SEASONAL CHANGES IN THE BODY ORGANS OF CULTURED SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, AND COINCIDENCE OF SPAWNING WITH WATER TEMPERATURE, SESTON, AND PHYTOPLANKTON COMMUNITY DYNAMICS

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Seasonal changes in the body organs of cultured sea scallop, *Placopecten magellanicus*, and coincidence of spawning with water temperature, seston, and phytoplankton community dynamics

by

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ABSTRACT

Cultured giant scallops, *Placopecten magellanicus*, were raised in suspension culture at a commercial shellfish farm in Newfoundland, Canada, during 1991. Total weight as well as the weight of soft body organs varied significantly with month of sampling. The effect of season on weight of body organs was different for small <70 mm S_h scallops compared to large >70 mm S_h scallops which were fully sexually mature. Seasonal changes in body organ weights were strongly associated with the seasonal reproductive cycle. Total weight and the weight of soft body organs typically were greatest in the spring and declined dramatically during spawning which lasted from mid-July through August. In large scallops, the weight loss typically continued through the remainder of the year while small scallops typically regained all their summer weight loss by December. The magnitude of weight changes associated with spawning was much more pronounced in large scallops than in smaller scallops. The timing of spawning, as determined by changes in the gonadosomatic index (GSI), was coincident with the start of a period of greatly improved growing conditions for young bivalves as indicated by a rise to maximum seasonal water temperatures, a rise in organic particulate seston, and the occurrence of a diatom bloom led by *Skeletonema costatum*. The bloom of diatoms caused a rapid increase in total phytoplankton concentrations as well as a shift in the available particle size spectrum from predominately phytoplankters <5 μm to a community dominated by the 11-20 μm size range.

RÉSUMÉ

Des pétoncles géants, *Placopecten magellanicus*, ont été élevés en suspension dans un élevage de mollusques de Terre-Neuve, Canada, en 1991. Le poids total des pétoncles, ainsi que le poids de leurs parties molles, ont présenté des variations significatives selon le mois de l'année ou l'échantillonnage a été réalisé. Le moment de l'année a eu une incidence différente sur le poids des parties molles selon qu'il s'agissait de petits pétoncles (coquilles de moins de 70 mm) ou de gros pétoncles (coquilles de plus de 70 mm) parvenus à maturité sexuelle complète. Les variations annuelles du poids des parties molles ont été fortement associées au cycle saisonnier de reproduction. Le poids total des pétoncles et le poids de leurs parties molles étaient en général les plus élevés au printemps; ils diminuaient ensuite considérablement durant le frai, qui se déroule de la mi-juillet à la fin d'août. Chez le gros pétoncles, la perte de poids persistait en général jusqu'à la fin de l'année, alors que les petits pétoncles avaient normalement retrouvé leur poids en décembre. L'ampleur des variations de poids associées au frai s'est révélée beaucoup plus prononcée chez les gros pétoncles que chez les petits pétoncles. Le moment du frai, révélé par les changements de l'indice gonadosomatique (IGS), coincide avec le début d'une période de forte amélioration des conditions de croissane chez les jeunes bivalves, manifestée par une hausse des températures saisonnières maximales de l'eau, un accroissement du seston organique particulaire et le début d'une prolifération de diatomées, en particulier de *Skeletonema costatum*. La prolifération des diatomées cause une rapide augmentation des concentrations totales de

phytoplancton, ainsi qu'un passage du spectre de taille des particules d'une communauté dominée par des phytoplanctontes de moins de 5 µm à une communauté dominée par les phytoplanctontes de 11 à 20 µm.

INTRODUCTION

In recent years, the sea scallop, *Placopecten magellanicus*, has emerged as a candidate aquaculture species with considerable commercial potential in Atlantic Canada. Initially, scallop culture was envisaged as a means of producing meats (the adductor muscle) as has been done in the traditional capture fisheries. However, a series of financial analyses have questioned the economic viability of a scallop culture industry based on production of meats using existing culture methods (Frishman et al. 1980; Gilbert 1987; Wildish et al. 1988; Gilbert and LeBlanc 1991). The financial viability of scallop culture would improve if production and sales for scallop products utilizing the roes or the whole scallop were possible (Atlantecon 1992; ARA Consulting Group 1993). This has led to considerable industry interest in development of markets for whole scallops, and 'meats with roe'.

For scallop producers who develop farm businesses which rely on year round sales of whole or roe-on scallops, significant seasonal changes in body organs, such as the gonad (roe), adductor muscles etc., whether they be in weight, sensory appeal, or in biochemical composition, may have potentially serious commercial consequences. Sea scallops, like most marine molluscs, experience seasonal cycles related to spawning and environmental conditions which affect their constituent body organs (Giese and Pearse 1974; Barber and Blake 1991). Reproduction and its concomitant production of gametes requires a considerable commitment of energy and body resources by the individual scallop (MacDonald et al. 1987; Thompson and MacDonald 1991). In pectinids, a considerable proportion of energy used to support gamete production is drawn from metabolism of proteins and glycogen stored in various body organs, including the adductor muscle, digestive gland and mantle (Robinson et al. 1981; Faveris and Lubet 1991; Couturier and Newkirk 1991).

Seasonal changes in body organs, particularly those related to the maturational and spawning cycle, may be predictable on an inter-annual basis. The cue or cues which have been reported to trigger spawning in invertebrates are diverse (see Giese and Pearse 1974), but many invertebrate groups reportedly spawn in response to the same environmental cues, often in mass spawning events (Minchin 1992; Babcock et al. 1992). The coupling of invertebrate spawning with environmental cues has given rise to a number of theories to explain the phenomenon, most of which impart the idea of an ecological or evolutionary advantage based on enhanced probabilities of fertilization success or optimization of subsequent larval survival (Himmelman 1975; Pechenik 1987; Olive 1992). In some species, spawning is highly synchronized, occurring within short, discrete time frames with most or all individuals in the population participating Babcock et al. 1992; Minchin 1992; Starr et al. 1990, 1991). Such brief, mass spawning episodes may be expected to result in a precipitous decline in soft body component indices with dramatic impacts on body component weight, composition and flesh quality.

Overall, sea scallops have a discrete annual spawning cycle with a well synchronized spawning period (MacDonald and Thompson 1988), but instances have been reported where

spawning may be protracted in duration and individuals may spawn partially in two or more episodes (Parsons et al. 1992). Sea scallops are also reported to switch from protracted spawning to highly synchronized spawning depending upon environmental conditions and the presence of a strong cue to act as a trigger (Langton et al. 1987). The purpose of this report is to describe seasonal changes observed in the body organ weights of cultured sea scallops which may impact upon the marketability of cultured scallop products. Coincident physical and biological environmental dynamics which may act as spawning triggers and, indirectly, of body organ weight variations related to the spawning cycle are considered.

METHODS

The study location was Charles Arm, Notre Dame Bay, on the northeast coast of Newfoundland, Canada, site of a commercial mussel and scallop farm owned by Thimble Bay Farm Ltd. The scallops used in this study originated from stock collected in spat collectors at Port au Port Bay in western Newfoundland and transferred as one year old spat to the farm site in Charles Arm for on growing. The farm uses the longline method of shellfish culture. Briefly, this method involves suspending long polypropylene ropes horizontally in the water column, supported at intervals by various types of floats, and secured at both ends either by anchors or shore fasteners. For scallop culture, at intervals of 1-2 meters along the line, arrays of Japanese pearl nets are hung vertically from the longlines. Approximately 30-50 scallops are placed in each pearl net and 10-15 pearl nets are tied sequentially in a string to make each array. The top pearl net in each array is located at approximately 3 meters water depth with the remaining nets in the array extending below to 6-8 meters, depending upon the total number of nets per array. Water temperature was monitored by continuous temperature recorders hung from the pearl net arrays.

During 1991, samples of about 30 scallops were taken biweekly or monthly from May to December (Total N=1030, ranging in size from 30-118 mm shell height). In order to obtain scallops of this wide size range over the entire sampling period, scallops from two separate year classes were taken and pooled. Each sample was frozen for later analysis. In the lab, samples were thawed and weighed using a digital electronic balance. Shell height (S_h), defined as the maximum distance perpendicular to the shell hinge, was measured using digital electronic calipers. Individual body organs including the adductor muscles, gonads and digestive glands were dissected out and weighed separately. Both the "quick" and "catch" adductor muscles were weighed together and recorded as such. The remaining organs, which mainly included the mantle and gills along with other organs of proportionally little weight, were weighed as a group, referred to as gills + mantle.

Due to variation in mean S_h of the samples, seasonal changes in body organ weights are reported for 'standard' scallops of 60 and 90 mm S_h. Data were log-transformed (natural logarithms) and $WGT_{body\ organ}$ vs. S_h regression equations (SAS Systems Inc. 1985) were

calculated separately for each month and for each of two S_h classes from May through December, and solved for 'standard' scallops of 60 and 90 mm S_h. All non-significant regressions ($F > 0.05$) were deleted from further analysis. The reported body organ weights are predicted values based on the respective regression equations (Sokal and Rohlf 1973). Since no significant differences between sexes were observed (ANOVA, $p > 0.05$), data for males and females were pooled. Since it became obvious during data analysis (discussed more fully later) that body organ weights of smaller scallops were affected differently by seasonal factors compared to larger scallops, separate regression equations for two size classes (<70 mm and >70 mm S_h) were calculated. The 70 mm separation point approximates the mean size of cultured scallops at age 2 years at this site as well as the average size of 'whole scallop in the shell' graded into large and small size grades by industry for marketing purposes. It also represents the point after which scallops may be considered fully sexually mature (Parsons et al. 1992).

Seston samples were collected from triplicate 1 liter surface (0.3 meters) water samples taken among the pearl net arrays. Each 1 liter sample was vacuum filtered using a Nalgene hand vacuum pump onto preweighed and pre-soaked Whatman GF/F 47mm diameter, 0.45 µm pore diameter glass fibre filters. Each filter was air dried to constant weight, weighed using an electronic microbalance, then combusted in a muffle furnace at 500 °C for 4 hrs, and re-weighed. This final weight represents inorganic particulates (IPM), while the weight of organic particulates (OPM) is the difference between the weights before and after combustion.

Phytoplankton analyses were carried out on 1 liter water samples taken in the same manner as the seston samples. Each 1 liter sample was immediately fixed with Lugol's Iodine and preserved in 5% buffered formalin. Phytoplankton were identified to species and counted wherever possible from measured aliquots of the sample settled using the Utermohl method (Utermohl 1958) observed using a Zeiss 35 Axiovert inverted microscope and 40X phase contrast objectives.

RESULTS

W_f, the total flesh weight of all soft body organs, W_m, the adductor muscle or meat, W_g, the gonad, W_d, the digestive gland, and W_{gm}, the gills + mantle, as well as W_t, the total weight (all soft body parts + the shell) varied significantly with month of sampling (ANOVA, $p < 0.05$). No significant differences due to sex were found for the weights of the various body organs or total weight (ANOVA, $p > 0.05$) and the interaction term of month and sex was also not significant. Therefore, data for both sexes were pooled for all subsequent analyses. The weights of all individual body organs as well as total weight varied significantly with shell height (ANOVA, $p < 0.05$) and the interaction term of month and shell height was also significant. When scallops were pooled into shell height groups, small (<70 mm S_h) and large (>70 mm S_h), the weights of all body organs and total weight were significantly different between shell height groups (ANOVA, $p < 0.05$) and the interaction term of month and shell height group was also significant.

Monthly log-transformed regressions of $W_{body\ organ}$ with S_h for each shell height group were significant for all body organs as well as total weight (ANOVA, $p< 0.05$) with the exception of the December regressions for large scallops ($p> 0.05$). This was largely due to small sample size caused by loss of a sample between time of collection and time of laboratory processing. These December data were subsequently dropped from further analysis. Comparison of slopes between the $W_{body\ organ}$ versus S_h regressions for the two shell height groups indicated the slopes were heterogeneous ($p< 0.05$) for all individual body organs as well as for total weight.

The strongest monthly variations in body organ weight were associated with the annual spawning event which started in late July and continued through August as indicated by the gonadosomatic index, W_g / W_f (Figure 1). Although the gonads were not examined histologically, visual examination indicated most individuals spawned during August with nearly all individuals having spent gonads by mid-September. Visual detection of sexually differentiated scallops, based on the deep red color of the female gonad, began at about 65 mm S_h when the gonad was about 0.5 g in weight. The gonadosomatic index indicated similar seasonal trends for both small (L60) and large (L90) scallops although maximum Spring values and the extent of the August decline were greater in large rather than small scallops. Changes in the GSI for small L60 scallops suggest spawning occurred somewhat earlier in this size group. However, since their overall gonadal development was much smaller compared to larger L90 scallops, the magnitude of this spawning would have been relatively minor.

Typically, the total weight, W_t, flesh weight, W_f, (Figure 1) as well as the weights of individual body organs were at a maximum in large L90 scallops in the Spring (Figure 2), and declined dramatically in Summer reaching an annual trough by September. All but the digestive gland weight, W_d, and the weight of gills + mantle, W_{gm}, continued to decline through the remainder of the year. W_d remained stable through December while W_{gm} recovered approximately 75% of its Summer weight loss. All body organs did show a partial recovery in October but this was short-lived for all except W_d and W_{gm} and the decline in weight resumed through the rest of the year. The October recovery appeared due to high water retention since most organs, particularly the gonads, were observed to have high water content in the period soon after spawning. The adductor meat in large scallops experienced most of its weight loss after spawning. Overall, the gonads of large scallops experienced the most dramatic seasonal variation. The digestive gland weight, W_d, began dropping early in May, while the gills + mantle, W_{gm}, gained weight during this period.

The seasonal trend in body organ weights for small L60 scallops was remarkably similar in some ways to that of the large L90 scallops. Total weight, W_t, flesh weight, W_f, and the weights of all individual body organs was typically high in May and declined, often by proportionally similar amounts, in Summer. However, the seasonal changes in $W_{body\ organ}$ were also sometimes very different in the small L60 scallops. While the weights of all body organs reached an annual trough in September in L90 scallops, in the L60 scallops, W_t, W_f, and W_m reached annual low points in July, W_d and W_g were lowest in August and W_{gm} was lowest in June. Even more striking was the pattern in body organ weights through the Autumn. With the exception of the gonad, W_g,

which regained approximately 50% of its lost weight, all individual body organs as well as W_t and W_f regained all their Summer weight loss by December. The adductor weight, W_m, was actually 20% higher in L60 scallops in December than in May.

When compared to spring peaks in weight, the loss of gonad weight associated with spawning in large scallops comprised ~80% of the total gonad weight or, in real terms, about 5.5 g for a 90 mm standard L90 scallop. Only the gills + mantle lost such a large amount of weight during spawning, about 5 g, but proportionally this involved only 30-35% of its Spring weight. The digestive gland and adductor meat lost approximately 3 g and 2.5 g respectively during spawning time or, proportionally, 55% of digestive gland weight but only 15% of adductor weight reached the previous spring. Proportionally, L60 scallops lost a similar amount of weight during the Summer. Overall, during spawning, L90 sea scallops lost ~19% of their total weight from the previous spring, and ~32% weight loss by December. By contrast, L60 scallops lost only 15% of their Spring weight during the Summer and had regained all their lost weight by December.

Based on changes in the gonadosomatic index and visual observations of the occurrence of spent gonads, spawning took place from about Julian Day 200 to 255 (late July to mid-September). The onset of spawning about Day 200 in L90 scallops coincided with the period of maximum seasonal temperature recorded during 1991 at Charles Arm (Figure 3) and came after the greatest sustained increase in temperature, climbing from about 5.5°C to 17.8°C in just 25 days, an average daily increase of about 0.5°C. Water temperatures then dropped over 5°C in the next 5 days. The onset of spawning about Day 200 also coincides with the start of a long rising trend in the amount of seston in the water column (Figure 4). Suspended organic particulates (OPM) had reached a seasonal low point about Julian Day 190 in mid-July at <0.1 mg l^{-1}, then increased through the Autumn to peak >2 mg l^{-1} in late November. During this same time, the IPM/OPM index, the ratio of suspended inorganic particulates to organic particulates, remained low. The IPM/OPM index was relatively high during the spring and in December, coinciding with periods of high rainfall and expected high influx of silt from terrestrial sources in freshwater runoff.

Diatoms were the numerically largest constituent of the phytoplankton seasonally, with large swings in abundance forming three distinct peaks detected during 1991 (Figure 5). The onset of scallop spawning inferred from the gonadosomatic index coincided with rising diatom numbers to form the second peak from late July through early August. This peak was also the largest in terms of total phytoplankton recorded during 1991 at 2.34×10^6 cells l^{-1}. The third peak occurred late in the year in December. Other than diatoms, various autotrophic nanoflagellate species were the only other group of phytoplankters of numerical importance during the year and their population abundance was relatively stable, compared to the diatoms, averaging about 0.3×10^6 cells l^{-1} throughout the year. The first of the diatom peaks, and the longest sustained period, was during late March through May. Much of this time was also coincident with very low seasonal water temperatures, always < 3°C, and generally < 0°C for most of that time. The second of the diatom peaks (the one coincident with scallop spawning) was relatively short-lived (Figure 5) lasting from about Day 200 to Day 240. From Day 240-260, overall phytoplankton abundance

was very low with small autotrophic nanoflagellates being numerically dominant. Based on estimated larval development times determined from the temperature data (Culliney 1974), this trough in phytoplankton abundance can at a time when many larval scallops derived from the main spawning event were still in their planktonic stage.

The phytoplankton species assemblages which comprised these various peaks were different, particularly comparing the first (spring) peak with the two later in the year. Both the second diatom peak which coincided with scallop spawning and the third peak were largely due to a single species, *Skeletonema costatum* (Figure 6), with some contribution from *Nitzschia longissimum*, *N. deliculata*, and *N. seriata*. *Leptocylindricus danicus* contributed somewhat to the third peak in November and December. However, the spring peak was largely comprised of *Fragilariopsis oceanica* and *F. islandica*, and *Leptocylindricus danicus*, with relatively minor contributions from *Skeletonema costatum*, *Nitzschia longissimum* and *N. deliculata*. In contrast to the diatoms, the various autotrophic nanoflagellate species were virtually unchanged throughout the year, being mainly comprised of *Ochromonas sp.*, *Micromonas sp.*, and *Chryptomonas sp.* The sudden and dramatic diatom population changes associated with the second peak also resulted in a significant shift in the particle size distribution of the phytoplankton community (χ^2, $p < 0.05$) . Immediately prior to spawning, approximately 85% of phytoplankters present were in the < 5 μm size category (Figure 7) and reflected the numerical dominance of small autotrophic nanoflagellates during this time. During the second diatom peak and scallop spawning, more than 75% of the phytoplankters were in the 11-20 μm size category or larger, indicating the contribution of the diatom *S. costatum* and others to the phytoplankton community.

DISCUSSION

In many marine molluscs, the weight of soft body organs in individuals of similar shell size is strongly influenced and, indeed, is indicative of localized site suitability, particularly as it relates to food availability. Both reproductive output, as indicated by the size of the gonad, and somatic growth, as indicated by weight of adductor muscle, are greatly reduced in scallops under conditions of restricted food availability (MacDonald and Thompson 1985; Bricelj et al. 1987). As well, in pectinid scallops the relative proportions of the soft body organs vary seasonally under the influence of the annual maturational cycle of gonad development, gamete production, spawning, and reconditioning (Robinson et al. 1981; Barber and Blake 1991). In comparison to wild scallops, cultured scallops appear to allocate relatively more of total available energy to somatic growth (adductor muscle, mantle, etc.) than do wild scallops and achieve heavier somatic weights and faster shell growth (MacDonald 1986; Parsons and Dadswell 1992). This is generally believed to result from the enhanced feeding conditions experienced by cultured scallops in suspension compared to conditions on the sea floor experienced by wild scallops.

The linkage between seasonal changes in soft body organ proportions and the maturational cycle offers a probable explanation for the observed differences (different seasonal pattern and overall less variation) in the pattern of seasonal changes in small versus large scallops. While gamete production can start in scallops as small as 30 mm S_h, the amount of gametes produced is small, increasing exponentially with increasing S_h (Langton et al. 1987). Parsons et al. (1992) found that in scallops > 70 mm the gonadosomatic index reached a plateau after which the GSI was independent of size, indicating that scallops > 70 mm are fully sexually mature. The partitioning of available energy into gamete production at the expense of somatic growth becomes more pronounced as S_h increases (MacDonald and Thompson 1985), reaching virtually 100% in scallops larger than 100 mm (Langton et al. 1987).

During the seasonal period included in this study, total weight of scallops reached a maximum in the spring, prior to spawning. During the spawning period, considerable loss of weight occurred in all body organs, not just the gonad. Pectinid scallops utilize their soft body organs as energy storage sites. The adductor muscle and digestive gland in particular are major reservoirs of stored energy, chiefly carbohydrate and lipid respectively (Robinson et al. 1981; Peirson 1983). When the spawning period begins, stored energy is drawn from these organs and converted into gametes by the gonad resulting in a sharp drop in the weights of the donor organs (Robinson et al. 1981; MacDonald and Thompson 1986; Epp et al. 1988). The extent of mobilisation of this stored energy transfer from somatic tissues to gamete production varies depending upon localized environmental conditions. When food supplies are poor, relatively more energy is drawn from the somatic tissues resulting in a proportionately larger loss of weight in these organs (Wallace and Reinsnes 1985). If feeding conditions remain poor after spawning and during the winter, scallops continue to draw energy reserves from the somatic tissues for gonad reconditioning, resulting in a delayed regaining of the lost weight in these organs (Thompson and MacDonald 1990).

Feeding conditions also play an important part in defining the duration of the spawning period in pectinid scallops. In *Placopecten*, localized environmental conditions have been found to cause a switch from highly synchronized, discrete spawning events to a more protracted spawning period (Langton et al. 1987). Individual scallops may not spawn completely all at once (Parsons et al. 1992) but rather may spawn partially in two or more episodes over a period of several days or weeks (Naidu 1970). While the use of the GSI has been criticized as a technique to study changes in reproductive condition for some species (de Vlaming et al. 1982), its effectiveness as an indicator of reproductive condition for the maturational and reconditioning cycle of marine molluscs with discrete spawning periods has been well established (Robinson et al. 1981; Parsons et al. 1992). In scallops, spawning periods inferred from changes in the GSI have been confirmed histologically (Beninger 1987), indicating its appropriateness to pinpoint spawning events. However, it may not be as accurate in predicting post spawning recovery (Beninger 1987).

The spawning period for cultured scallops in this study, as inferred from the changes in GSI, lasted about 60 days from mid-July to early September, which agrees well with previously published records of scallop spawning. However, the duration of the spawning event may be overestimated by the data and could have been improved if more frequent sampling during the spawning period had been done. Throughout its considerable geographic range, the giant scallop spawns from July to October (Naidu 1970; Robinson et al. 1981; Barber et al. 1988; Parsons et al. 1992). In Newfoundland, wild scallop stocks normally spawn during August and September (Naidu 1970; Thompson 1977), but July spawnings have been previously recorded from Port au Port (Naidu 1970). The long spawning period observed at the Charles Arm site in this study may be indicative of poor environmental conditions during 1991. Penney (1993) reached a similar conclusion based on observations of mussel veliger dynamics and mortality in mussel veligers and settled spat. It has been postulated that a protracted spawning period during times of poor feeding conditions in marine molluscs may have evolutionary significance for species survival since it increases the odds of survival of at least some of the spawned gametes (Langton et al. 1987).

Olive (1992) postulated that synchronized spawning to coincide with improved environmental conditions maximized survival of the offspring. Initiation of scallop spawning at Charles Arm in 1991 coincided with high water temperatures as well as improved food availability, both in terms of quantity and overall quality as a potential food source for young scallops. The physical and biological changes coincident with spawning at Charles Arm signalled the onset of a period of good growth and survival conditions for scallop larvae. Minchin (1992) documented the occurrence of synchronized spawning in a multi-phyla assemblage of invertebrates coincident with rising temperature in inshore areas. Parsons et al. (1992) detected a coincidence between tidal/lunar cycles and spawning in scallops. Smith and Strehlow (1983) noted the presence of adequate food concentrations in the water was an important contributing cue for gamete release in mussels. Overall food availability observed at Charles Arm, as indicated by OPM, rose during the spawning period and in the estimated larval development period for offspring from the scallop spawning event (Culliney 1974). Observed OPM levels were comparable to other records for inshore Newfoundland waters (Navarro and Thompson 1995).

Also, the IPM/OPM index, which may be regarded as an index of food quality (Wallace and Reinsnes 1985), remained low during this period. Index values <3.5 may be critical for filter feeding bivalves. High ratios in excess of 3.5, indicating relatively high concentrations of inorganic particulates, have been associated with impaired feeding (Vahl 1980; Wallace and Reinsnes 1985).

Living phytoplankton is superior to all other forms of organic particulates ie. detritus in the seston as food for filter feeding invertebrates (Jørgensen 1975). The presence of appropriate phytoplankton in the water column has been demonstrated to directly stimulate spawning in several invertebrate species (Himmelman 1975; Starr et al. 1990). At Charles Arm, the phytoplankton bloom coincident with the initiation of scallop spawning was dominated by a single diatom species, *Skeletonema costatum*. A rapid increase in cell numbers of this particular species has been shown to stimulate spawning in sea urchins and mussels (Starr et al. 1990). Pechenik (1987) identified *S. costatum* as a species with good nutritional value for planktonic invertebrate larvae. The bloom of *S. costatum* and related diatoms also brought about a switch in size structure of the phytoplankton community with individuals in the 11-20 μm size range becoming dominant. This particular size class of phytoplankton has been demonstrated to be very effective as a food source for larvae of filter feeding invertebrates (Pechenik 1987).

Since temperature changes as well as phytoplankton population changes were coincident with spawning at Charles Arm in 1991, it is difficult to pinpoint which acted as the actual spawning trigger or if all acted in concert. Determining the environmental cues which trigger spawning in marine invertebrates has been the subject of intensive research over the years. Many factors have been implicated, both physical and environmental. Direct synchronization of spawning with phytoplankton blooms offers enhanced likelihood of reproductive success. As a means to maximize survival of the offspring, detection of appropriate phytoplankton in the water column as a cue to trigger spawning offers the best probability of ensuring larval release at a time of good growing conditions. Using direct contact with phytoplankton or detection of their metabolic products (Starr et al. 1990; 1991) as the direct trigger for spawning has the obvious advantage as a spawning signal in that it directly indicates food is present for the offspring.

Finally, the potential commercial ramifications of seasonal cycling of scallop body proportions must be considered. At present, North American markets for scallop products are concentrated heavily towards meats alone. Success by various scallop producers to develop new markets for non-traditional products such as whole live scallops or 'roe-on' products has been localized and mostly concentrated in various ethnic areas. Yet, based on available bio-economic analyses, development of a profitable scallop culture industry in Atlantic Canada may depend upon wide scale consumer acceptance of such products. The fact that cultured scallops have distinct seasonal changes in the weights and proportions of their respective organs, as well as their body weight overall, must be seriously considered with respect to its potential impact on development of a scallop culture industry utilizing non-traditional production. Both small and large scallops display seasonal trends in body organ weights, although the variations between seasons are amplified for large size scallops. The body organ weights and proportions of large

scallops in particular reach seasonal maxima in the spring. Therefore, on a weight basis, farm production by the grower may be maximized by concentration of harvesting during the spring. Even meat weights undergo seasonal changes indicating that meat production may also be optimized by spring harvesting. Large scallop roes are only available prior to the July-August spawning period. Therefore, production and sales of fresh 'roe-on' products will be confined to this period each year. Similarly, where market acceptance of large whole scallops depends upon the presence of large, mature roe, sales of these products may as well be restricted to spring and early summer.

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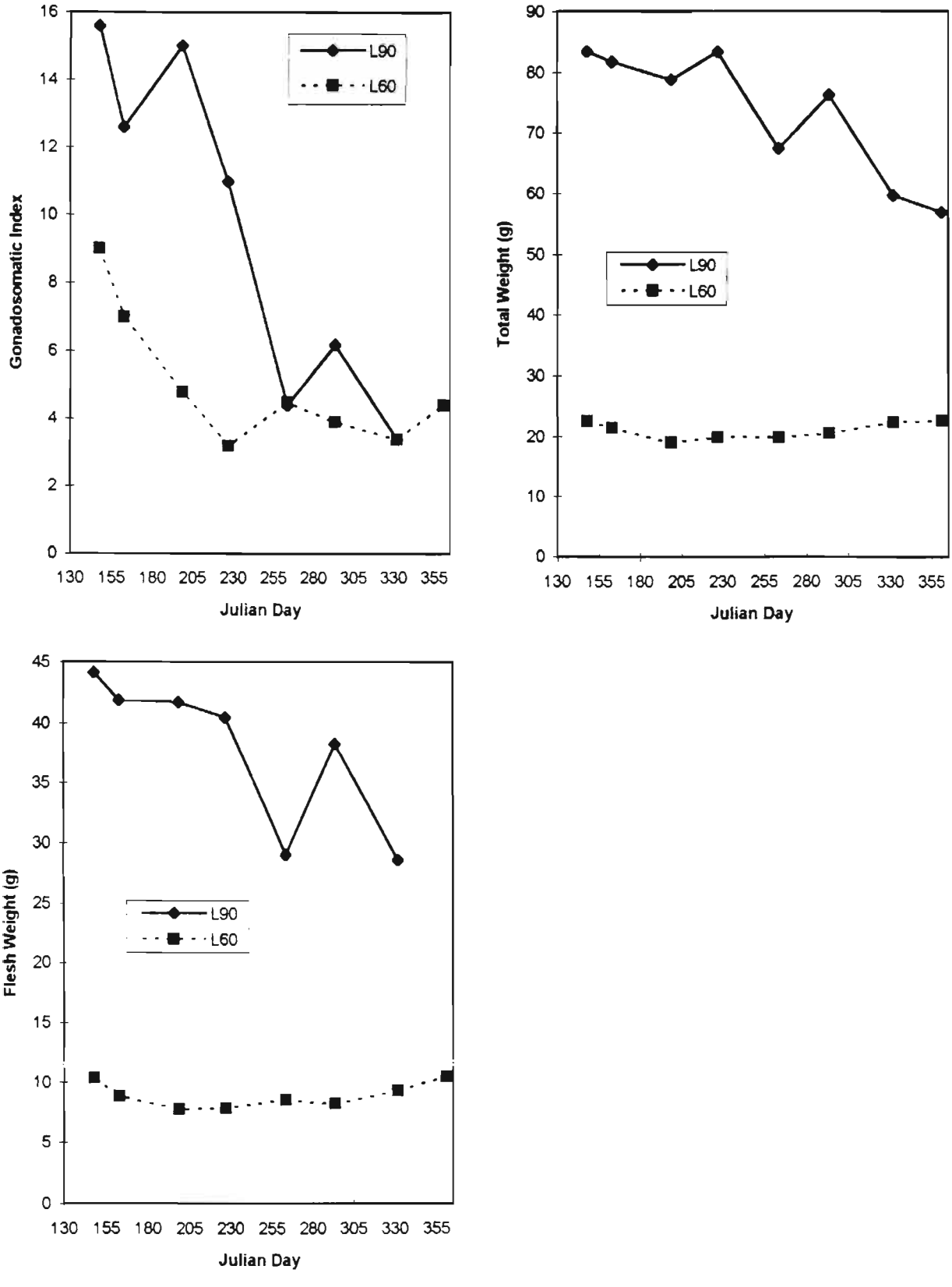

Figure 1. Temporal changes in the gonadosomatic index (W_g/W_f), total weight (W_t), and flesh weight (W_f) from May through December, 1991, for 60 mm (L60) and 90 mm (L90) scallops. Plotted points are standardized values derived from the respective $W_{body\ organ}$ vs. S_h regression equation.

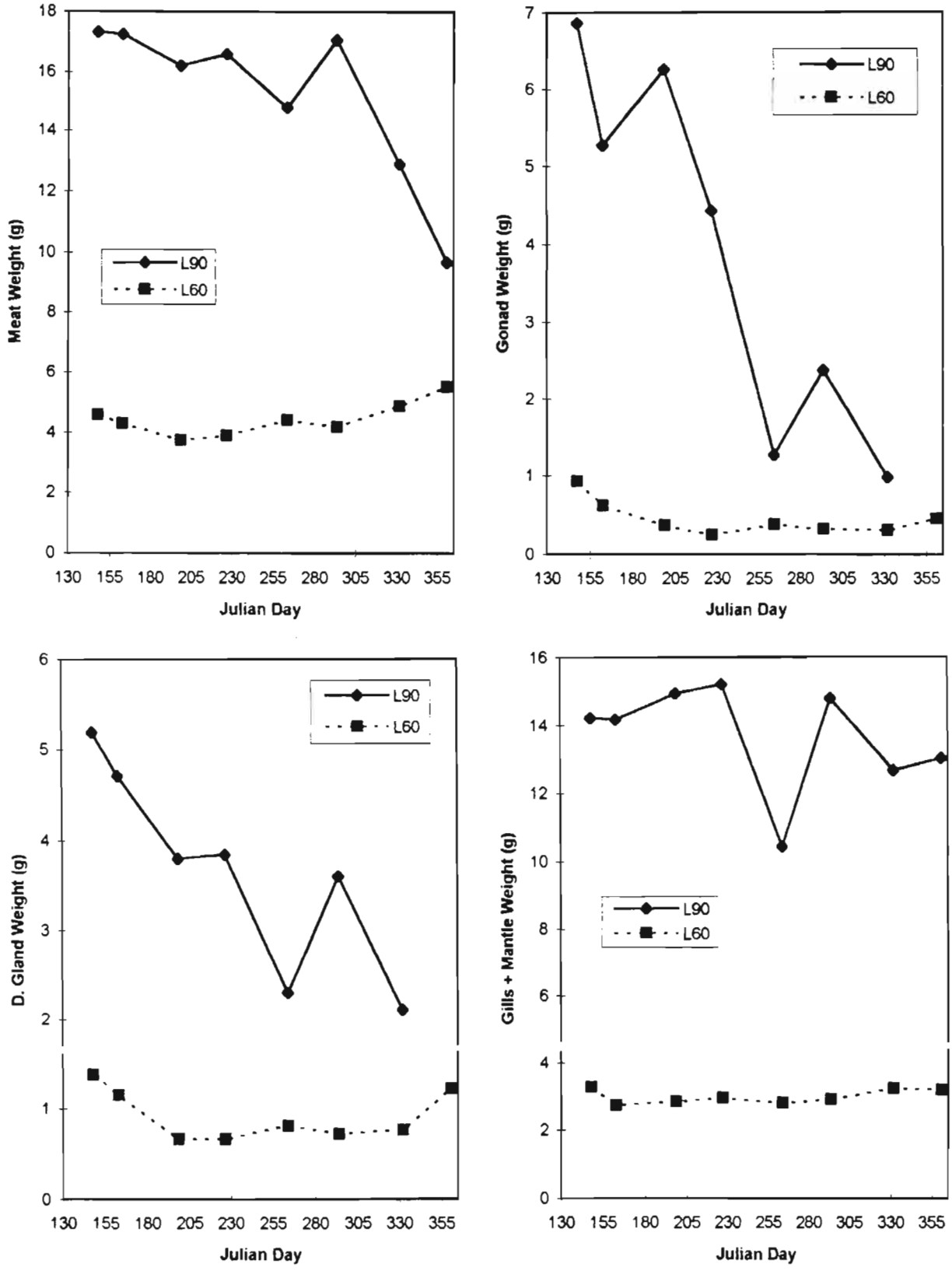

Figure 2. Temporal changes in the weight of various individual body organs from May through November, 1991, for 60 mm (L60) and 90 mm (L90) scallops. Plotted points are standardized values derived from the respective $W_{body\ organ}$ vs. S_h regression equation.

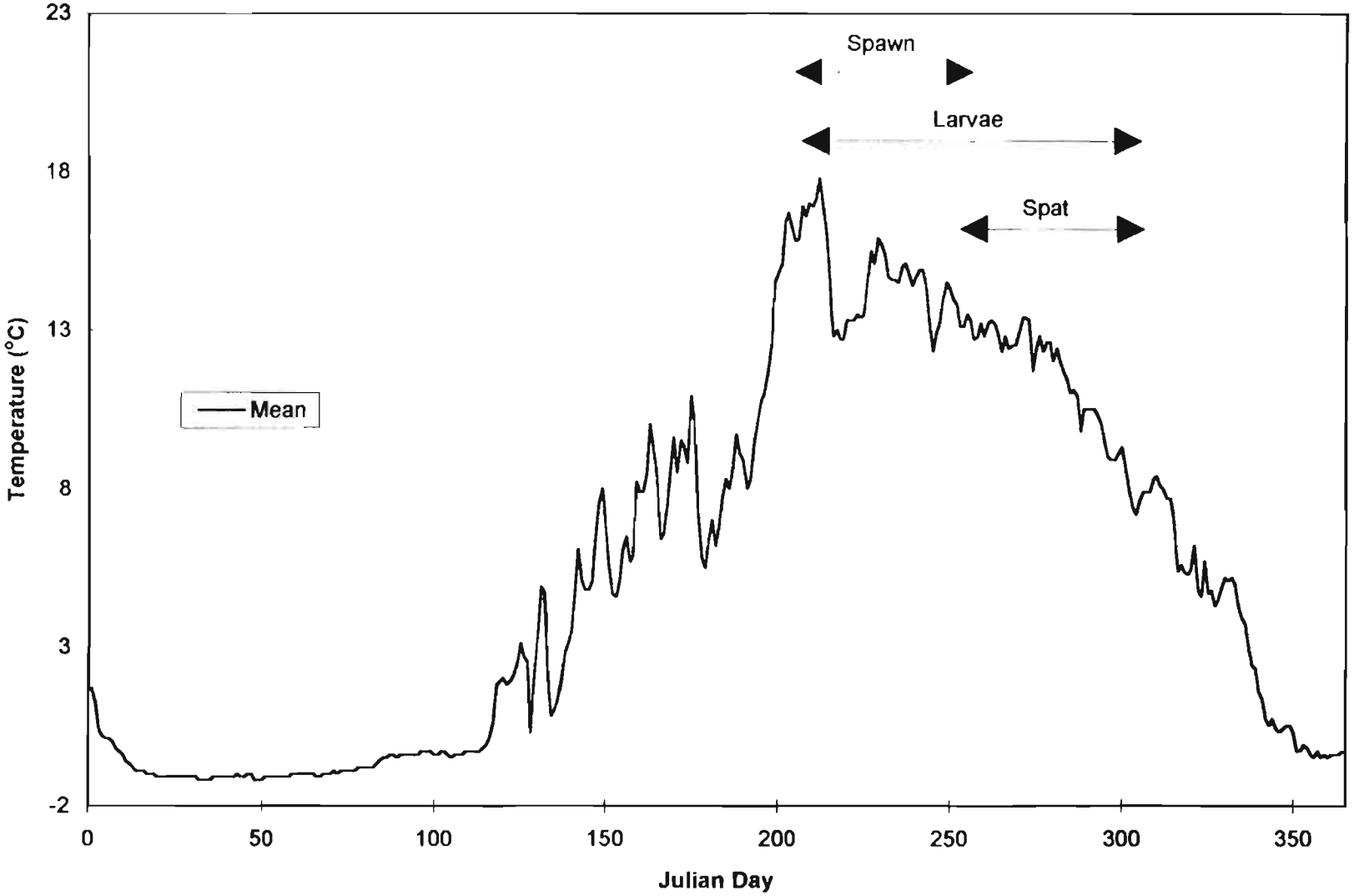

Figure 3. Mean daily water temperature recorded by thermograph during 1991 and estimated scallop spawning times, duration of planktonic larval stage, and spat settlement period based on temperature dependent larval development rates of Culliney 1974.

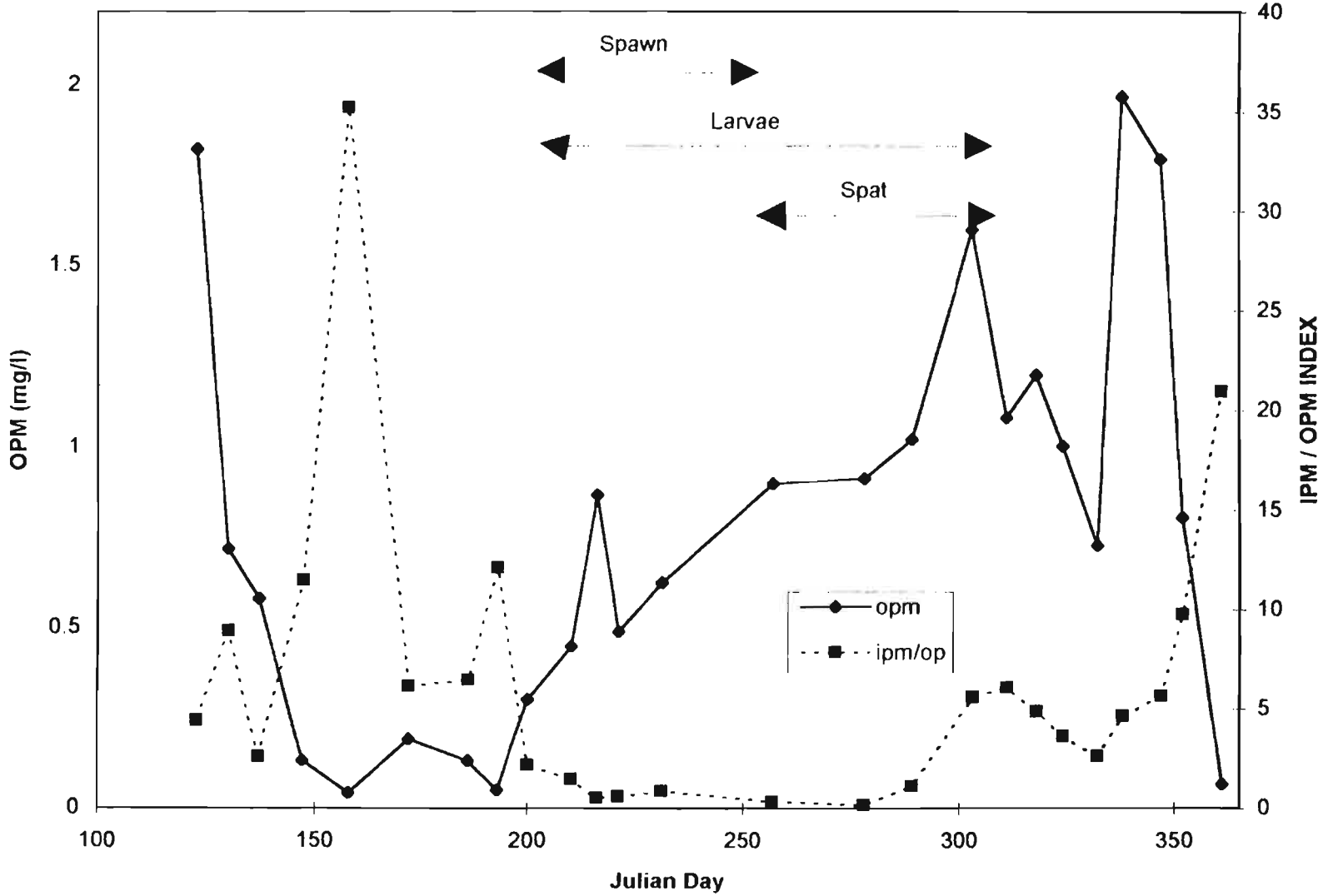

Figure 4. Temporal changes in the seston from May through December, 1991, including the organic particulate matter (OPM) and the ratio of inorganic to organic particulate matter (IPM/OPM).

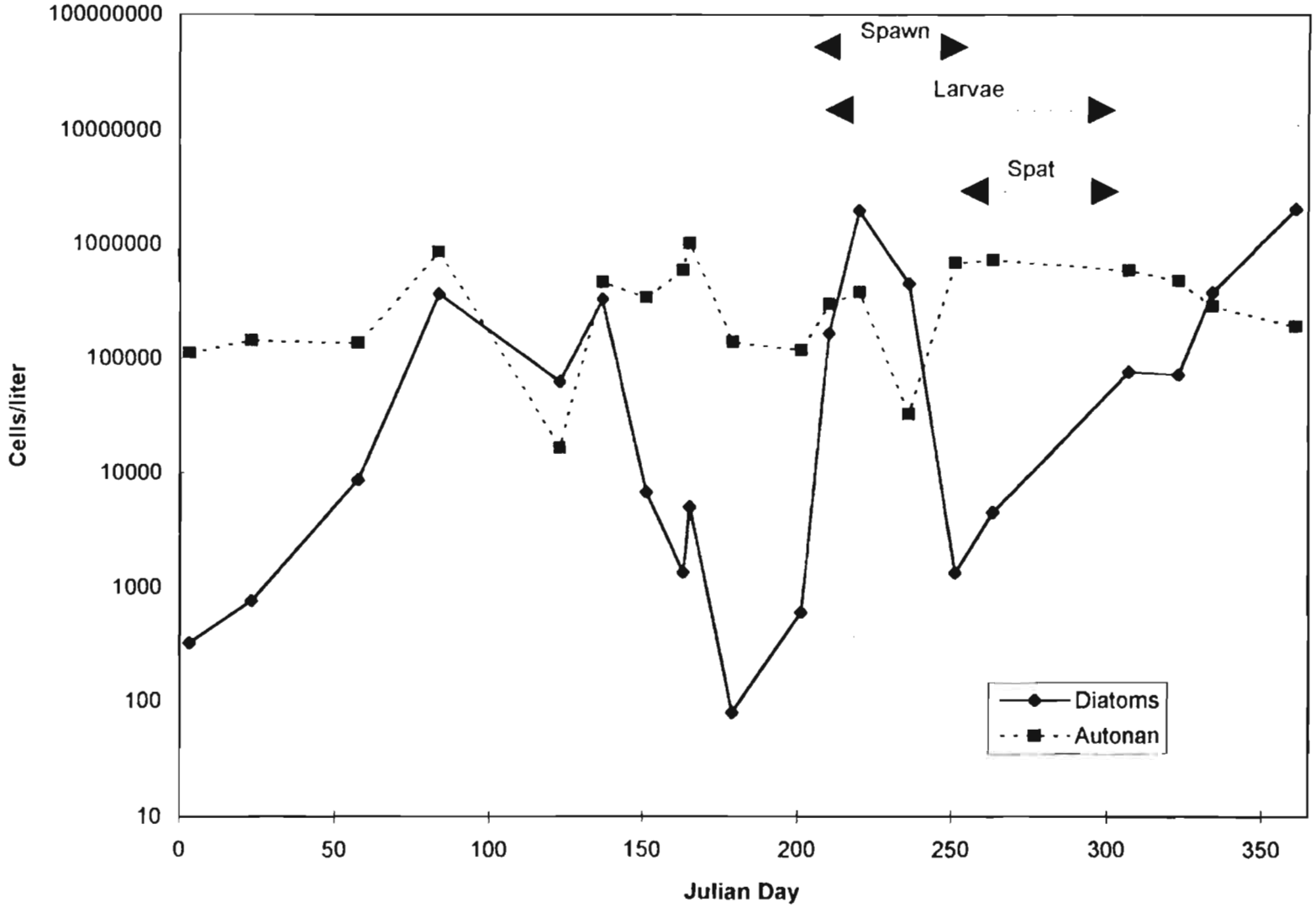

Figure 5. Abundance of diatoms and autotrophic nanoflagellates (the numerically dominant phytoplankton groups) in cells/liter during 1991.

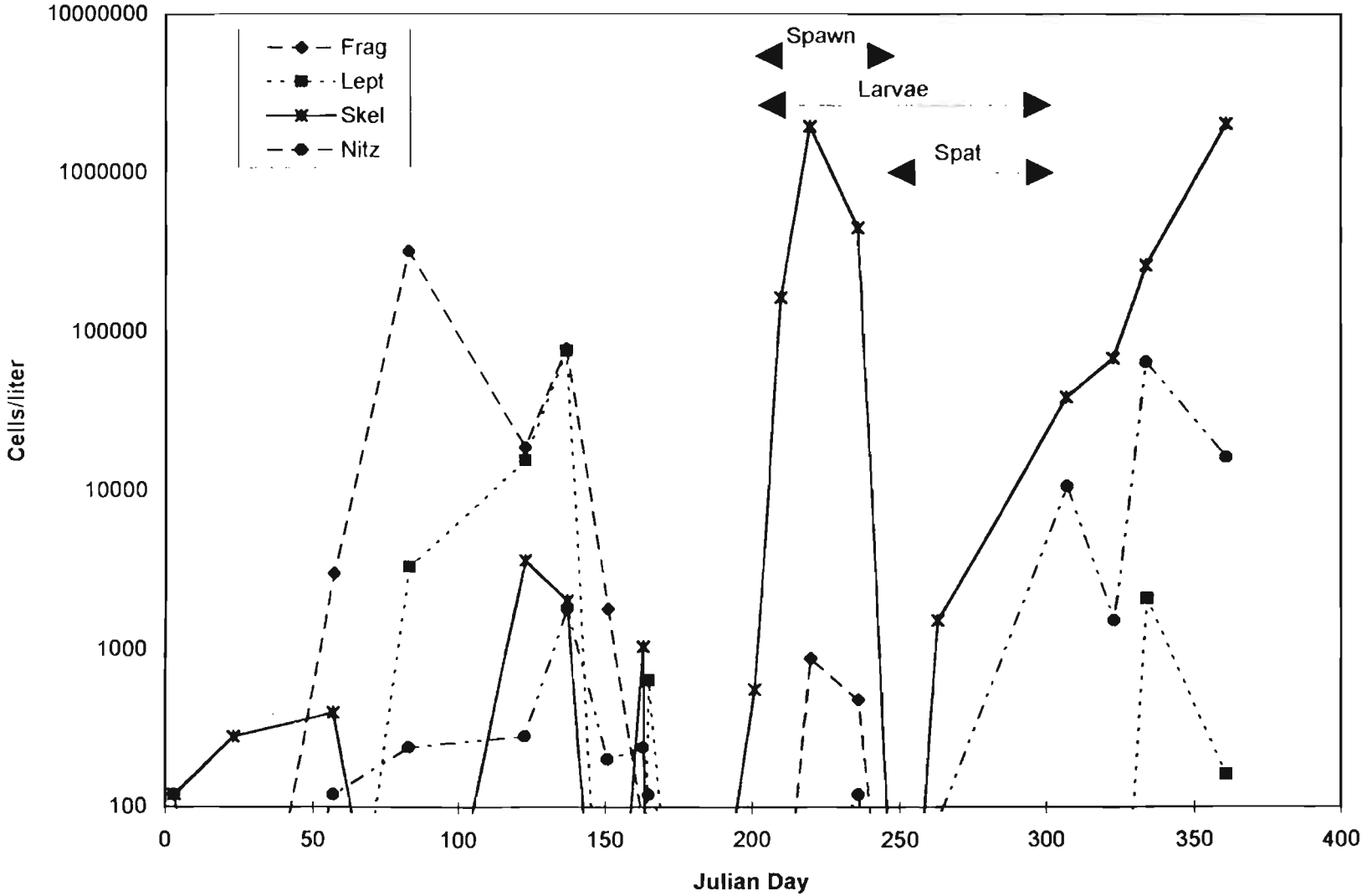

Figure 6. The numerically dominant diatom species and their abundance in cells/liter during 1991. Frag= Fragillaria sp., Lept= Leptocylindricus sp., Skel= Skeletonema sp., and Nitz= Nitzschia sp.

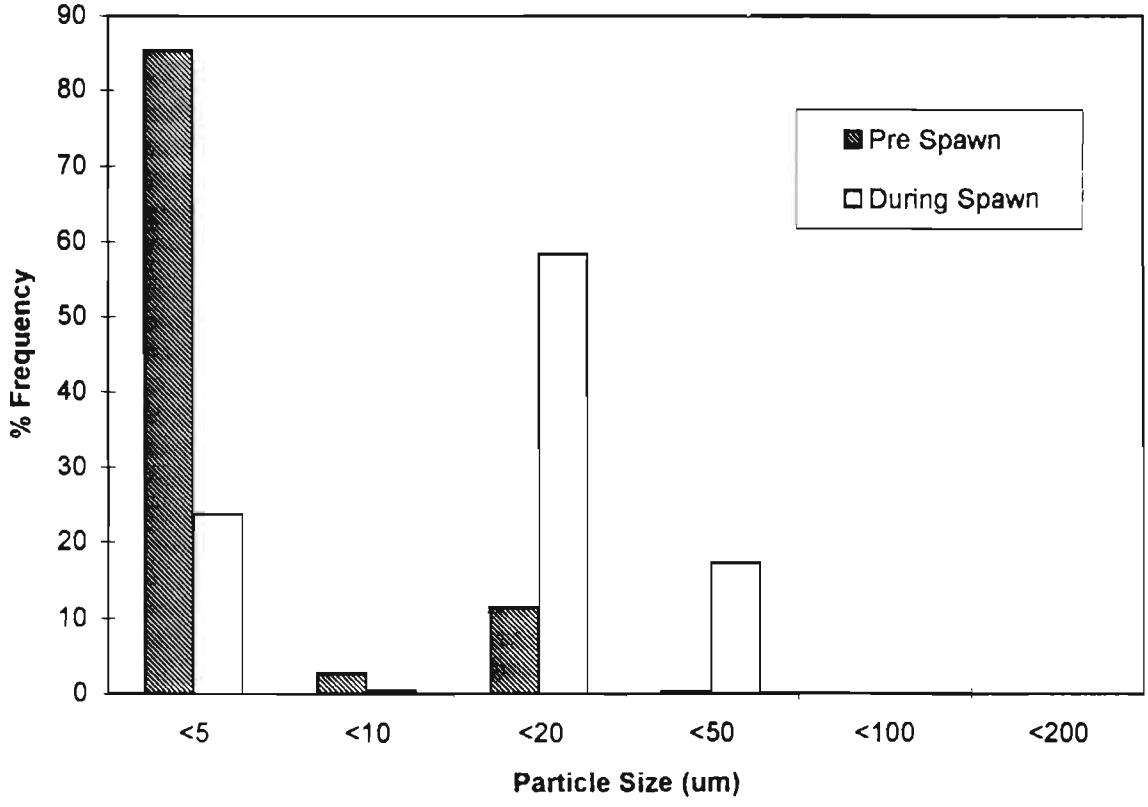

Figure 7. Particle size frequency distribution of available phytoplankton immediately prior to the initiation of scallop spawning (Pre spawn) and during the spawning event (During spawn) in 1991.