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EVIDENCE OF A SEMIANNUAL REPRODUCTIVE CYCLE FOR THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS* (GMELIN, 1791), IN THE MID-ATLANTIC REGION

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ABSTRACT The reproductive cycle of the sea scallop, *Placopecten magellanicus* in the mid-Atlantic region was studied over a 15 month period. One to 15 samples a month were collected from commercial vessels fishing from Long Island to Cape Hatteras in water depths of 37–68 m. Gonad weights were determined for four shell size intervals as an indicator of the reproductive cycle. A sharp decline in mean gonad weights between April–May 1987 and a subsequent increase and decrease in weights between September–November 1987 indicated reproductive processes were occurring on a semiannual cycle. A major spring spawning season was reconfirmed in 1988 by a rapid increase in mean gonad weights between December 1987–January 1988, followed by variable declines in the weights through June. The occurrence of spawning activity for 2 consecutive spring seasons in addition to a fall spawning season suggests that a semiannual reproductive cycle may be a characteristic feature of *P. magellanicus* in the mid-Atlantic region. The ramifications of spring spawning to the mid-Atlantic sea scallop fishery and management policies are addressed.

KEY WORDS: semiannual reproduction, *Placopecten magellanicus,* scallop, gonad weight

INTRODUCTION

In fisheries in which the weight of an individual or part thereof forms the basis for regulation and enforcement, information on the reproductive cycle is necessary. In several bivalve species, including the sea scallop *Placopecten magellanicus* (Gmelin), the adductor muscle decreases in weight during periods of gametogenic development and spawning as its energy reserves are utilized (Ansell 1974, Barber and Blake 1981, Robinson et al. 1981). If regulations and enforcement standards based on weight or count per unit weight fail to consider the changes associated with the reproductive cycle, the objectives of a management plan may not be achieved or industry may experience regulatory compliance problems. The latter problem is of growing concern for the United States sea scallop fishery of the mid-Atlantic region.

Reproduction in bivalves requires that sufficient energy is available for the development of mature viable gametes (Bayne 1976). In *P. magellanicus* this available energy is dependent on accumulated biochemical energy reserves within the organism, food sources in the water column, and water temperature conditions (Sastry 1966, MacDonald and Thompson 1985, 1986, Barber et al. 1988). Since these factors vary with latitude, depth, and hydrographic conditions, differences may exist in the reproductive cycle of the sea scallop as conditions vary along its geographic range from the Gulf of St. Lawrence to Cape Hatteras.

In marine invertebrate species of wide geographic range, variations in reproductive cycles often accompany changes in latitude. Clear latitudinal trends are not always evident. They can be masked by local environmental conditions such as available food and temperature (Giese and Pearse 1974, Sastry 1979). Southern populations, compared to their more northerly counterparts, have been shown to exhibit less synchronization of spawning (Newell et al. 1982), prolonged spawning seasons (Sastry 1979), and reduced fecundity (Serchuk and Rak 1983). The occurrence of semiannual spawning in southern populations as opposed to annual spawning in northern populations of the same species has been reported for *Mercenaria mercenaria* (Porter 1964), *Mya arenaria* (Pfitzenmeyer 1965), and *Spisula solidissima* (Ropes 1968).

Considerable research has been done on the reproductive cycle of sea scallops in the Northwest Atlantic. Most of this research has concentrated on the reproductive cycle of sea scallops on Georges Bank (Posgay and Norman 1958, MacKenzie et al. 1978), Gulf of Maine (Welch 1950, Robinson et al. 1981, Langton et al. 1987), Bay of Fundy (Stevenson 1936, Dickie 1953), and Newfoundland (MacDonald and Thomspon 1986). Research for these areas indicate an annual reproductive cycle, with a single spawning period occurring during the fall when water temperatures range between 8–16°C. Naidu (1970) and Barber et al. (1988), however, noted the possibility of minor spawning during the spring in addition to a major spawning period during the fall off the coasts of Newfoundland and Maine, respectively. MacKenzie et al. (1978), however, did provide information that sea scallops in the mid-Atlantic region may spawn slightly earlier than those in the Northwest Atlantic. These results, based on macroscopic observations of gonad tissue over a 1-week period, indicated that scallops off Long Island and Virginia spawned during July or August.

In comparison, little sea scallop research appears to have been concerned with determining whether or not there are differences in the reproductive cycles for different fishery

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resource areas. As a result, the management and regulation of the sea scallop fishery have been based upon the assumption that the primary spawning period for sea scallops of all resource areas is during the fall.

This paper examines the possibility that scallops in the mid-Atlantic region may have a different reproductive cycle than previously documented. The examination of the reproductive cycle is based on an analysis of gonad weights for 4 shell size ranges over a 15-month period.

MATERIALS AND METHODS

Scallops were obtained from commercial fishing vessels participating in the cooperative sea scallop research program involving industry, National Marine Fisheries Services, New England Fisheries Management Council, and Virginia Institute of Marine Science. Data collection began in April 1987 and is to continue through December 1988. Due to the commercial nature of the scallop samples, it was not possible to preselect the catch location or frequency.

Samples ranged from south of Long Island (40°00′N 73°00′W) to north of Cape Hatteras (37°30′N 74°30′W). This is an area ~290 km long running northeast to southwest in water depths of 37–68 m. Most samples were from areas off the coasts of Virginia and Maryland between 38°30′N 74°00′W and 37°30′N 74°30′W. This is an area ~145 km long (Fig. 1).

This study is based on a subsample of scallops obtained from 123 trips between April 1987–June 1988. The number of trips in a given month varied between 1–15. An entire sample usually consisted of 1–2 baskets of unshucked scallops containing between 140–400 scallops/basket. Each basket has an approximate capacity of 1.5 bushels. A subsample of 40–120 scallops was randomly selected from each of these samples.

Each sample was processed within 48 hr of initial collection. At the time of collection, the date and time of the sample, Loran C coordinates, water depth, and surface water temperature were recorded. The adductor muscle and gonad were dissected from each animal. The wet weight of the gonad, with the crystalline style included, was measured to the nearest 0.1 g using an Ohaus Portogram scale. The shell height, the maximum distance between dorsal and ventral margins, was measured to the nearest mm using a standard fish measuring board. A total of 8,002 gonad weight-shell height measurements were compiled for the 15 months of data used in this study.

Time of spawning can be approximated from macroscopic observations of gonad tissue. Changes in gonad weight, however, provide a quantitative indicator of spawning and reproductive development (Giese and Pearse 1974). Standardized gonad weights have been used to determine the reproductive cycle of many bivalve and fish species, and are especially accurate for *P. magellanicus* because the gonad is self-contained and the follicles are retained after spawning; therefore, the majority of weight differences prior to and following spawning can be attributed to the presence or expulsion of gametes as well as their state of maturity (Langton et al. 1987). As gonadal development proceeds, the organ will increase in weight and reach a maximum size just prior to spawning and a minimum size immediately following spawning. Studies which have utilized standardized gonad weight changes or indices with *P. magellanicus* include Thompson (1977), Robinson et al. (1981), Serchuk and Rak (1983), Beninger (1987), Langton et al. (1987), and Barber et al. (1988).

Four 5 mm size intervals for each month were selected for analysis. The selected intervals were 85–89 mm (N = 1,153), 90–94 mm (N = 1,522), 100–104 mm (N = 1,104), 110–114 mm (N = 744), and 85–124 mm (N = 8,002). These intervals were selected because they contained the largest number of observations for each month and were indicative of the size distribution of the commercial harvest. Moreover, the 85–89 and 90–94 mm intervals represent size ranges which generally yield more or less than 30 meats/lb., respectively. The 90–94 mm interval also represents scallops which are believed to have been reproductively active for at least one spawning season (N.E.F.M.C. 1982). Data for both males and females were combined to calculate monthly mean gonad weights for each size interval. Student's t-tests (Snedecor and Cochran 1980) were performed on data from adjacent months for all size groups to determine significant differences.

RESULTS

Mean values of the gonad weights for the four, 5 mm size ranges indicated a consistent pattern over the 15-month period of observations (Table 1, Fig. 2). The weights declined between April–May 1987 and remained low with minor variation between May–September. The weights increased between September–October, followed by a decline in November 1987.

The mean gonad weights for the 4 size groups displayed a less synchronous pattern during the first 6 months of 1988. Although weights for all sizes increased between December 1987–January 1988, mean gonad weights did not reach maximum values during the same month following January. Maximum values for the 110–114 mm size group were observed in February, the 100–104 mm group in January, and the 85–89 and 90–94 mm scallops in March. After March, the mean gonad weights for all size groups declined.

While similar changes in gonad weights were evident in all size groups, results of one-tailed t-tests for inequality of indices between adjacent months were not identical, indicating slight variation in the timing of gonadal development and decline (Table 1). T-tests did not support the null hypothesis of no significant difference between mean gonad weights of adjacent months in the 4 size intervals between April–May 1987, September–October 1987, October—November 1987, December 1987–January 1988, and

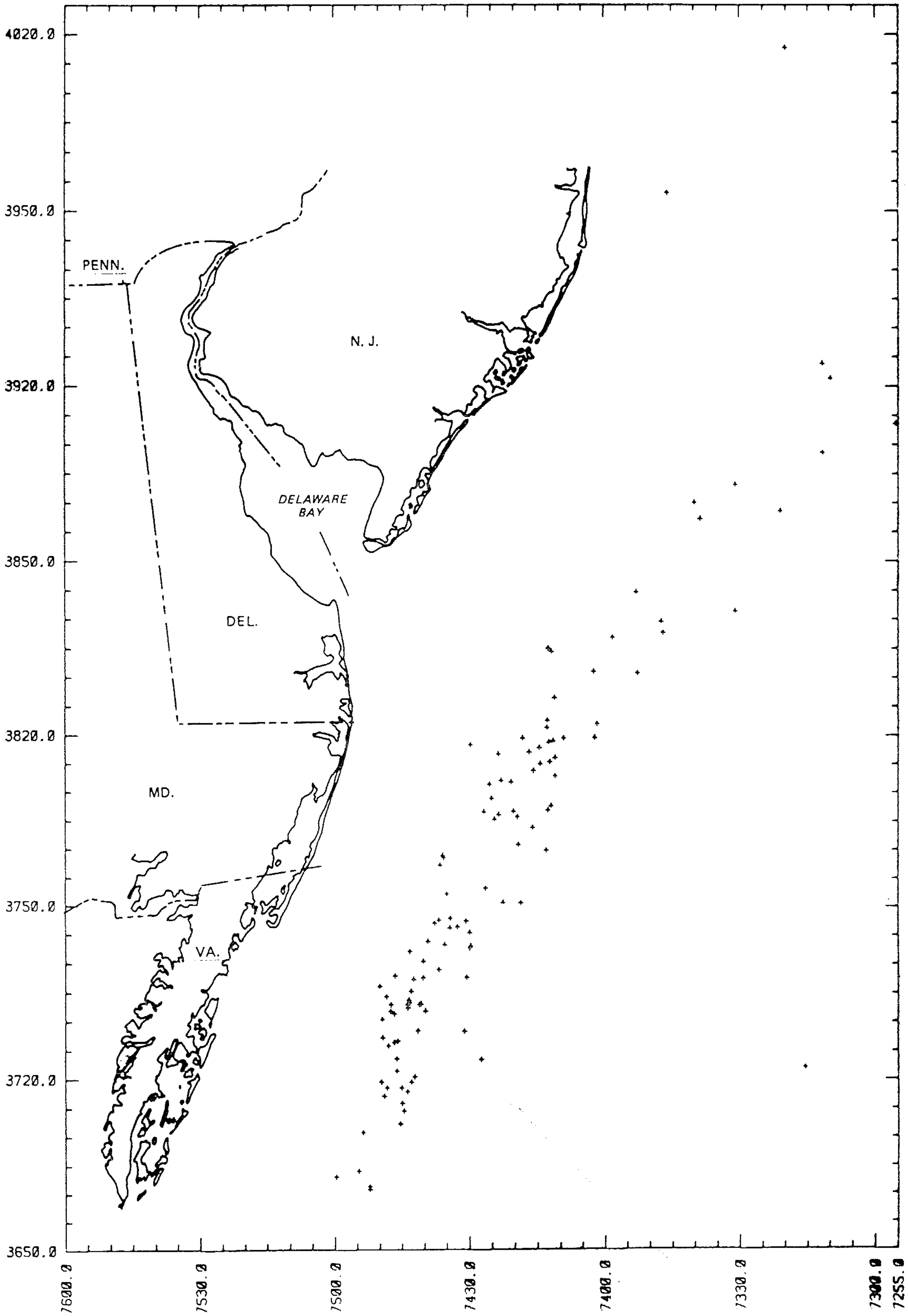

Figure 1. Distribution of *P. magellanicus* samples collected from commercial fishing vessels in the western, mid-Atlantic region (N = 123).

TABLE 1.

Mean gonad weight (X), standard deviation (S), and number of observations per shell size interval (N) for *P. magellanicus*, mid-Atlantic region, April 1987–June 1988.

Month	Shell height (mm) 85–89			90–94			100–104			110–114		
	Gonad weight (grams)											
	X	S	N	X	S	N	X	S	N	X	S	N
Apr. 87	7.6	1.9	25	8.5	1.6	17	12.1	2.9	6	16.4	5.4	4
May	3.0	2.4	34[1]	3.1	1.9	35[1]	5.9	1.8	13[1]	6.7	3.0	11[1]
Jun.	2.4	1.3	22	3.4	1.6	41	4.6	3.0	24	6.9	1.9	2
Jul.	2.0	0.5	6	2.1	0.7	9	3.6	1.9	5		——[2]	
Aug.	2.3	0.7	46	2.4	0.8	80	4.0	1.0	40	5.2	1.1	6
Sep.	2.8	1.1	30[1]	3.0	2.1	58[1]	4.0	1.6	33	6.2	3.6	10
Oct.	5.1	2.9	33[1]	5.4	2.7	52[1]	8.1	3.9	45[1]	12.3	4.5	19[1]
Nov.	2.2	1.8	18[1]	2.9	1.7	35[1]	4.4	2.4	33[1]	7.4	5.1	26[1]
Dec.	2.6	1.1	35	2.8	1.0	33	6.4	2.5	53[1]	7.4	2.1	43
Jan. 88	3.9	0.6	163[1]	5.2	0.2	138[1]	9.7	0.3	138[1]	12.4	0.4	103[1]
Feb.	4.5	2.0	137[1]	5.0	2.1	159	9.2	4.2	54	13.0	5.0	61
Mar.	5.2	1.8	180[1]	6.0	2.0	227[1]	9.4	3.4	128	12.3	3.7	128
Apr.	4.1	1.8	128[1]	5.1	2.5	156[1]	7.3	3.3	156[1]	11.0	5.2	99
May	3.6	1.7	172[1]	4.0	1.9	219[1]	6.3	3.2	188[1]	10.4	5.2	132
Jun.	1.6	0.8	163[1]	2.1	1.0	262[1]	3.6	1.7	239[1]	4.9	2.1	128[1]

[1] Indicates statistically significant difference ($p < 0.05$) between the preceding and referenced month.
[2] No data available for size range.

May–June 1988 ($P < 0.05$). Significant differences in weights were also detected between other adjacent months but not consistently for all size groups and time periods. An increase in gonad weight occurred between August and September 1987 was significantly different for only the 2 smaller size groups. Gonad weights in the 100–104 mm interval significantly increased in weight between November–December 1987. Gonad weights significantly increase for all size ranges between December 1987–January 1988. Significant increases were also evident in the 85–89 mm group from January–March 1988 and in the 90–94 mm group between February–March 1988. While all groups rapidly decreased in weight between May–June 1988, significant decreases in weight also occurred from March–May 1988 in the 3 smaller size groupings.

DISCUSSION

The sharp decline in mean gonad weights betwen April–May 1987 was the first indication of major spawning activity in the spring. Minimal mean gonad weights from June–August reflected a period of quiescence. The majority of the gonads were observed to be undeveloped, translucent and small in size. Slight increases in the mean gonad weights between August–September 1987, significant in the 85–89 mm and 90–94 mm size groups marked the initiation of gonadal development in the fall. The increase to maximum values by October 1987 indicated that most reproductive development was rapid and complete within a one month period. Subsequent post-spawning indices in November were similar to post-spawning indices observed in the preceding summer but of shorter duration. The majority of gonad redevelopment preceding the next spring spawning season occurred rapidly between December 1987–January 1988.

There is evidence of differential gonadal development in various size classes from January–March 1988. Although gonadal development in this second spring season appeared to be protracted over an extended period, subsequent spawning indicated by the sharp decline of mean gonad weights in all size intervals between May–June was similar to that observed between April–May of the previous year. This repeated pattern in spring 1988 confirms the presence of a major spring spawning period.

Because this study period did not cover pre-spawning months for spring 1987, it could not be determined if the protracted state of gonad maturity evident from January–March 1988 also occurred in early spring of the preceding year. A protracted period of gonad development did not precede the fall spawning period. However, when a semiannual reproductive strategy exists, the 2 spawning events occurring within 1 year are often unequal in magnitude and duration (Mason 1958, Ropes 1968, Comely 1974). While variability in initiation, duration, and nature of the reproductive cycle may exist, the occurrence of spawning activity for 2 consecutive spring seasons concurrent with a fall spawn suggests that the semiannual frequency of reproductive development may be a characteristic feature of *P. magellanicus* in the mid-Atlantic region.

Small but significant differences in gonad weight between size groups from January–April 1988 may be attrib-

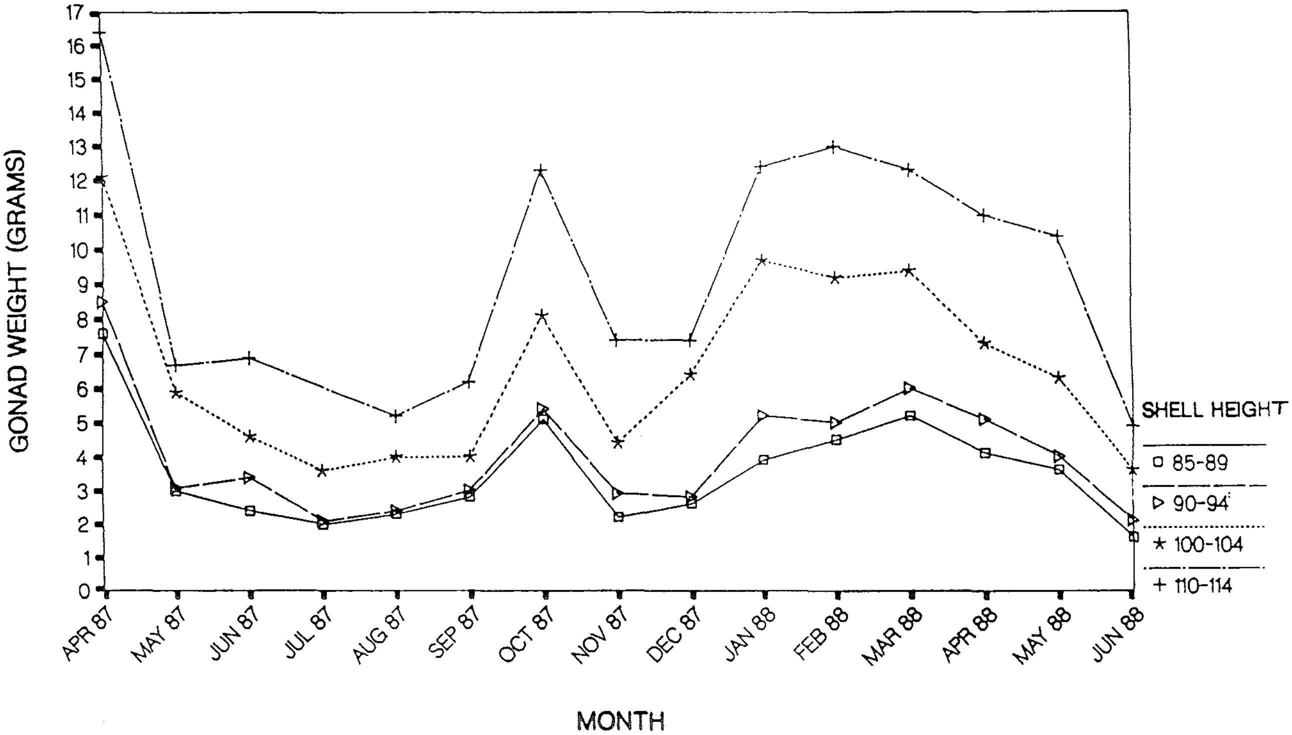

Figure 2. Mean gonad weight (X), standard deviation (S), and number of observations (N)/shell size interval for *P. magellanicus*, mid-Atlantic region, April 1987–June 1987.

uted to aggregation bias as a result of pooling data over a relatively large geographic area and depth range. As a result, the mean gonad weights may reflect area and depth differences as well as monthly differences. Unfortunately, the available data were inadequate for a more precise area and depth analysis. However, despite noted site specific variability in bivalve reproduction, it is important to recognize that the semiannual frequency of reproductive development was observed in all areas sampled. This phenomenon, consistent over a wide geographic range, should be considered a significant factor in the reproductive strategy of the sea scallop.

The significance of the spring spawning to the recruitment processes of the mid-Atlantic sea scallop fishery is uncertain. However the possibility of 2 periods of recruitment warrants further study. In species in which fertilization occurs externally in the surrounding water, synchronicity is critical to the reproductive success of a spawning season and the size of the resultant year class (Langton et al. 1987). The possibility of lysis and resorption of mature oocytes as opposed to the spawning of viable ova is also possible. This phenomenon has been observed in *Argopecten irradians* (Sastry 1966), *Pecten maximus* (Lubet et al. 1987), and *P. magellanicus* (Barber et al. 1988) when spawning was delayed due to low temperatures or lack of food.

Despite the unknown significance of the spring spawning in terms of fishery recruitment, the economic and management ramifications of semiannual spawning may be quite significant. Previous studies have indicated that meat weight for a given shell size changes significantly over the duration of a spawning event (Robinson et al. 1981). Recent management decisions (N.E.F.M.C. 1985, 1987) to allow a seasonal increase to 33 meats/lb. during the months of October–January are an indication that management is sensitive to the problem. Similar implications for a semiannual spawning period represent inequities for harvesters in the mid-Atlantic region when spawning related meat weight losses occur in the spring. Given the indications that there may be significant spatial, seasonal, and interannual variation in sea scallop meat weights, serious consideration must be given to altering the management strategy and enforcement procedures based on meat counter restrictions. Additional management strategies such as gear modifications and effort control measures should be under continuous review given the nature of the fishery. Concurrent with the data presented in this paper, further studies of the reproductive cycle are being undertaken, including histological examination of gonadal tissue, analysis of gonadal index changes associated with seasonal, depth, and spatially related influences, and correlation of adductor meat weight changes to reproductive activity.

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