDE SERIES, SEASIDE BEACH, MAY 1952—DECEMBER 1953.

Census Tide Number	*Tide Series*	*Number in Year Class*								*Total Clams*
		1952	*1951*	*1950*	*1949*	*1948*	*1947*	*1946*	*1945*	
	1952									
0	May 1–15	...	...	...	...	...	...	...	...	...
1	May 16–30	...	...	...	...	...	...	...	...	...
2	May 31–June 15	...	39	334	82	15	10	6	...	486
3	June 16–28	...	189	395	68	37	20	6	3	718
4	June 29–July 15	...	470	565	141	40	18	9	...	1,243
5	July 16–27	...	551	600	172	131	111	58	9	1,632
6	July 28–Aug. 13	...	440	368	79	48	21	8	1	965
7	Aug. 14–23	...	222	178	13	4	...	...	...	417
8	Aug. 24–Sept. 12	...	718	95	14	...	...	...	...	827
9	Sept. 12–26	...	...	...	...	...	...	...	...	...
10	Sept. 27–Oct. 10	...	1,461	66	17	1	...	...	...	1,545
11	Oct. 11–25	...	1,072	48	13	1	...	...	...	1,134
12	Oct. 26–Nov. 8	...	964	17	1	0	1	...	...	983
13	Nov. 9–23	...	...	...	...	...	...	...	...	...
14	Nov. 24–Dec. 8	...	...	...	...	...	...	...	...	...
15	Dec. 9–23	...	78	...	...	...	...	...	...	78
	1953									
16	(Dec. 24)–Jan. 7	...	...	...	...	...	...	...	...	...
17	Jan. 8–21	...	...	...	...	...	...	...	...	...
18	Jan. 22–Feb. 6	...	...	...	...	...	...	...	...	...
19	Feb. 7–19	...	1,640	32	3	1	1	...	...	1,677
20	Feb. 20–March 7	...	...	...	...	...	...	...	...	...
21	March 8–20	...	939	12	2	...	...	...	...	953
22	March 21–April 5	...	1,742	23	0	1	1	...	...	1,767
23	April 6–18	2	1,026	57	6	4	1	...	...	1,096
24	April 19–May 6	48	648	17	3	...	...	...	...	716
25	May 7–19	6	175	8	2	...	...	...	...	191
26	May 20–June 3	351	1,094	16	7	...	...	...	...	1,468
27	June 4–17	755	1,444	37	4	1	...	...	...	2,241
28	June 18–July 2	134	262	2	2	1	1	...	...	402
29	July 3–18	352	814	26	2	...	...	...	...	1,194
30	July 19–Aug. 1	483	819	21	5	2	...	...	...	1,330
31	Aug. 2–17	262	388	24	2	0	0	1	...	677
32	Aug. 18–30	84	28	...	...	...	...	...	...	112
33	Aug. 31–Sept. 14	...	...	...	...	...	...	...	...	...
34	Sept. 15–29	453	597	29	...	...	...	...	...	1,079
35	Sept. 30–Oct. 14	...	...	...	...	...	...	...	...	...
36	Oct. 15–28	132	141	1	1	...	...	...	...	275
37	Oct. 29–Nov. 13	...	...	...	...	...	...	...	...	...
38	Nov. 14–27	...	...	...	...	...	...	...	...	...
39	Nov. 28–Dec. 13	...	...	...	...	...	...	...	...	...
40	Dec. 14–27	163	6	...	...	...	...	...	...	169
	Total	3,225	17,967	2,971	639	287	185	88	13	25,375

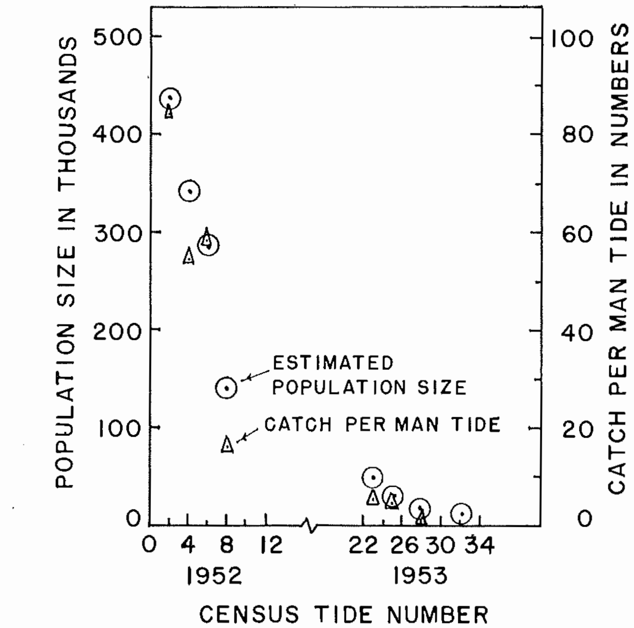

FIGURE 16. ESTIMATES OF POPULATION SIZE AND COMMERCIAL CATCH PER MAN TIDE (YEAR CLASS 1950 AND OLDER), SEASIDE BEACH, JUNE 1952–SEPTEMBER 1953.

TABLE 14. **ESTIMATED POPULATION OF RAZOR CLAMS (1950 YEAR CLASS AND OLDER), BASED ON COMMERCIAL RECOVERIES OF MARKED CLAMS, SEASIDE BEACH, 1952 AND 1953.**

Release Number	*Census Tide Number* i	*Number of Marked Clams Released* t_i	*Estimated Number of Commercial Recoveries*① $\sum_{j=i+1}^{36} s_{ij}$	*Estimated Number of Clams in Commercial Catch*② $\sum_{j=i+1}^{36} n_j$	*Weighted Population Estimate*③ N^*_w
52–1	2	335	78.125	79,576	437,231
52–2	4	459	87.500	48,645	340,206
52–3	6	189	65.625	30,151	183,218
52–4	8	286	95.313	24,793	140,512
53–0	23	380	81.250	7,811	49,855
53–1	25	489	71.875	3,668	32,043
53–2	28	448	64.063	1,298	16,254
53–3	32	467	45.313	474	10,823

① Corrected for reportability by dividing the number of actual recoveries by 0.64.

② Excludes year-classes 1951 and 1952 which were not fully recruited to the commercial fishery at the beginning of the census. The numbers caught and the population estimates refer to the abundance of only the 1950 and earlier year classes.

③ Based on $N^* = \frac{(n+1)\,(t+1)}{(s+1)}$ as given in Chapman (1948) and $N^*w = \frac{\sum_{i+1}^{k} N_{ij}\, n_j}{\sum_{i+1}^{k} n_j}$ as suggested by Chapman (private communication).

The annual expectation of death due to fishing (E) was estimated from the mark recoveries during the first 24 tide series following each release applying the reportability factors discussed earlier. Separate mark releases produced estimates ranging from 54.3 to 76.8 per cent (Table 15). The lowest was from the first release and may have been affected by lower reportability during the initial part of the census than is indicated by the over-all correction. Since area designations of commercial catch records were also found incomplete at the outset of the marking program, the data from this release were excluded from calculations of mortality rate and population size. The 1952 values were generally lower than those for the second year reflecting a higher fishing intensity in 1953 (cf. Table 11). For our purposes the last four 1952 estimates of E were of interest since they cover dates similar to those of total annual mortality as obtained from the population estimates. Their weighted average is 0.65, corresponding to a fishing mortality coefficient (F) equalling $\frac{2.52}{0.92}$ (0.65), or 1.78.

Estimates of population size as well as exploitation rate were probably affected by errors of several types. Of those due to the marking (and handling) process itself, initial vulnerability is thought to have been the most important. Marking mortality, which was discussed earlier, was not believed to have been substantial. The effect of no lateral mixing of marked with unmarked clams is believed to have been minimized by basing the recovery data on sufficiently long fishing periods following each release. However, these terminated in late 1953 for all releases and were thus of variable length. An additional source of error lay in the small numbers of the year classes under consideration that were encountered in 1953, and their irregular occurrence in age samples of the commercial catch. Finally the seasonal changes in availability undoubtedly affected the results. No corrections were made for any of these factors.

Since the width of the planting area was subject to seasonal variation along with differences in tide level at time of planting, values of the annual expectation of death due to fishing cannot refer to an area of fixed width; rather they represent averages that apply to generally accessible beach levels subject to exploitation during a complete annual beach cycle. They do not refer to offshore bars which become accessible occasionally by boating and wading. Although bars are marked at times by high commercial catches, their short exposure and constant shifting does not permit a rate of exploitation for any given unit area comparable to the more regularly exposed inshore areas where marks were distributed. Reduced fishing pressure may account for the fact that commercial catches originating on offshore bars frequently contain older age groups in higher proportions than do inshore catches.

Based on the above estimates of Z and F, the quantity (Z—F) is usually attributed to natural causes. The coefficient so obtained is 0.74. However, this value is not considered representative in the present case, since it includes wastage which is believed an important factor in razor clam fisheries, especially the recreational fishery.

TABLE 15. **ESTIMATED ANNUAL EXPECTATION OF DEATH DUE TO FISHING BASED ON RECOVERIES OF MARKED CLAMS FROM 1952 AND 1953 RELEASES.**

Release Series	*Census Tide Number (i)*	*Number of Marked Clams Released* (t_1)	*Number of Actual Recoveries*			*Total Calculated Recoveries*①	*Annual Expectation of Death (u) (%)*
			Com-mercial	*Recrea-tional*	*Total*		
52–0	0	326	37	52	89	177	54.3
52–1	2	335	54	56	110	212	63.3
52–2	4	459	64	92	156	310	67.5
52–3	6	189	43	20	63	113	59.8
52–4	8	286	71	32	103	184	64.3
53–0	23	380	67	82	149	292	76.8
53–1	25	489	75	108	183	364	74.4
53–2	28	448	60	90	150	299	66.7
53–3	32	467	70	96	166	329	70.4
Total		3,379	541	628	1,169	2,280	67.5

① Factors used: commercial recoveries $\frac{1}{0.64}$, recreational recoveries $\frac{1}{0.44}$.

Estimates of wastage have been obtained on Oregon beaches as well as in Washington. Values given for Washington beaches (Washington State Department of Fisheries, 1950) ranged from 17.6 per cent on Copalis Beach to 28.6 per cent on Long Beach. On Clatsop Beaches a value of 24 per cent was obtained in 1951, based on examining 459 holes made by clam diggers, and counting as wasted only those that had clams in them which were considered incapable of survival. Estimates obtained in this manner are likely to underestimate the damage done. They assume that every hole inspected represents a clam dug although many amateurs are unskilled in recovering the clams after digging; or that no clams are fatally injured that are not recovered by either the digger (and then discarded) or the biologist. Also, predation of discarded clams by seagulls prior to inspection by biologists may affect the estimates obtained. Although difficult to prove, it seems likely that lack of skill among amateur diggers produces many fatalities in clams of all sizes which are beyond visual detection. This type of mortality would affect the estimates of exploitation rate and coefficients F and M. In particular, the values in Table 15 may underestimate the true exploitation rate and overestimate the corresponding estimate of natural mortality rate.

YIELD CALCULATIONS

The effect of age at first capture on the potential yield from a standard number of recruits was examined by utilizing the growth and mortality data obtained in this study. The values of weight-on-age and the "fishable life span" were presented earlier in Table 7, with age expressed in intervals of ⅛ years beginning with July 1 of the first year. This date was taken to represent the nominal age at which a year class, or substantial portions of it, appeared in the catches of both the recreational and commercial fisheries. The instantaneous rate of total mortality ($Z = 2.52$) was obtained from the population estimates shown in Table 14. In the absence of firm estimates of mortality due exclusively to natural causes, the quantity ($Z - F$) was assumed to include wastage at levels such that the recorded rate of fishing mortality represented 80, 90, or 100 per cent of the clams destroyed in the course of digging, as well as true natural mortality. The calculation of potential yield generally followed along the lines of Beverton (1953), with the differences noted earlier.

Figure 17 shows potential yield in pounds per 1,000 recruits as function of age at first capture, under each of the three conditions of wastage outlined. The lowest yield curve (A) represents the case of fishing being 100 per cent efficient and the instantaneous rate of true natural mortality $M = 0.74$. A slight increase appears achievable by deferring harvest one year beyond recruitment. Curve B is based on the assumption that digging is 90 per cent efficient and the rate of true natural mortality $Z - F/0.9$, or 0.54; for 80 per cent digging efficiency this value is $M = 0.29$, and was used to obtain curve C. In curves B and C, the yields shown are those of potential yield reduced by the wastage levels indicated. Substantial gains appear achievable under both conditions. Curve B is considered most nearly representative of conditions prevailing over the census period.

Yield isopleths, not shown here, have been constructed for various levels of natural mortality ($M = 0.35$, 0.40, 0.70) and fishing mortality and operating either continuously throughout the year or seasonally (May-September). In all cases increased yields appeared attainable by deferring harvest until spring of the second year of age at levels of fishing mortality rate greater than about 0.90 (or about one-half the value obtained in the present study).

DISCUSSION

The yield relationships discussed in the preceding section contain no information regarding long term effects resulting from modification of spawning potential with changes in age at first capture. A direct association between the size of the fished population and subsequent production has been assumed for razor clams (e.g. Schaefer, 1939), but information available for Clatsop Beaches seems inconclusive. Seaside Beach has been the most heavily and regularly seeded of Clatsop Beaches despite the consistently high fishing intensity observed. Nevertheless, the very low average age of the Seaside population during this census strongly suggests the need for measures to increase the accumulation of older age groups, apart from the benefits accruing from a higher yield in weight.

A graphic picture of the intensity of the razor clam fishery is given by Figure 18 which shows Seaside Beach during a summer low tide. Each hole in the sand represents a clam that was dug or pursued.

In view of the relatively small differences in growth rate of clams

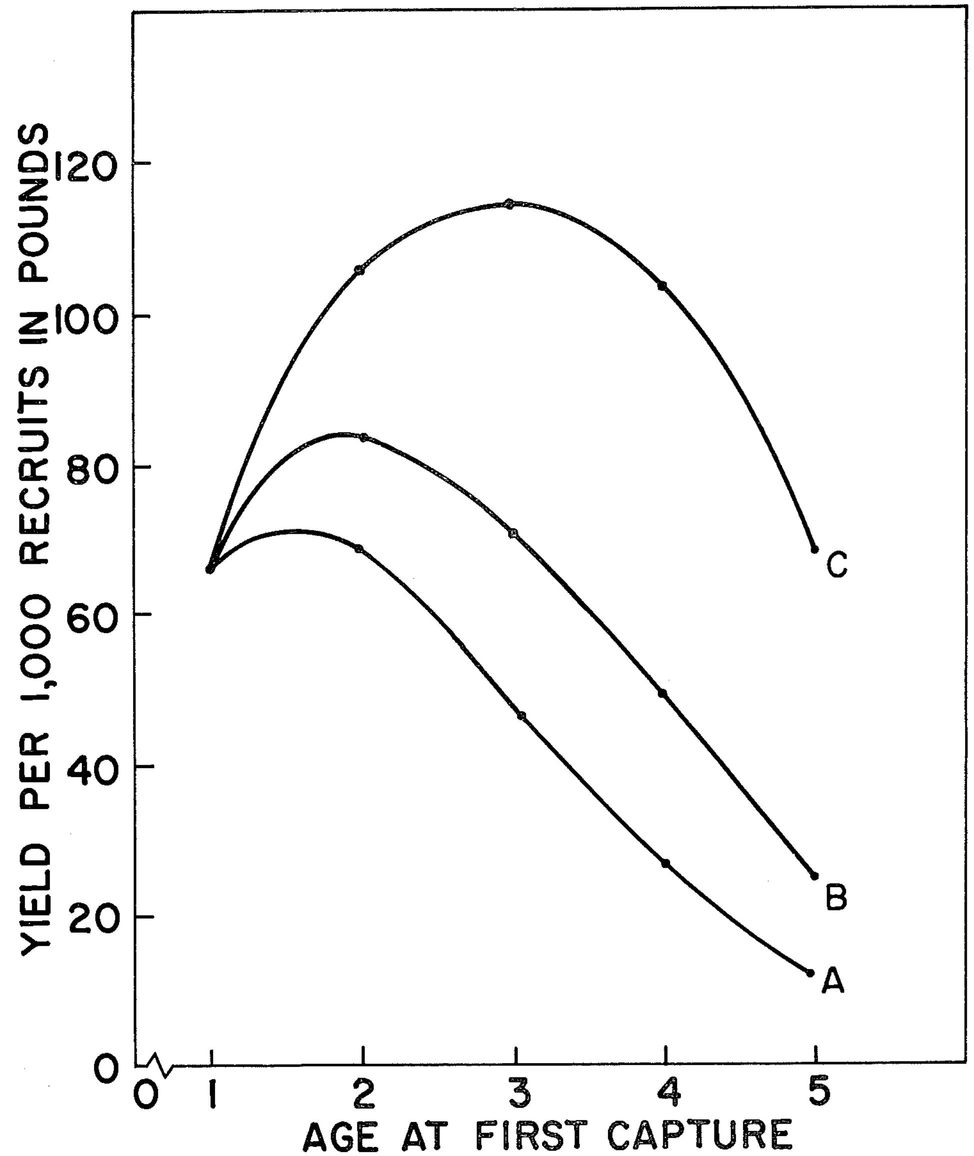

FIGURE 17. YIELD PER 1,000 RECRUITS AT THREE LEVELS OF FISHING MORTALITY (F) AND NATURAL MORTALITY RATE (M). FOR CURVE A, F = 1.78, M = 0.74; CURVE B, $F = \frac{1.78}{0.9}$, M = 0.54; AND CURVE C, $F = \frac{1.78}{0.8}$, M = 0.29.

from the various parts of Clatsop Beaches, a delay in harvest is likely to produce similar results in all sections. While fishing mortality has not been measured in areas other than Seaside, it would probably not be sufficiently small in any area to cause a decrease in yield. However, the recreational fishery for razor clams is inherently wasteful and its destruction of first-year clams—without harvest—is always likely to lessen the yield which the population is naturally capable of producing.

FIGURE 18. A SUMMER LOW TIDE ON SEASIDE BEACH.

SUMMARY

Clatsop Beaches have supported commercial and recreational razor clam fisheries for many years under a commercial minimum size limit of 3.5 inches and a recreational fishery bag limit of 36 clams. In 1955 this was changed to 4¼ inches and 24 clams, respectively.

Both extremities of Clatsop Beaches were subject to modification since the turn of the century but are productive of razor clams at present. The annual cycle of sand transport characteristic of open, exposed beaches appears capable of distributing razor clams of the fall set over the entire beach area, extending to the breaker zone.

Length-weight relationships corresponding to ⅛-year intervals were calculated.

The set of the 1949 year class was traced through December 1950 and the seasonal pattern of linear growth over this period noted. A comparison of the total length of this year class in December 1950 with the length of the first ring in members of the same year class in 1952, 1953, and 1954 indicated no major differences.

Recent sets of first-year clams displayed bimodal length-frequency distributions which were probably due to unequal dates of set. First-year clams taken by the recreational fishery indicated superior growth in the central beach portions, with smaller sizes found on the northern and southern beaches.

Slightly larger members of a year class were found at lower than at upper beach levels; however, the comparison did not extend to offshore bars.

Ring measurements of second-, third-, and fourth-year clams indicated no major or consistent size differences between year classes or subareas.

Seasonal linear growth in adult clams was described by the means of marginal increments. Relative shell width was found to increase during the period March-July, which is also the period of maximum increase of total length, and both increases appeared to be associated with seasonal rises in water temperature.

Age-length and age-weight relationships prevailing at the time of ring formation are adequately described by von Bertalanffy equations after the completion of the first calendar year of life.

A census of the Seaside Beach population of razor clams involved the release of 3,379 marked clams in 1952-53. There were no significant differences in recoveries with respect to condition at release, or the number planted per tenth-mile section of beach.

An analysis of the variance of digger counts indicated no significant differences between tenth-mile sections of the major part of Seaside Beach.

Based on adjusted returns of marked clams, the annual expectation of death due to fishing ranged from 54 to 77 per cent in different series of releases. The average for the 1952 releases was 65 per cent and for the 1953 releases 72 per cent.

The total annual mortality coefficient (Z) was 2.52 for 24 tide series based on the means of four population estimates of fully recruited year classes in 1952 and 1953. The component values of fishing and natural mortality ($F = 1.78$, $M = 0.74$) were believed affected by the destruction of clams not reflected in records of harvest.

The effect of varying degrees of wastage on yield per 1,000 recruits was examined at the total mortality level encountered in this study. An increase in yield by deferring harvest until the second year of age appears realizable under every condition examined, regardless of whether the fishery is continuous or seasonal in occurrence.

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