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NOTE ON MUSCLE GLYCOGEN AS AN INDICATOR OF SPAWNING POTENTIAL IN THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*

During the reproductive cycle of the Atlantic sea scallop, *Placopecten magellanicus*, glycogen levels rise and fall in the hemolymph (Thompson 1977) and in the adductor muscle (Robinson et al. 1981; Gould 1983), reflecting the buildup of glycogen reserves in the muscle and their later transfer to the gonad. Muscle glycogen normally rises to a yearly peak in spring after the phytoplankton blooms, then is transferred to the gonad for gamete differentiation and maturation (Robinson et al. 1981). The glycogen transfer is followed by an increase in size of the maturing gonad and a loss of muscle weight (Gould 1983). During the autumnal algal blooms, glycogen levels in the muscle rise again slightly and drop thereafter to an annual low during the winter months, when the small energy reserves are used for basal maintenance and to initiate gametogenesis.

Glycogen reserves from the muscle and lipid reserves from the digestive gland are the major sources of stored energy supplied to the scallop gonad. High spring glycogen levels most dramatically indicate the degree of buildup of energy stores used to fuel gamete differentiation and maturation, whereas low winter muscle glycogen levels correspond to the postspawning exhaustion of reserves. Winter values higher than the normal range for any given population, therefore, could indicate an unusually large and extended period of nutrient availability, but more probably would suggest resorption of gametes.

We suggest, therefore, that the spring peak and the winter ebb of muscle glycogen be used as measures of the relative spawning potential and spawning success, respectively, for *Placopecten*. Sampling during these two seasons may readily provide information on the recruitment contribution of different scallop populations.

Timing of the seasonal high and low values for this metabolic parameter can vary by several weeks from year to year, reflecting the timing and intensity of phytoplankton blooms (themselves dependent on other environmental variables), and the time and degree of success in spawning. To obtain a practical data base for this major measure of seasonal energy reserves, therefore, we sampled a single bed of sea scallops off Asbury Park, NJ, on a year-round monthly basis for 3½ years. In examining mean annual high and low muscle glycogen values for these scallops, data were averaged for animal collections from mid-April through June each year to arrive at a general value for the spring buildup and peak. Although such values do not indicate the maximal glycogen values, which may be reached either gradually or quickly in any of those months, an average better enables year-to-year comparisons. Data for collections from late November through February were similarly averaged to obtain a value for the postspawning winter period of low muscle glycogen.

We used this same parameter for specimens collected from random sites in the Gulf of Maine, and found a different seasonal pattern in scallops from depths greater than ca. 110 m. Because these deepwater sea scallops came from many different sites in the Gulf of Maine, data were averaged for each collection date for each site. This report presents our data for spring and winter adductor muscle glycogen in a single subtital sea scallop population for the years 1981–84, and in deepwater sea scallops from the Gulf of Maine for 1980–82.

Materials and Methods

Asbury Park sea scallops were collected by trawl from a site 31 m deep on the southern shelf of the Hudson River Canyon off Asbury Park, approximately 37 km NNE of Manasquan Inlet (ca. 40°13′ × 73°47′). Collections were made at monthly intervals from spring 1981 through late July 1984 and during two intensive weekly sampling periods from early May through mid-June in 1983 and 1984, to monitor the spring buildup of muscle glycogen. For some months, particularly in the spring of 1982, collections were not available. Each collection comprised 6 males and 6 females (shell height 95–110 mm). The sea scallops were held overnight in 5°C aerated seawater at the Northeast Fisheries Center's (NEFC) laboratory at Sandy Hook, NJ, and transported the following day in a cooler to the Milford, CT, NEFC laboratory. For transport, the sea scallops were placed on top of paper toweling that had been soaked in seawater, then wrung out and layered over ice enclosed in a sealed plastic bag. The animals were dissected the same day, and all tissue specimens were stored at −80°C until testing. Gonad volumes were also noted. Deepwater sea scallops were dissected on shipboard immediately after collection by trawl, and the muscle tissue held at −40°C while at sea, then transferred on dry ice to the −80°C freezer in Milford. Because we relied on volunteer help for many of these collections, gonad data were not always available for shipboard samples of adductor muscle from deepwater sea scallops.

Muscle dissection, tissue preparation, and the procedure for glycogen analysis are described in detail elsewhere (Gould et al. 1985); glycogen levels are presented as μg of glucose per gram of wet tissue ($\mu g\ g^{-1}$). Because there were no detectable differences between sexes for muscle glycogen levels, data for males and females were combined.

Results and Discussion

Asbury Park Sea Scallops

In the spring of 1981, the Asbury Park sea scallops had muscle glycogen levels averaging higher than 2,000 $\mu g\ g^{-1}$ (Table 1). Such levels are not uncommon in well-fed scallop populations, as observed during several years of monitoring activity on the continental shelf off New England and the mid-Atlantic states (Gould 1981, 1983) during the NEFC's Ocean Pulse/Northeast Monitoring Program (NEMP) and the NEFC's Resource Assessment surveys. The mean annual low levels in the

TABLE 1.—Seasonal high and low levels in adductor muscle glycogen for both males and females in a single population of sea scallops off Asbury Park, NJ. Values were averaged for mean seasonal highs during and after spring phytoplankton blooms (April, May, June) and for mean seasonal lows after spawning (December, January, February). Gonad volumes are also shown for the same time periods.

Year	Season	Sample N	Muscle glycogen ($\mu g\ g^{-1}$) $\bar{x}$	SE	Annual ratio spring:winter	Gonad volume (mL) $\bar{x}$	SE
1981	Spring	34	2,217	283		no data	
1982	Spring	24	544	32		5.42	0.74
1983	Spring	84	610	15		6.23	0.29
1984	Spring	72	254	12		4.51	0.24
1981–82	Winter	22	203	18	10.9	6.50	0.47
1982–83	Winter	24	226	14	2.4	3.00	0.46
1983–84	Winter	12	490	57	1.2	2.75	0.39

Asbury Park sea scallops the following winter were within the normal range (200–300 $\mu g\ g^{-1}$) observed for sea scallop populations over those same years of monitoring.

In 1982 and 1983, the Asbury Park sea scallops were apparently adequately fed during the spring months, although glycogen levels were less than one third of those seen in 1981 and had no discernible peak. Muscle glycogen in the winter months of 1983 and 1984, however, was sufficiently high in both sexes (as compared with postspawning levels for this population, and with mean winter levels in other populations) to prompt the suspicion that gamete resorption had taken place, and that the 1983 spawning season had not been very successful. Moreover, although an intensive weekly sampling was performed in May and June 1984, we did not observe the normal seasonal increase in muscle glycogen; instead, the values resembled those of a typical winter low. When spring values for each year are compared with the subsequent winter's postspawning values (Table 1), a picture emerges of declining nutritional status from 1981 to the end of the study.

It is possible, of course, that the spring values in 1982 and 1983 were more typical for this population and that spring values for 1981 may have been unusually high. The latter phenomenon could have been the result of especially heavy phytoplankton blooms, or of oceanic currents favorable to the bottom settlement of planktonic nutrients. Certainly the most important single variable is nutrient availability.

The 1984 glycogen levels indicated either that little or no food was available to the sea scallops (at 30 m), or that they were not assimilating normally any food that was available. This phenomenon has yet to be explained satisfactorily, because the phytoplankton bloom in the area that year was extensive (J. O'Reilly[1]). Steven K. Cook[2] had suggested that some oceanographic event, such as the inshore intrusion of an offshore water mass known as the "cold pool" (e.g. Hopkins and Garfield 1979) may have caused an unusually early formation of a thermocline, one that effectively prevented settlement of planktonic detritus to the bottom. Whatever the reason, the Asbury Park sea scallops showed diminishing glycogen reserves for spawning from 1981 to the end of the study in 1984. Either planktonic nutrients were not reaching that population, or food was available but the sea scallops were not feeding or assimilating properly.

If the latter should be the case, it is perhaps relevant that the Asbury Park sea scallop population lies approximately 24 km downstream from the Christiaensen Basin, where general current patterns are southwesterly. Several active dumpsites are located in the Christiaensen Basin, including those for New York's sewage sludge and dredge spoils, where copper is a major contaminant (see Steimle et al. 1982). Moreover, as little as 10 $\mu g\ L^{-1}$ copper in the water column has been shown to interfere with gamete production and maturation (resorbing gametes) and probably also with feeding or nutrient assimilation in *Placopecten magellanicus* (Gould et al. 1985, 1988). Chemical analysis of tissues from these same Asbury Park sea scallops is under way, to determine whether metal levels were sufficiently elevated to induce this effect.

Deepwater Scallops

A data pattern for muscle glycogen similar to that seen in the Asbury Park sea scallops for 1984 has been observed in deepwater sea scallops taken from various sites in the Gulf of Maine (Table 2). These sea scallop beds were sampled randomly during the NEFC trawl survey cruises, and one fixed station was sampled seasonally during NEFC NEMP cruises (Gould 1981, 1983). Sea scallops taken from waters >110 m deep routinely showed very low glycogen levels throughout the year, the highest annual levels being reached in December. In the fall, vertical mixing of the subsurface and intermediate water increases to as deep as 150 m (McLellan et al. 1953; Colton 1968; Hopkins and Garfield 1979; Mountain and Jessen 1987), with the disappearance of any strong thermocline. In a recent comparison of food resources in shallow (20 m) and in deepwater (180 m) populations, Shumway et al. (1987) observed that a number of intact planktonic algal species reached the deepwater sea scallops after the fall phytoplankton bloom; this late annual food source "may provide just enough energy to sustain the population." On the whole, however, nutrient availability is very low at such depths, as indicated by the absence of chlorophyll in the deeper water column (J. O'Reilly[3]).

Deepwater sea scallops are visibly undernourished

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[1] J. O'Reilly, Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 428, Highlands, NJ 07732, pers. commun. October 1984.

[2] Steven K. Cook, National Weather Service, 2980 Pacific Highway, San Diego, CA 92101, pers. commun. March 1984.

[3] J. O'Reilly, Northeast Fisheries Center Sandy Hook Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 428, Highland, NJ 07732, pers. commun. May 1985.

TABLE 2.—Mean seasonal high and low levels of adductor muscle glycogen in deepwater sea scallop populations of the Gulf of Maine.

Station coordinates							
Lat.	Long.	Date of collection	Depth (m)	Bottom temperature (°C)	Sample N	Mean gonad volume (mL)	Muscle glycogen (μg g⁻¹)
43°21′	[1]69°03′	01/29/82	160	7.0	12	2.25	153
43°23′	69°55′	04/23/80	168	4.2	5	—	303
43°25′	69°22′	04/23	180	4.9	5	—	164
43°16′	69°40′	04/23	159	4.0	5	—	248
43°20′	69°03′	05/07	155	5.0	5	—	282
43°21′	67°06′	05/07	155	5.0	4	—	274
42°49′	68°49′	05/10/81	202	6.0	2	—	145
43°07′	68°42′	05/10	174	5.5	8	—	199
43°30′	69°30′	05/24	144	4.2	12	—	178
43°33′	69°07′	05/24	152	8.4	4	—	180
44°21′	67°21′	08/03/82	137	10.4	12	4.70	178
42°56′	70°16′	08/16/80	155	4.9	8	—	226
43°26′	69°57′	08/16	134	5.3	9	—	120
43°21′	[1]69°03′	08/24/82	156	5.5 (at 100 m)	12	8.67	361
43°21′	[1]69°03′	09/07/80	155	6.0	18	9.09	133
43°17′	69°18′	11/04/80	161	6.0	10	—	437
43°18′	69°03′	11/04	167	7.2	10	—	330
43°00′	69°20′	11/04	181	5.8	10	—	318
43°37′	69°32′	11/04	113	8.1	5	—	582
43°21′	[1]69°03′	12/06/82	160	7.5	12	2.42	587
43°25′	69°22′	12/06	162	10.0	12	3.75	495
43°18′	70°03′	12/07	158	7.2	12	2.67	409
42°59′	70°10′	12/07	183	7.8	13	2.58	424

[1] Deepwater station off Toothaker Ridge that was sampled whenever possible; other stations were selected randomly during resource survey cruises.

(thin shells and small adductor muscles), lack the necessary glycogen reserves for successful spawning, and very probably resorb gametes. Moreover, bottom temperatures seldom reach 10°C (Mountain and Jessen 1987), the lowest temperature at which *Placopecten magellanicus* has been observed to spawn (Culliney 1974). In a recent study of a single deepwater sea scallop population in the Gulf of Maine, Barber et al. (1988) report reduced fecundity, followed by gamete resorption and a possible minor spring spawning, in turn followed by redevelopment, continued resorption, and an abrupt fall spawning attempt. Almost certainly, deepwater sea scallops do not spawn successfully. Recruitment to these beds, therefore, would be haphazard and originate both from populations on nearby ledges and from spatfall out of the Gulf of Maine gyre, from upstream spawning populations.

We have reported here that glycogen levels in *Placopecten magellanicus* adductor muscle, measured during the annual peak period in late spring and during the annual low period in winter, can indicate scallop populations with little energy reserves for successful spawning. In the case of the deepwater sea scallops in the Gulf of Maine, lack of available nutrients is undoubtedly the reason for their low muscle glycogen. Still to be clarified are the events leading to the 1984 failure of the Asbury Park sea scallops to develop the necessary energy reserves for spawning.

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VERTICAL DISTRIBUTION AND MASS MORTALITY OF PRAWNS, *PANDALUS PLATYCEROS*, IN SAANICH INLET, BRITISH COLUMBIA

Prawn, or spot prawn, *Pandalus platyceros* Brandt, 1851, British Columbia's largest shrimp species, is extensively fished in Canada and is of considerable economic importance (Noakes and Jamieson 1986). The species ranges from California to Alaska and, being largely associated with rocky terrain, is fished with traps in many of the region's coastal inlets (Butler 1980).

This study reports a fortuitous observation of catastrophic mortality of prawn in Saanich Inlet, noted during a series of observations on the vertical distribution of prawn on the walls of this fjord using a submersible. These observations are important because, under the circumstances involved, these mobile benthic organisms had ample opportunity to avoid the apparent rapid intrusion of lethal environmental conditions by moving upwards, and thereby remaining in a favorable environment.

Well-documented sudden mass deaths of adult marine invertebrates in subtidal environments have usually been associated with man-induced environmental perturbation, such as an oil spill, pollutant discharge, entrainment of organisms into a lethal environment (e.g., dredge or power plant cooling water intake), or the entrapment of benthic organisms by some lethal environmental event (Tulkki 1965). However, the selective high mortality of one or only a few species in a subtidal community, with no associated physical habitat perturbation and with apparent opportunity for escape, has been infrequently described in documented catastrophic mortalities (Brongersma-Sanders 1957; Swanson and Sindermann 1979; Levings 1980a, b; Tunnicliffe 1981; Burd and Brinkhurst 1984, 1985; Renaud 1986). It is known that species differ in their relative tolerances to environmental stress (e.g., Renaud 1986), but for subtidal invertebrates, the proximity to lethal conditions of the majority of a population for extended time periods has not been generally noted. This study shows that prawn may occur close to lethal environmental conditions, and that abrupt mortality results if lethal water conditions suddenly intrude. In certain locations, such mortality may be more frequent than previously recognized and may justify a unique exploitation strategy.

Materials and Methods

This study was conducted between 6 and 10