ASPECTS OF REPRODUCTION OF THE BLUE MUSSEL, *MYTILUS EDULIS* (PELECYPODA: MYTILIDAE) IN LONG ISLAND SOUND

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ABSTRACT

A population of *Mytilus edulis* in Long Island Sound, Fairfield, Conn., was studied for 2 years to determine the sequence of gametogenic development of gonadal tissue and the frequency and duration of spawning under natural conditions. This population spawned annually in May-June. "Dribble spawning" occurred during the winter months of 1982. Sexes were distinguishable in all size classes studied, except those individuals in an "inactive" condition (stage 0). A low incidence of simultaneous hermaphroditism suggests that *M. edulis* is a stable gonochoric species. There was no evidence of protandry. Sex ratios of *M. edulis* 26.0-72.1 mm shell length did not differ significantly from 1:1. Photomicrographs of the gametogenic cycles of both male and female mussels are included.

The edible blue mussel, *Mytilus edulis*, is a widely distributed species, common to littoral and shallow sublittoral habitats in boreal and temperate waters of both Northern and Southern Hemispheres. The literature on the reproduction of *M. edulis* is extensive, probably because of the species' ubiquity in nature, as well as its commercial value (see Bayne 1976). Most of the studies have been done on European populations of *M. edulis*, which, in general, are characterized by extended spawning seasons with gamete release possible throughout the year (Lebour 1938; Lubet 1957; Havinga 1964; Andreu 1968; Jensen and Sakshaug 1970).

Limited information on North American populations suggests that although spawning can occur throughout the year (Moore and Reish 1969), the majority of the populations have a well-defined breeding season. On the basis of a 6-mo study (April-September) of the larval settlement period of *M. edulis*, Loosanoff and Engle (1944) concluded that the spawning period for blue mussels in Long Island Sound is May-August. Similarly, Hrs-Brenko (1971), after a 5-mo study (March-July) involving the examination of gonadal tissue, concluded that the spawning season of blue mussel in the southwestern part of Long Island Sound occurred with a single release of gametes during May and June. Since neither study followed the reproductive cycle for an entire year, however, it is difficult to draw conclusions about the annual spawing cycle of blue mussels in this locale.

In the most complete study to date in the Long Island Sound region, Newell et al. (1982) concluded that *M. edulis* from Stony Brook, Long Island, (southeastern shore of Long Island Sound) spawn in the spring, while they noted that a population at the same latitude on the southern shore of Long Island spawns 3 mo later. Clearly, it is difficult to make generalizations about the spawning behavior of this species.

In an attempt to more clearly define the breeding habits of *M. edulis* in Long Island Sound, the results of a 2-yr study to determine 1) the age of maturation and annual gametogenic development in a natural population and 2) the frequency of spawning of blue mussels along the southwestern shore of Long Island Sound are presented in this paper.

MATERIAL AND METHODS

Monthly collections of *M. edulis* were made from the mouth of Southport Harbor in Fairfield, Conn., (lat. 41°08'N, long. 73°17'W) from September 1980 to January 1982 and March 1982 to August 1982 (Fig. 1). In February 1982, two sampling collections were made, one in the beginning of the month and the other at the end. Sample sizes varied from 18 to 25 mussels, 26.0-72.1 mm shell length. A total of 534 mussels were examined and used in the analysis of the reproductive cycle.

In the laboratory, *M. edulis* samples were numbered, their maximum length (±0.1 mm) measured, and their gonad color noted. A section of the mantle with gonad was removed and fixed in 10% buffered

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Manuscript accepted May 1983.
FISHERY BULLETIN: VOL. 81, NO. 4, 1983.

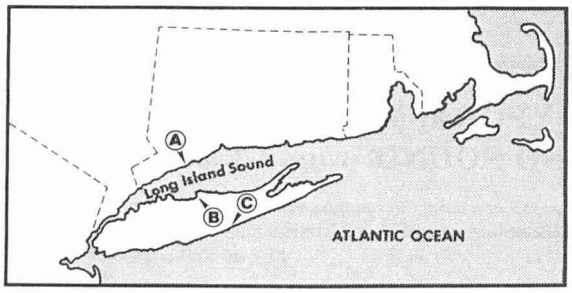


FIGURE 1.—Map showing locations of the Fairfield, Conn., study site (A) and the Stony Brook and Shinnecock, N.Y., study sites (B and C, respectively) (Newell et al. 1982).

Formalin[2]. This procedure was carried out during the first 4 mo of study. During the remainder of the study, sections of the mantle tissue and the visceral mass gonadal tissue were removed, since a closely related mussel of the family Mytilidae, *Geukensia demissa*, was shown to contain one type of sex cell in the mantle and the other in the visceral mass (Brousseau 1982). The *M. edulis* tissues were then prepared histologically for examination according to the method described by Brousseau (1978). A microscopic examination was made of the mantle and visceral mass gonadal tissues before assigning each individual to the appropriate category of gonadal condition as described by Chipperfield (1953). The results were based on the developmental condition of the mantle tissue in all individuals examined.

Mean oocyte diameter was determined for a representative sample of ripe females, selected at random from each of the reported spawning periods. Twenty oocytes per individual were measured using an ocular micrometer. Only those oocytes which were spherical in shape and ready for release were selected for measurement.

The reproductive condition of the mussels was measured by stereology, a procedure adopted by Bayne et al. (1978) and Newell et al. (1982). This method is based on a procedure referred to as point-counting volumetry, which is accomplished by superimposing a regular point lattice on the tissue section and counting the points which lie on transections of the sex cells (Weibel et al. 1966). The proportion of gonadal tissue that is comprised of follicles containing developing or ripe gametes is reported as the "gamete volume fraction" (GVF). For any individual mussel, the GVF can vary between zero, for a reproductively inactive mussel, and one, for a mussel showing maximal reproductive development. The monthly mean GVF represents the mean of 10 estimates of the GVF from each mussel sampled. The number of mussels included in the estimate varied from 18 to 25. These proportions were then arcsine transformed, and the variance for each monthly GVF was calculated.

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

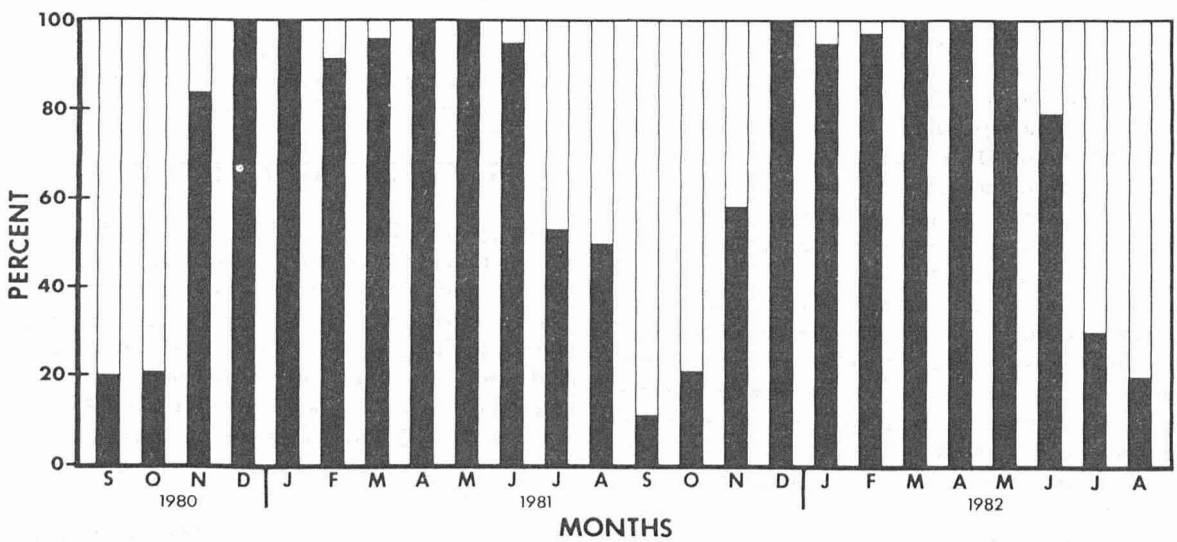


FIGURE 2.—Proportion of *Mytilus edulis* population with active or inactive gonads during 1980-82. Open portions of each represent inactive gonads (indifferent, no gametogenesis, or spent); solid portions represent active gonads (developing, ripe gametes, or partially spawned). Observations on males and females are combined.

RESULTS

Reproductive Cycle

Reproductively active individuals were encountered throughout the 2-yr study period with the largest numbers occurring in December 1980; January, April, May, and December 1981; and March, April, and May 1982 (Fig. 2). In September 1980, gametogenesis had begun in both sexes. Ripe mussels were observed in the February samples and by mid-April about 96% were gravid (Fig. 3). Spawning began in May and continued through the summer with most of the gametes released in June.

A similar spawning pattern was observed in 1981-82, except that gametogenesis began 1 mo later, and individuals with ripe gametes appeared in December. Presence of a sizable number of ripe individuals in the population during winter months suggests that the spawning period in 1981-82 was earlier and less defined than in the previous year. Although completely spent individuals were not present in any of the samples until June 1982, the presence of partially spawned mussels indicates that during the second year of this study, "dribble spawning" may have occurred during the winter and early spring. Although no direct information is available on the environmental factors, such as temperature and food availability, it seems reasonable to assume that annual variation in one or a combination of such factors was responsible for this difference in the timing of gametogenic events.

The GVF values for male and female *M. edulis* from this population are given in Figure 4. During both

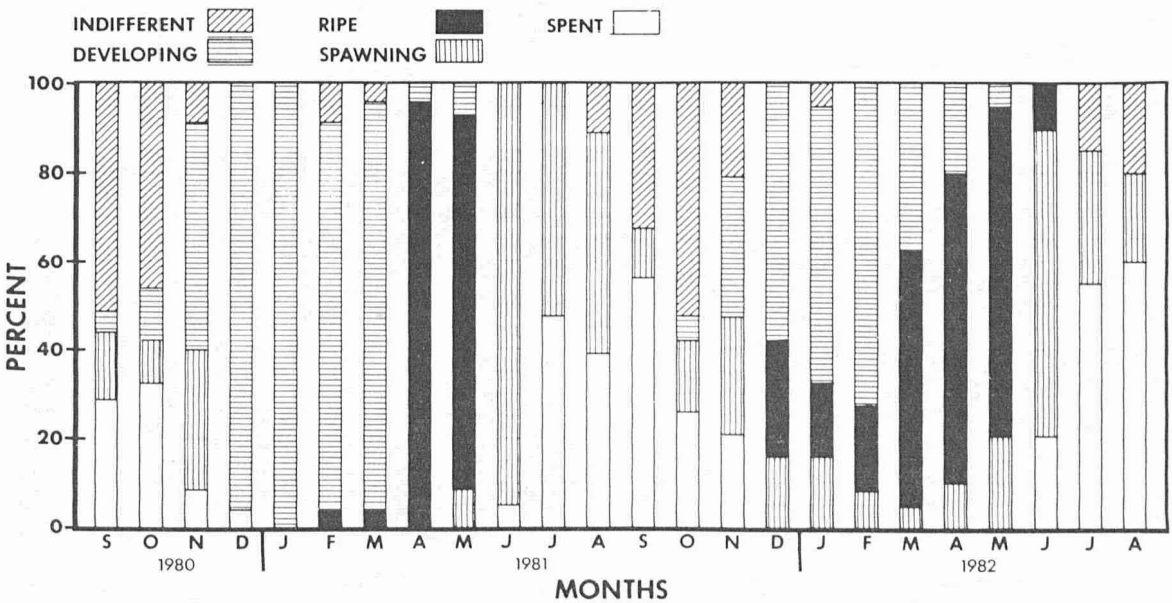


FIGURE 3.—Proportions of *Mytilus edulis* with gonads in each developmental phase during 1980-82. Values for males and females are combined.

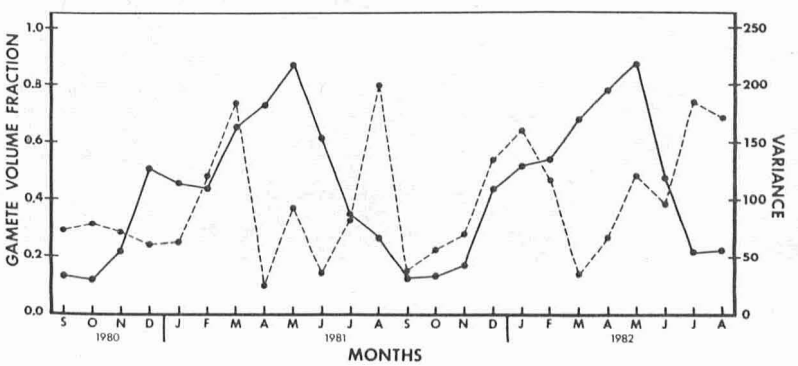


FIGURE 4.—Mean gamete volume fractions (solid line) and variance (dotted line) for *Mytilus edulis*. Values for males and females are combined.

years of the study, the pattern of the GVF values and the maximum GVF attained were similar. The postspawning minimum GVF occurred in October 1980 and in September 1981. Increasing GVF values in November of both years were due to the onset of gamatogenesis. Peak GVF values of 0.87 were observed in May of both years.

Variance in GVF during each sampling period provides a measure of the intrapopulation synchrony of the reproductive cycle. The larger the variance, the greater the variability in the gametogenic condition of individuals during that sampling period. In general, the mussels were most closely synchronized (i.e., lowest variance) during the spring months, when

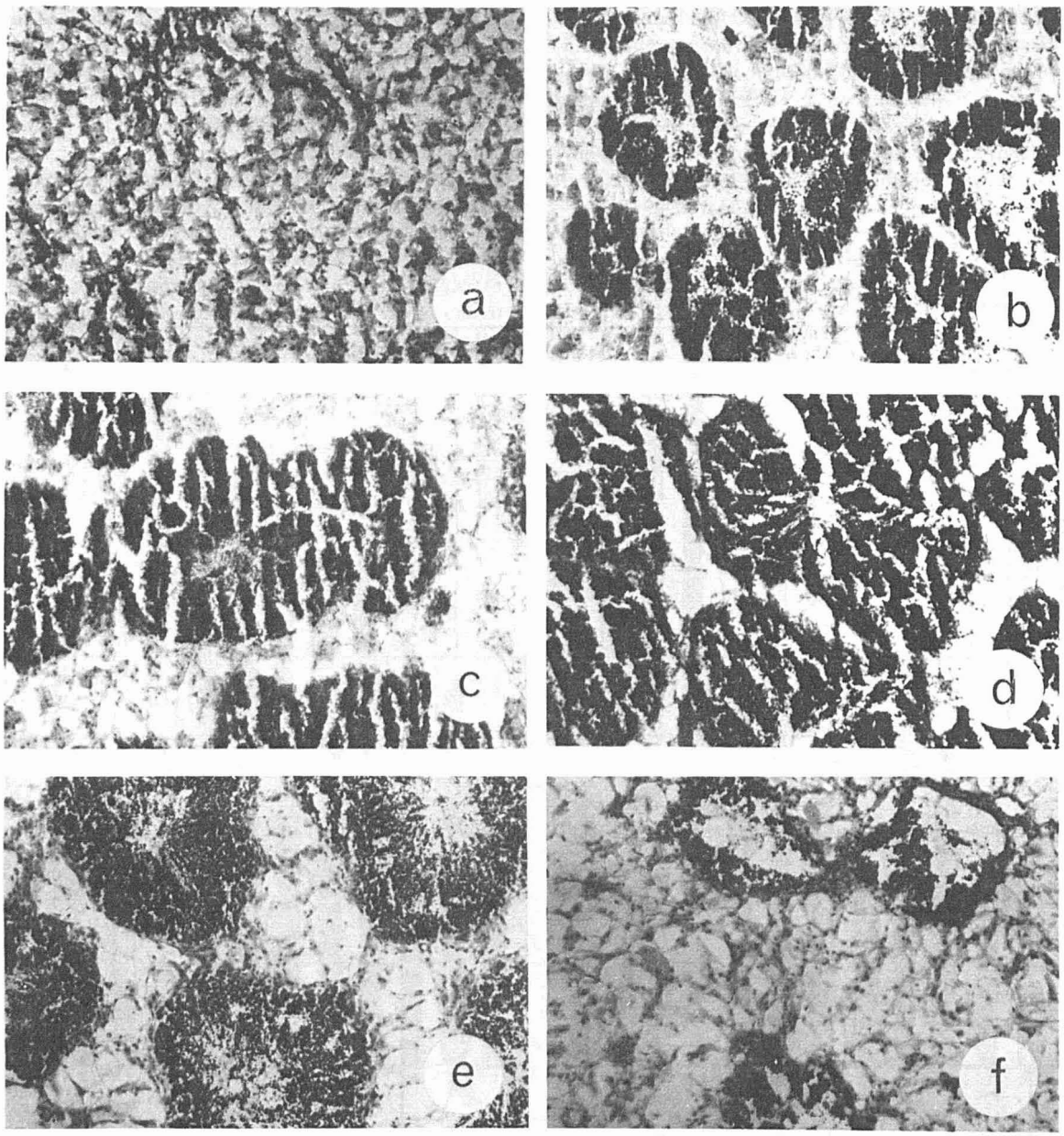
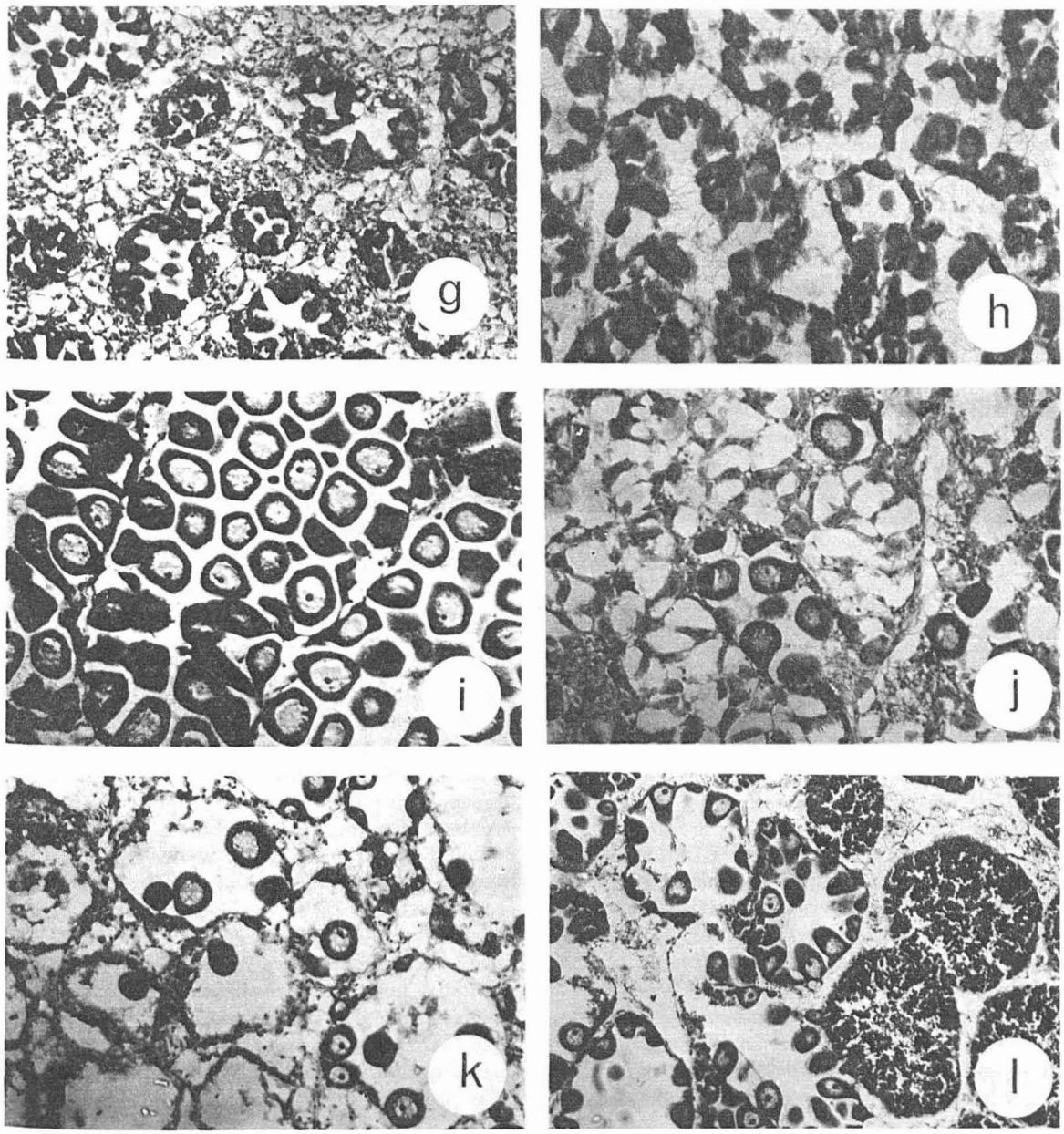


FIGURE 5.—Photomicrographs of the gonadal stages of male and female *Mytilus edulis* at 125× magnification. a) Inactive male or female (stage 0), 9 September 1980, b) early-developing male (stage I), 25 January 1981, c) late-developing male (stage II), 17 March 1981, d) ripe male (stage III), 15 April 1981, e) spawning male, 22 June 1982, f) recently spent male, 15 July 1981, g) early-developing female (stage I), 22

most mussels were in a ripe condition (stage III) (Fig. 3). As spawning proceeded, the variance increased, indicating that the mussels did not all release gametes at the same time. A second peak in the variance, however, occurred during February and March 1981 and December and January 1982. This apparent synchrony was probably due to an extended spawning period, especially during 1982. During that period, mussels were reported in various reproductive states (gametogenic, gravid, and spawning).

Photomicrographs of representative male and female stages in the spring and summer peaks of the annual cycle are shown in Figure 5. Stages are assigned according to the "index of bivalve gonad



December 1981, h) late-developing female (stage II), 17 March 1981, i) ripe female (stage III), 4 May 1982, j) spawning female, 5 October 1981, k) recently spent female, 22 June 1982, l) hermaphrodite, 22 January 1982.

maturity" procedure, first used by Chipperfield (1953). One problem with such a subjective approach is that it does not recognize intermediate stages of development. However, the stereology technique described above is also subject to criticism, since different gametogenic stages may have similar GVF values, as is the case with *M. edulis* (Fig. 6). It is only when the two methods are used together that a meaningful description of the gametogenic development of an animal can be constructed.

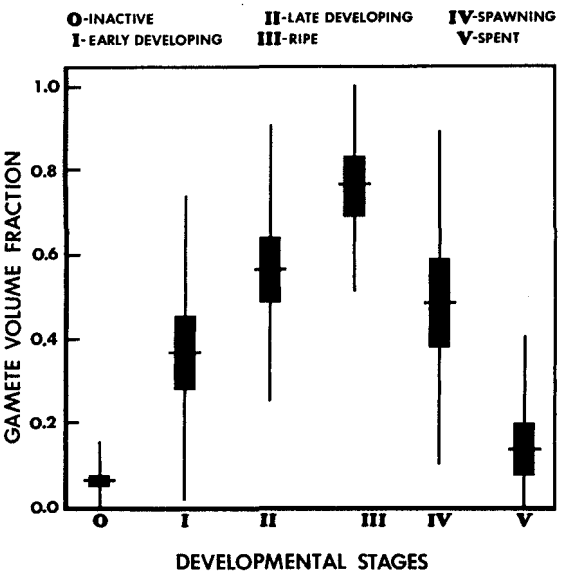


FIGURE 6.—Mean values of gamete volume fraction for each developmental stage of *Mytilus edulis*. Values for males and females are combined.

Sex Ratios and Gonad Color

Oocyte diameter of ripe females at the time of spawning was 0.065-0.070 mm. It is possible to determine the sex of mussels from the gonad color once the animal has reached stage III. At this time, the female gonad (mantle) is a definite apricot hue, while the male gonad is cream or yellow. During the other developmental stages, however, gonad color does not serve as a reliable indicator of the animal's sex.

In the population studied, the proportion of females in all size classes ($N = 235$) did not differ significantly from one-half. Male and female gonads were distinguishable in all size-classes studied (>26 mm). Although no protandry was observed, there was evidence of a simultaneous hermaphroditism in some individuals. One mussel contained both male and female gametes in the mantle, and 7 of 360 mussels (2%) contained one type of sex cell in the mantle and the other in the visceral mass. Trematode sporocysts (species undetermined) were found in the digestive gland and gonadal tissue of eight individuals collected from June to November.

DISCUSSION

Mytilus edulis is dioecious, the sexes of which are distinguishable either by examining the sex products or from inspection of gravid individuals. Female *M. edulis* are characterized by a bright orange to apricot gonad, whereas the males have a cream-colored gonad. This is due to the accumulation of carotenoids in the gonads at maturation (Campbell 1969). Few species of bivalves can be sexed in this manner. The low incidence of hermaphroditism exhibited by this species suggests *M. edulis* possesses stable gonochorism, a condition characterized by the presence of some hermaphrodites in a normally gonochoristic species.

Gonad examinations indicate that *M. edulis* from Fairfield, Conn., spawn once annually during May and June; however, the presence of ripe and partially spawned mussels during the winter months in 1982 (January and February) suggests that the major reproductive effort in the spring may have been preceded by a less synchronous release of gametes. It is interesting to note that Newell et al. (1982), in their study of two *M. edulis* populations on Long Island, reported that the one from Stony Brook exhibited one spring spawning peak, whereas the Shinnecock population spawned 3 mo later and over a more prolonged period. The spawning pattern of the Fairfield population is more similar to that observed for the mussels from Stony Brook than that of the Shinnecock population. This is not surprising; although all three populations are located at approximately the same latitude, only the Stony Brook and Fairfield populations are in Long Island Sound (Fig. 1). This finding, therefore, reinforces the interpretation by Newell et al. (1982) that latitudinal effects on the reproductive cycle of *M. edulis* are secondary to effects of habitat-specific differences in the time and duration of maximum food availability.

As more information on bivalves is gathered, it becomes clear that the traditional view of a single, fixed pattern of spawning for a population is inadequate. Instead, a certain degree of flexibility is possible, depending on variation in environmental factors. This flexibility can be manifested either as geographic variation among populations or as annual variation within a population. Existence of the former is well documented (see Bayne 1976; Sastry

1979); reproductive cycles of spatially separated populations differ. Annual variation is more difficult to document since establishing that this type of variation exists requires long-term, descriptive studies which are often laborious to carry out. Nevertheless, some information is beginning to emerge.

The dribble spawning which occurred during the winter of 1982 in the Fairfield mussels suggests such annual variation does exist in the *M. edulis*. Data on European populations also indicate that this species shows a remarkable ability to vary its spawning cycle in response to annual fluctuations in exogenous conditions (Bayne 1976). Similarly, data for other shallow water species, such as *Mya arenaria* (Brousseau 1978) and *Petricola pholadiformis* (Brousseau 1981), point to the existence of year-to-year variability within populations

ACKNOWLEDGMENTS

I wish to thank D. DeBeradinis for technical assistance in the field and the histological preparation of some of the material used in this study.

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