CALICO SCALLOP DISTRIBUTION, ABUNDANCE, AND YIELD OFF EASTERN FLORIDA, 1967-68[1]

RICHARD B. ROE,[2] ROBERT CUMMINS, JR.,[3] AND HARVEY R. BULLIS, JR.[4]

ABSTRACT

During 18 months, from August 1967 to December 1968, the National Marine Fisheries Service Exploratory Fishing and Gear Research Base in Pascagoula, Miss., conducted a comprehensive survey of the calico scallop (*Argopecten gibbus*) grounds off eastern Florida. The survey disclosed various aspects of the life history, distribution, abundance, and yield and annual variation in geographical and depth distribution. Predictions for a fall fishery are possible since distribution and abundance are established at spat set and can be delineated by midsummer. A fall fishery is recommended as catch rates and yield were highest between September and December and decreased rapidly during late winter and spring.

There are two or more species of *Argopecten* called "calico" scallops (Waller, 1969); however, the more common is *A. gibbus* (L.). This is the species involved in our study, occurring from Delaware Bay to the Caribbean Sea and throughout the Gulf of Mexico (Johnson, 1934; Bullis and Ingle, 1959; Carpenter, 1967; Waller, 1969). Calico scallops derive their name from the blotched coloration of their shells which vary from red to light brown on a white background, giving a "calico" effect to the shell.

Three commercial grounds have been delineated by the Exploratory Fishing and Gear Research Base at Pascagoula, Miss., and its Field Station in Brunswick, Ga. These are located off North Carolina (Cummins, Rivers, and Struhsaker, 1962), off eastern Florida near Cape Kennedy (Bullis and Cummins, 1961; Cummins, et al., 1969;[5] Drummond, 1969), and in the northeastern Gulf of Mexico (Bullis and Ingle, 1959; Carpenter, 1967). Explorations had shown a large resource exists, particularly off Florida, but monthly and yearly changes in distribution and abundance had seriously hampered delineation of the resource.

In August 1967 an 18-month survey was initiated on the Cape Kennedy grounds to assess the scallop stock and determine the causes of variation in distribution, abundance, and yield. These grounds were selected because of size, location, and a developing industry.

The survey provided information on the dynamics of the scallop population present at that time, but there is a need for additional studies on life history, age, and growth.

METHODS

Cruises were conducted monthly between August and December 1967, and bimonthly between February and December 1968. Four standard transects, each extending from 10 to 40 fm, were made on each cruise. These were: transect A at lat 28°03′ N, transect B at lat 28°27′ N, transect C at lat 29°03′ N, and transect D at lat 29°25′ N (Figure 1). Tows were also made between transects. An 8-ft scallop dredge, fitted with 2-inch bag rings and 2½-inch mesh nylon liners, was used in the survey. All tows were 30 min.

[1] Exploratory Fishing and Gear Research Base, Pascagoula, Miss., Contribution No. 232.

[2] National Marine Fisheries Service Exploratory Fishing and Gear Research Base, Pascagoula, Miss. 39567.

[3] National Marine Fisheries Service Exploratory Fishing and Gear Research Station, Brunswick, Ga. 31520.

[4] National Marine Fisheries Service, Washington, D.C. 20240.

[5] Cummins, R., Jr., R. Maurer, L. May, and J. Rivers. 1969. Summary log of scallop locations with predicted catch rates of Cape Kennedy grounds — fall 1969. Issued by Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Field Station, Brunswick, Ga., for limited distribution.

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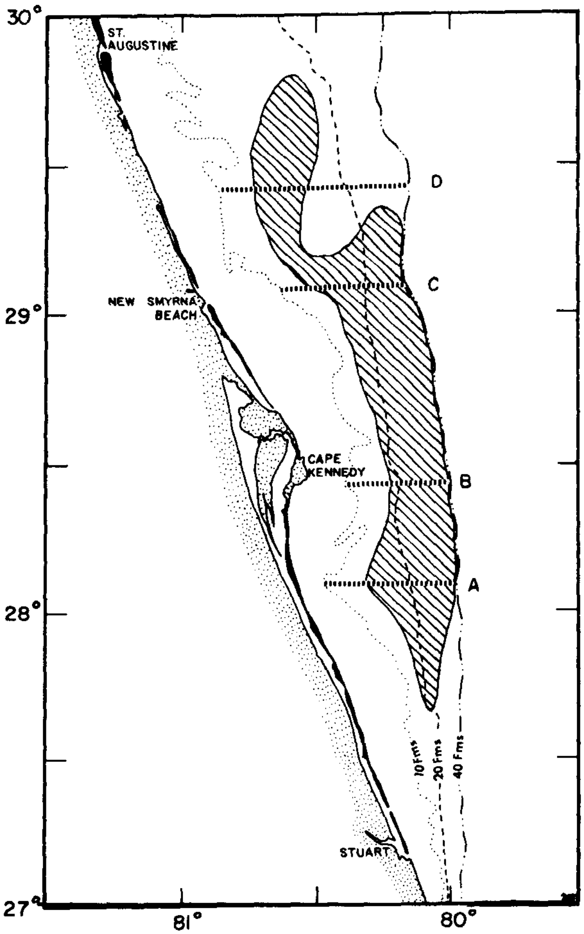

FIGURE 1.—General distribution of calico scallops and four standard transects occupied during the 1967-68 survey off the Florida east coast.

A total of 1,483 drags was made during the survey—285 in transect A, 403 in transect B, 493 in transect C, and 302 in transect D. The following were determined for each drag: total catch in bushels (using a standard steel shrimp basket averaging 70 lb.), number of bushels of live scallops, pounds of meat per bushel, number of pints of meat per bushel, number of meats per pint, and size frequency (measured as shell diameter in millimeters). Randomly selected individuals were examined for gonad coloration and sexual maturation. The data were analyzed with the UNIVAC 9200 computer at the Exploratory Fishing and Gear Research Base at Pascagoula, Miss.

The survey results are subdivided according to spawning, age and growth, mortality, distribution and abundance, and yield.

SPAWNING

Bourne and Bligh (1965) found sea scallop (*Placopecten magellanicus*) ovaries change color during maturation, progressing from pink at early stages to deep coral-red when ripe. Color changes were also noted in calico scallop ovaries, undeveloped ovaries being whitish, ripe ovaries bright reddish-orange.

Yellowish-orange coloration was seen in very few scallops during the August cruise, but by September the rate and incidence of color change was highly noticeable. Coloration and incidence increased into fall and winter and by February ovaries were predominantly reddish-orange or ripe. The majority of ovaries taken in April were bright reddish-orange. June ovaries were largely uncolored.

Sexual maturation in sea scallops begins in March, spawning occurring 7 months or so later in September or October. Calico scallops apparently have a similar maturation period based on color change progression which begins in August and ends in March or April. Protracted spawning does take place in some areas since small numbers of 5 to 30 mm scallops occur throughout the year (Figure 2).

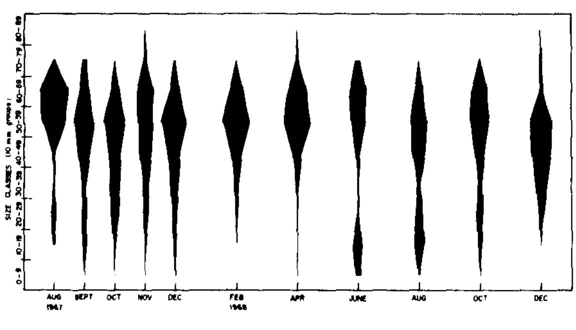

FIGURE 2.—Monthly size/frequency distribution of scallops for the combined transects off the Florida east coast during the 1967-68 survey.

AGE AND GROWTH

Monthly size frequencies are shown in Figure 2. From June until September the distribution is bimodal, but in October the lower mode disappears and a single mode exists until April. This is clearly illustrated in the 1968 data beginning in June when modes occur at 11.9 and 62.1 mm. In August modes are present at 26.0 and 60.6 mm and in October at 34.0 and 61.5 mm. Only one mode at 51.0 mm occurs in December.

The lower mode value gradually increases during this period while the upper mode decreases. These changes reflect a melding of year classes caused by a more rapid growth rate in the younger year class than in the older one. In December the two year classes are indistinguishable. Since year classes cannot be separated in the winter data, it is difficult to determine when the older class disappears. Presumably this occurs some time between December and April.

Growth rates could not be accurately determined from the data because of gear selectivity for the smaller sizes and because year classes were often inseparable in the size-frequency distribution. A growth estimate was derived for a selected bed located on transect C in 22 to 27 fm. The size-frequency data indicate two year classes were present most of the survey period (Table 1). These are more distinct in the separated 1968 data (Table 2).

The mean size increases linearly by about 1.0 to 2.0 mm per month during August to February (Table 1). From April to December the mean gradually decreases because of recruitment from the spring spawn.

TABLE 2.—Monthly size frequency data for transect C, 22 to 27 fm, divided by year class. Classes are 10 mm.

Size class	Year class A				Year class B			
	June	Aug.	Oct.	Dec.	June	Aug.	Oct.	Dec.
0-9	6	1	--	--	--	--	--	--
10-19	24	57	2	--	--	--	--	--
20-29	4	163	61	125	--	--	--	--
30-39	--	41	3	260	--	--	--	--
40-49	--	--	--	116	1	--	--	--
50-59	--	--	--	103	44	41	8	--
60-69	--	--	--	--	72	211	103	138
70-79	--	--	--	--	31	38	21	7
Mean	13.9	23.8	25.7	37.8	63.5	64.4	65.5	65.0

Since the age groups interact the means given in Table 1 actually represent a combined year class average. Therefore, the June to December 1968 data have been separated into two year classes based on size (Table 2). Year class A was spawned in the spring of 1968 and year class B, representing the larger sizes, was spawned in the spring of 1967. The monthly mean for year class A increased curvilinearly 24 mm from June to December. Year class B mean increased only 2.0 mm from June to October then decreased slightly in December. The increase appeared linear.

Both year classes show evidence of a sigmoid growth curve. Gibson (1956) gives a sigmoid curve for *Pecten maximus* where time is measured in years rather than months as in calico scallops.

MORTALITY

Calico scallops on the Cape Kennedy grounds experienced light commercial exploitation prior

TABLE 1.—Monthly size frequencies for transect C, 22 to 27 fm, by 10-mm size classes, 1967-68.

Size class	1967					1968					
	Aug.	Sept.	Oct.	Nov.	Dec.	Feb.	Apr.	June	Aug.	Oct.	Dec.
0-9	--	--	--	--	--	--	--	6	1	--	--
10-19	1	4	--	--	--	--	--	24	57	2	--
20-29	1	4	1	1	--	--	--	4	163	61	125
30-39	1	3	--	3	--	3	--	--	41	3	260
40-49	2	16	3	7	--	4	38	1	--	--	116
50-59	11	58	72	23	38	295	185	44	41	8	103
60-69	9	42	43	39	25	567	343	72	211	103	138
70-79	2	18	2	7	1	28	46	31	38	21	7
80-89	--	--	--	--	--	--	1	--	--	--	--
Mean	55.2	56.4	57.9	59.1	58.7	61.3	61.0	54.2	45.1	51.9	43.0

to 1967. Landings in 1967 totaled approximately 5,000 bu and although several vessels fished the area in 1968, the overall catch was light. Mortality during the survey period was therefore assumed largely due to natural causes.

Catch curves using Ricker's (1958) method of plotting $\log_e$ (average number per drag per month) were constructed (Figure 3). A linear

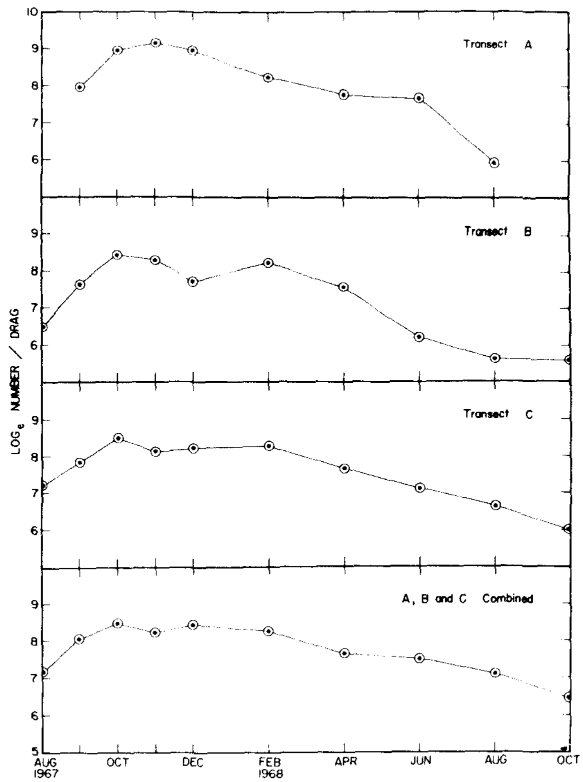

FIGURE 3.—Catch curves for transects A, B, C, and combined.

regression was applied to the descending curve according to Beverton and Holt (1957), using b as an estimate of $F + X$. Since F was negligible, b is an estimate of X or natural mortality. The instantaneous mortality rate (i) is equal to b and the monthly mortality rate (a) was derived from Ricker's appendix.

Data used in the analysis represented the 1967 year class except in transect D where catch data were too sparse for analysis. December 1968 data were not available except for transect C. October 1968 was omitted from transect A because of insufficient data.

The ascending left limb of the curve reflects recruitment. Mortality during this period is difficult to determine because small scallops are inaccessible to the dredge. The dome varied among transects but occurred from October to December or February. The descending limb extended from December to October (August in transect A). All limbs are curvilinear but vary in shape. The curve for transect A is variable. That for transect B is concave from February to June then becomes convex. Transect C curve is almost linear.

Monthly mortality rates, computed assuming a linear relationship (as in Beverton and Holt, 1957), are given in Table 3. Two time periods

TABLE 3.—Monthly mortality rates (a) and instantaneous mortality rates (i) for transects A, B, and C, individually and combined, for various time periods.

Transect	Time period	i	a
			%
A	10/67-12/67	−0.012	1
	12/67- 8/68	−0.327	27
B	10/67-12/67	−0.365	31
	12/67-10/68	−0.286	25
C	10/67-12/67	−0.150	14
	12/67-10/68	−0.236	21
COMBINED	10/67-12/67	−0.020	2
	12/67-10/68	−0.189	18
C (22-27 fm)	2/68-10/68	−0.231	21

were treated: one from October to December (the optimum fishing season) and the other from December to October (the descending limb). The latter period includes the spawning season. Although accurate rates for the first period (the dome) could not be accurately ascertained, a crude mortality estimate was desired for the fishing season.

Monthly mortality rates ranged from 1% to 31% for the dome and 18% to 27% for the descending limb. Averages were 12% and 23% respectively.

Age classes were difficult to distinguish and all data may not have been from the 1967 year class. This could have caused differences in the catch curves. To test this possibility, data from a bed of known age composition were used to construct a catch curve. This bed, located at lat 29°16′ N in 22 to 27 fm on transect C, was established in August 1967 and can be accurately traced through October 1968 with length-frequency data.

The catch curve for the bed (August 1967 to October 1968) is given in Figure 4. Recruitment in late summer and fall was strong. Recruitment and mortality seem balanced from October to February, but neither can be accurately determined. The convex descending limb (February to October) indicates a nonuniform mortality rate, increasing rapidly after June with the termination of spawning.

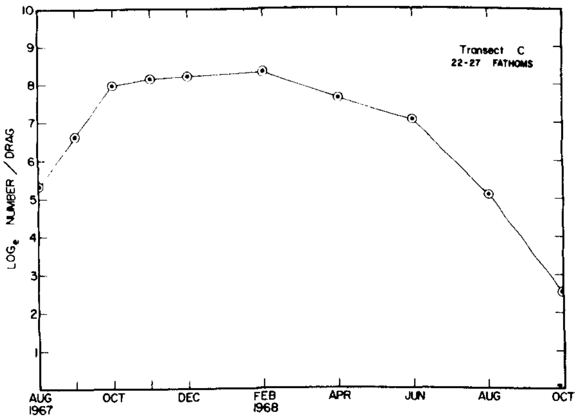

FIGURE 4.—Catch curve for transect C, 22 to 27 fm. Data are for the 1967 year class.

The February to October segment was treated linearly to estimate monthly mortality. Results were $i = -0.231$ and $a = 21\%$ (see Table 1). Mortality rates for the dome (October to February) were not calculated.

Although these rates are similar to those in Table 3, enough discrepancy exists to indicate more than one year class might have been included in Table 3 data, causing some differences in mortality rates. This does not preclude mortality rate differences on the grounds.

The major calico scallop predator appears to be the starfish (*Asterias*) which is often taken in large numbers in dredge tows (Figure 5) and has been seen by submarine observers feeding on scallops (Figure 6). Rays and skates may feed on calico scallops (Struhsaker, 1969) and puffers (*Sphoeroides*) have been taken with numerous small (2 to 5 mm) scallops in their stomachs. Other predators are not known.

Little is known about those environmental factors affecting scallops though water temperature is considered most important. Past explorations have shown evidence of occasional mass mortalities that may have been due to temperature fluctuation. Dickie and Medcof (1963) reported that mass mortalities often occur in sea scallops when water temperatures fluctuate rapidly. Further, temperature changes may indirectly cause death through dehabilitation, thereby rendering scallops highly susceptible to predation.

DISTRIBUTION AND ABUNDANCE

Calico scallops occurred in 13 to 37 fm with greatest concentrations between 19 and 30 fm (Figure 1).

Depth distributional differences north and south of the Cape were noted (Figure 7). Scallops south of the Cape were generally found shallower than north of the Cape. The reasons for this are unknown though the thermal structure may be different in these areas. Also the shelf is narrower with a steeper gradient south of the Cape, and available habitat is restricted. Optimum bottom may occur 4 to 5 fm shallower in that area.

A slight seasonal change in depth distribution occurred in both areas. Scallops were in slightly deeper water in winter than summer, this difference being less noticeable north of the Cape.

Yearly differences in bed distribution were noted during the survey. In 1967 beds were primarily located between 19 and 30 fm; however, in the fall of 1968 very few scallops occurred in that depth range and a developing bed was found at lat 29°10′ N in 15 to 17 fm. This bed extended northward beyond lat 29°25′ N.

Scallops were usually found in north-south windrows several hundred yards to a quarter mile long. Bed size varies but without a means

FIGURE 5.—Dredge catch of starfish aboard the RV *Oregon* taken during an exploratory fishing survey on the Cape Kennedy grounds.

of underwater observation there is no way of mapping beds definitively. A remote-controlled underwater assessment vehicle (RUFAS) has since been used to survey the Cape Kennedy grounds and preliminary data analysis verifies our findings (Cummins et al., see footnote 5).

Major abundance occurred at slightly different depth ranges north and south of the Cape (Figure 8). Seasonal changes, while not noticeable in these areas, did occur at some depth ranges. Abundance was highest in 21 to 23 fm south of the Cape and 24 to 27 fm north of the Cape. By August 1968, scallops were gone south of the Cape. North of the Cape the population diminished through October 1968 and had practically disappeared by December.

YIELD

Yield is presented as pounds of meat per drag. Preliminary calico scallop investigations had used bushels per drag as a yield criterion, but owing to differences in size, barnacle encrustation on the shell, and changes in meat condition, the meat yield per bushel was highly variable.

Variation in bushel yield due to size differences is obvious, but the effect of barnacle encrustation is more subtle. The sedentary nature

FIGURE 6.—Starfish (*Asterias*) observed attacking calico scallops during a submarine survey off Cape Kennedy in September 1969.

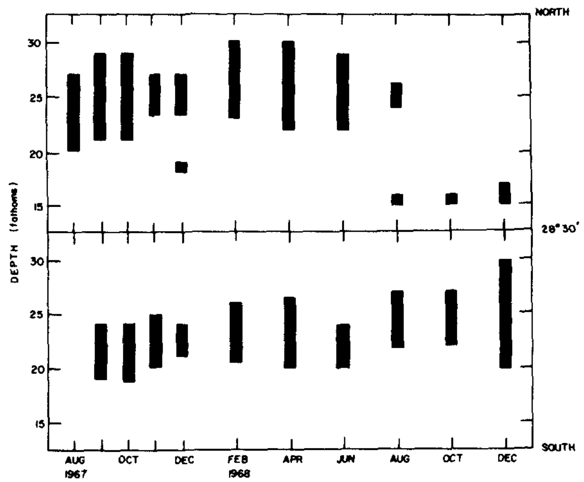

FIGURE 7.—Monthly depth distributions north and south of Cape Kennedy.

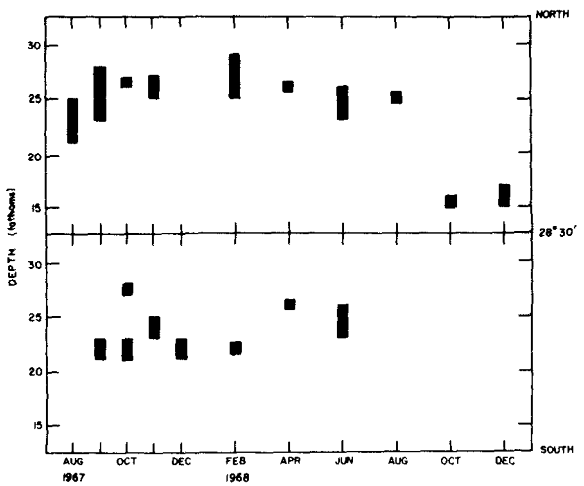

FIGURE 8.—Depths at which maximum abundance occurred north and south of Cape Kennedy.

of scallops enables a gradual buildup of barnacles on the shell which decreases the number of scallops per bushel. This leads to an overestimate of meat yield per bushel.

Meat condition was found to fluctuate seasonally. From December to April meat counts increased rapidly (Figure 9) owing to increased flaccidity resulting from physiological changes

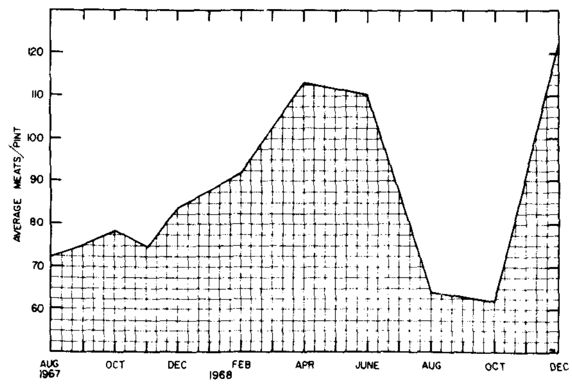

FIGURE 9.—Average number of scallop meats per pint by month during the 1967-68 Florida east coast survey.

associated with spawning. Though most scallops are generally large (50 to 60 mm) at spawning, the meat yield per bushel is much lower than during the fall when scallops are smaller.

These conditions caused us to discard number of bushels and use total pounds of meat per drag as a more meaningful measurement of yield.

Meat count per pint is an excellent index of fishing productivity when used in conjunction with total pounds. A wide seasonal variation in meat count was caused by differences in meat condition and scallop size (Figure 9). From August to December the meat count per pint stabilized at 70 to 80. During December through June the count increased due to deterioration of meat firmness and/or contribution by a nonspawning population remnant.

The fall increase in meat count per pint is due to increasingly large numbers of small scallops entering the fishery from the shallow bed on transect C.

Commercially significant yields were taken between September and February with a maximum in October (Figure 10). Yield rapidly decreased after February because of spawning. Yield in the fall of 1968 was appreciably lower than in 1967 owing to the failure of the survey to locate quantities of scallop. The population in 15 to 17 fm at lat 29°10′ N, spawned in 1968, was not found in any abundance during the Oc-

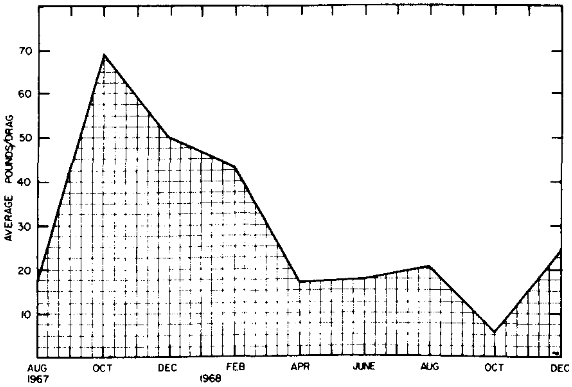

FIGURE 10.—Average number of pounds of scallop meats per 30-min drag by month during the 1967-68 Florida east coast survey.

tober or December cruises, indicating spawning occurred much later in 1968 than in 1967.

DISCUSSION

Reproduction in calico scallops is related to age rather than size. It is probably triggered by water temperature as Loosanoff and Davis (1950) have shown that raising the ambient water temperature induces spawning in some bivalves. Since spawning generally occurs in the spring, rising temperatures would be expected to be the initiating mechanism.

Maturation, taking 7 to 9 months beginning in late summer, is easily detected in the field by coloration changes in the ovaries. Resting ovaries are whitish-yellow but as maturation progresses their color changes through various stages of deepening yellow-oranges to a reddish-orange at the ripe condition. Ripe gonads have been collected from a wide size range indicating that the minimum age of sexual maturity is quite low. Data indicate maturation does not begin simultaneously in all scallops within even the same bed. This presumably accounts for the 2- to 3-month differential in maturation time.

Spawning begins in late February or early March and continues to June. In some areas the season is protracted since small scallops are caught throughout most of the year. This is probably due to variation in sexual maturation rate, growth rates, and water temperature. The lowest frequency of small scallops occurred in February indicating decreasing temperatures in the fall terminate any protracted spawning.

Protracted spawning during one season conceivably leads to protraction during the next. Since growth is related to temperature, scallops spawned early in spring have a longer growing season than do those spawned later in the year. Therefore, the older individuals in a year class would undoubtedly be larger at spawning than the younger individuals. Further, maturation is probably controlled by hormones which in turn are influenced by some environmental factor such as water temperature. This interaction between age, environment, and reproduction needs clarification.

Growth curves through all sizes ranges cannot be calculated from the survey data since the earliest stages are omitted. The curve is sigmoid from seed size to senility, rapidly increasing from 5 to 50 mm. Then the rate decreases through senility with maximum size about 80 mm.

Data from 1967 and 1968 indicate only one year class is present in spring but two year classes are present from early summer through winter. Therefore, the maximum age reached by calico scallops must not be greater than 24 months and averages 18 to 20 months.

Mortality rates computed from the survey data support a 2-year maximum life span. Post-spawning mortality averages 23% per month. At that rate only 20% of the year class would remain by early fall. Assuming that some mortality occurs during the pre-spawning period, the remaining population in 18 to 20 months would be exceedingly small.

Scallops are not randomly distributed but form north-south windrow configurations. These configurations, established at spat set, are heavily influenced by currents. Olsen (1955) indicates that windrow-like configurations result from strong tides, their orientation running lengthwise to the tide. He also shows strong linear configurations result in eddy systems.

This latter situation is analogous to that off eastern Florida. Little is known about substrate preference. Some beds offering optimum conditions may be perpetuated for several years, but competition for space between adults and spat must minimize such occurrences. If spat are unable to compete effectively for substrate, the presence of live adult scallops on the bed may prevent spat set. This question needs to be answered in the near future.

Yearly distribution and abundance depend on both spawning success and spat set. Commercial size and abundance are generally reached by early fall, usually in October. Fishing remains optimal until February when catch rates and yield decrease. This is due to spawning and associated factors such as increased mortality and meat deterioration.

In October 1967 scallops averaged about 45 mm and yielded 75 to 80 meats per pint. During October the survey produced an average catch of 70 lb. of meats per 30-min drag as compared with 20 lb/drag in April.

A fall and early winter fishery is expected to be most productive. Fishing is not recommended during spring because catch rates and yield are generally low and a spring fishery could have an adverse effect on the spawning population.

The nonrandom distribution and variable size of beds make it difficult to estimate the standing crop from dredge surveys. Scallops were found over approximately 285 square miles of bottom during the survey but less than 14% (37 miles) was covered by the dredge. About 6,500,000 scallops were caught during the survey. Scallops are not randomly distributed on the grounds but occur in beds where very high densities are often reached. Relatively few individuals occur between beds. Beds are difficult to measure but some were estimated to be several hundred yards in width and over a half mile in length.

Photographs taken during the *Aluminaut* dive show that densities of five scallops per square foot occur on some beds (Taylor, 1967). A minimum of 285 square miles of scallop bottom was found during the survey and varied densities occurred over that area. If 10% (28 square miles) supported densities approximating those found by the *Aluminaut*, then an estimated standing crop of 3,892,000,000 scallops existed in 1967-68. This figure is derived from the following: 28×27.8 million (no. ft^2/mile^2) $\times 5$. That population could easily support 10 boats fishing at a rate of 1,500 lb/day. At an average of 70 scallops per pound, 10 boats would take a total of 31,500,000 scallops per month at the above rate. This is approximately 1% of the estimated standing crop.

Recent explorations with RUFAS indicate that densities estimated from the *Aluminaut* cruise may be ultraconservative (Cummins et al., see footnote 5). Films from the RUFAS survey indicate that scallops may reach densities as high as 10 or more per square foot providing a standing crop is considerably above that given previously. Findings from the RUFAS survey will be published in the near future by personnel from the Exploratory Fishing Station in Brunswick, Ga.

Yearly variations in distribution and abundance may at first glance be discouraging to a fishery. However, the remarkable opportunity to predict each fall fishery exists because distributional and abundance patterns are established in spring or early summer—perhaps as early as May or June. Population assessment at that time would provide estimates on the standing crop and determine the success of a fall fishery some 4 or 5 months prior to its onset. The authors tested this hypothesis in the spring and summer of 1970 using the RUFAS vehicle.

SUMMARY AND CONCLUSIONS

The survey data show that calico scallops have a short life span of 18 to 24 months. Spawning occurs after a 7- to 9-month sexual maturation period in early spring. Some protracted spawning was noted for localized areas. Although growth rates were not determined for sizes smaller than about 5 mm, the estimated growth curve between 5 mm and senility (75 to 80 mm) is sigmoid, rapidly increasing to about 50 mm and then decreasing to death.

Monthly mortalities for December to October average approximately 20%. Mortality curves were generally curvilinear after spawning, indicating a rapid post-spawning dieoff.

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