Effect of Gear Type and Initial Stocking Density on Production of Meats and Large Whole Scallops (*Placopecten magellanicus*) using Suspension Culture in Newfoundland

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INTRODUCTION

In Canada, scallop culture has gone through a lengthy experimental and developmental phase. Its beginnings can be traced to the 1960's (Couturier, 1990; Couturier et al. 1995). In the Atlantic provinces, efforts to commercialize culture of the giant sea scallop, *Placopecten magellanicus*), were initially based on production of meats, the traditional scallop product of the wild fishery, using technology, equipment, and rearing practices widely used in the extensive Japanese scallop culture industry (Taguchi, 1977; Young-Lai and Aiken 1986; Naidu and Cahill 1986). Development of the industry has been slow, due mainly to unreliability of wild spat collection caused by wide interannual fluctuations in spat settlement, and by high production costs for meats which marginalized economic viability (Frishman, et al. 1980; Gilbert 1987; Gilbert and LeBlanc 1991; Wildish et al. 1988).

Efforts to reduce production costs have led to experimentation with a variety of equipment and culture technique modifications (Wildish et al. 1988; Parsons and Dadswell 1994; Shell Fresh Farms 1993) as well as exploration of markets for scallop products other than traditional meats. The latter have been spurred on by knowledge that a variety of products utilizing other parts of the scallop are marketed elsewhere. These include whole scallops, mantles and roes in Japan (Ikenoue and Kafuku 1992; Young-Lai 1989), whole scallops in the United States (Rhee, 1991), and whole scallops and roes in Europe (Hardy 1991; de Franssu 1990). Studies in Newfoundland indicate production of young, whole scallops, 60-70 mm in size using suspended pearl net culture can probably become quite profitable although considerable market development is needed before such products find large volume markets (Atlantecon 1992; ARA Consulting Group Inc. 1993).

Three, and possibly four, scallop product types have emerged as aquacultural candidates on scallop farms from the experimentation and trial market development thus far. These are whole scallops, produced in two size ranges, 60-70 mm and 90-110 mm; traditional meats, and possibly meats with roe (T. Mills, Thimble Bay Farms Ltd. pers. comm.). Whole scallops, 60-70 mm in size may be produced on Newfoundland farms after two years in pearl nets (Penney, unpubl.). Production of the other product types requires an extension of the production cycle and determination of the most advantageous equipment and techniques for commercial industry. Many different factors need to be considered, including gear type, capital cost, handling costs, stocking densities, growth rates, and survival rates in various gear. It has been determined that growth and survival are inversely related to stocking density in the Japanese scallop, *Patinopecten yessoensis*, and the bay scallop, *Argopecten irradians*, and for giant scallops, *Placopecten magellanicus*, in the intermediate stage culture (Duggan, 1973; Imai, 1977, Rhodes and Widman, 1980, 1984; Ventilla, 1982; Parsons and Dadswell, 1992). This paper investigates the production of large, whole giant sea scallops and meats in suspension culture using pearl nets and lantern nets and describes the effect of varying initial stocking density on growth and survival during final growout to market size.

METHODS

The study site was located at a commercial mussel and scallop farm, Thimble Bay Farms Ltd., at Charles Arm in Notre Dame Bay on the northeast coast of Newfoundland (see Penney, 1993). During September, 1991, sea scallops in the size range 70-75 mm Shell Height (all references to size or length hereafter shall be shell height unless otherwise indicated) were selected during culling from pearl nets used for intermediate culture. This size range was selected since it represented the typical size achieved by sea scallops, stocked from wild spat, in intermediate culture at this site by autumn of the second year on the farm (three year old scallops). Shell height, defined as the maximum distance perpendicular to the shell hinge, was measured by digital electronic calipers.

Scallops were stocked into both pearl nets and lantern nets at five different densities with 3-8 replicates of each gear type-density combination. The number of replicates of each gear-density combination was varied being highest for nets with the lowest densities (Total N=770). For both gear types, the net mesh was 21 mm. Each lantern net contained 10 trays. The pearl nets were standard 34 cm square nets and the lantern trays were round 50 cm diameter trays. Both gears were suspended from horizontal longlines at depths of 3-6 m. The five selected densities were based on proportions of floor space utilized (Table 1), calculated by approximating the surface area of each scallop to be a circle equal to πr^2, where $r = 0.5$ shell height (Wildish et al. 1988; Parsons and Dadswell 1992). This resulted in numeric stocking densities of 6, 10, 14, 18, and 25 scallops per net for the pearl nets and equivalent densities (based on per cent of floor space occupied) of 10. 16, 23, 30, and 40 scallops per net tray for the lantern nets. Subsequently, in May, 1992 and again in September, 1992, the scallops were retrieved, measured and weighed, and any mortalities noted. In September, 1992, all scallops were shucked and meat weights recorded. Differences in shell height, survival, total weight, and meat weight among stocking densities and gear types were analysed by analysis of variance and covariance techniques (SAS Institute Inc., 1985).

RESULTS

At the start of the experiment in September, 1991, the stocked scallops varied in size from 70-74 mm. There were no significant differences in mean shell height ($\bar{x}_{sh}$) among stocking densities or gear types (ANOVA, $p > 0.05$). By the first sampling time in May, 1992, an inverse relationship existed between shell height and stocking density with $\bar{x}_{sh}$ increasing as stocking density decreased, irrespective of gear type. Scallops were now significantly different among both stocking densities and gear types, when controlled for differences in initial shell height observed in September, 1991 (ANCOVA, $p < 0.01$). A significant interaction effect between density and gear type was also observed (ANCOVA, $p < 0.05$). Scallops were larger at comparable densities in pearl nets than in lantern nets with $\bar{x}_{sh}$ ranging from a low of 81.4 mm at the highest density (D5) to a high of 84.7 mm at the lowest density (D1) (Figure 1) in pearl nets. In lantern nets, $\bar{x}_{sh}$ ranged from a low of 77.3 mm at stocking density D5 to a high of 83.5 mm at stocking density D1 (Figure 2).

During the final sampling time in September, 1992, similar significant relationships in $\bar{x}_{sh}$ among stocking densities and gear types still existed (ANCOVA, $p < 0.01$) although the interaction effect was no longer significant (ANCOVA, $p > 0.05$). In pearl nets, $\bar{x}_{sh}$ had increased to a high of 93.6 mm at the lowest density, D1, to a low of 87.3 mm at the highest density, D5 (Figure 1). In the lantern nets, $\bar{x}_{sh}$ was lower, compared to pearl nets at all densities, ranging from a high of 90.1 mm at density D1 to a low of 80.8 mm at density D5.

There were significant seasonal differences in growth rate. The growth rates observed, when expressed as mean daily growth rates, are greatest for scallops in both pearl nets and lantern nets during the summer, 1992 period (May to September) (Table 2). However, scallops also grew considerably during the autumn to spring (September - May) period. Mean daily growth rates were greater for scallops in pearl nets rather than lantern nets, irrespective of season or stocking density. For both pearl and lantern nets, the mean daily growth rate observed at the lowest density, D1, was approximately 60-80% higher than that observed for scallops at the highest stocking density, D5.

Survival of stocked scallops was excellent at all stocking densities and for both gear types (Table 3). No significant differences in survival among stocking densities or gear types were observed during either of the sampling periods (ANOVA, $p > 0.05$). Overall survival during the experiment exceeded 93% for all gear types and stocking densities, with mean survival for all gear-density combinations being 97.8%.

The combined effect of increasing growth of individual scallops and survival within each gear may be expressed in terms of floor space utilization in the nets (Table 4). Because growth rates were higher in pearl nets rather than lantern nets, overall floor space utilization was also highest in the pearl nets, exceeding 100% at stocking density D5 by May, 1992 in pearl nets. By September, 1992, per cent floor space utilization exceeded 100% at stocking density D5 for both gear types. Since, scallops naturally lie flat in their nets, this means the stocked scallops in these nets were now so crowded they were partially overlaying each other. Even at these high densities, survival was not compromised although growth rate was significantly reduced.

By the first sampling period in May, 1992, scallops stocked in both pearl and lantern nets had developed an inverse relationship with stocking density, with the largest weights observed at the lowest density. Significant differences were observed in mean total weight, $\bar{x}_{tw}$, among stocking densities and gear types, when controlling for shell height (ANCOVA, $p < 0.01$). For all stocking densities, $\bar{x}_{tw}$ was greater in pearl nets compared to the lantern nets (Figure 3), ranging from a low of 77.8 g at the highest density, D5, to a high of 88.5 g at the lowest density, D1 in the pearl nets. In lantern nets, $\bar{x}_{tw}$ ranged from a low of 65.1 g at stocking density D5 to a high of 80.7 g at stocking density D1. Mean total weight at the lowest density, D1, was 14% greater than at the highest density, D5, in the pearl nets, while for lantern nets the mean total weight at stocking density D1 was 24% greater than at D5.

Similar significant relationships were observed in $\bar{x}_{tw}$ among stocking densities and gear types during the final sampling period in September, 1992, when controlled for shell height (ANCOVA, $p < 0.01$). A significant interaction effect between density and gear type was also observed (ANCOVA, $p < 0.05$). As in May, $\bar{x}_{tw}$ was greater in pearl nets than in lantern nets, irrespective of stocking density (Figure 4), ranging from 68.8 g at stocking density D5 to 88.7 g at density D1 in pearl nets. In lantern nets, $\bar{x}_{tw}$ ranged from 59.3 g at stocking density D5 to a high of 80.0 g at density D1. The difference in mean total weight between the highest and lowest stocking densities had now increased to 29% for pearl nets and 35% for lantern nets compared to the May, 1992 sampling period. However, $\bar{x}_{tw}$ was generally lower in September, 1992 compared to May, 1992, for all density-gear combinations except pearl nets at density D1. At the lowest stocking density, the final $\bar{x}_{tw}$ observed in pearl nets was 11% greater than the comparable density in lantern nets.

By the final sampling period in September, 1992, significant inverse relationships had appeared between meat weight and stocking density, with highest mean meat weights, $\bar{x}_{mw}$, observed at the lowest stocking density in both pearl and lantern nets. Significant differences were observed in $\bar{x}_{mw}$ among stocking densities and gear types, when controlling for shell height (ANCOVA, $p < 0.01$). Significant interaction effects between gear type and density were also observed (ANCOVA, $p < 0.01$). For all stocking densities, $\bar{x}_{mw}$ was greater in pearl nets than in lantern nets (Figure 5), ranging from a low of 15.5 g at stocking density D5 to 19.8 g at density D1. In lantern nets, $\bar{x}_{mw}$ ranged from 12.9 g at density D5 to a high of 17.2 g at the lowest stocking density, D1. Comparing $\bar{x}_{mw}$ among stocking densities, the mean meat weight observed at density D1 was 28% greater than at D5 for pearl nets and 33% greater for lantern nets. At the lowest stocking density, the final $\bar{x}_{mw}$ observed in pearl nets was 15% greater than the comparable density in lantern nets.

DISCUSSION

Rate of growth is one of the major factors that influence the feasibility of sea scallop culture since it defines the length of the growout period and thus much of the production cost (Côté et al. 1993). Many factors influence the growth rate of bivalves - some of which are environmental such as food availability and water temperature (Kirby-Smith and Barber 1974; Bayne and Newell 1983; MacDonald and Thompson 1985; Wilson 1987; Lodeiros and Himmelman 1994; Couturier et al. 1995), and others which are biological and physiological such as age, size, and reproductive maturity of the animals themselves (MacDonald 1986; MacDonald and Thompson 1988). In scallop aquaculture systems, whether it be a choice of suspension culture in nets, cages, or ear hanging, or on the sea bottom, such factors as depth of the culture gear, type of gear and mesh size, stocking density, extent of fouling, labour and capital costs, predation by other organisms, etc. must also be added (Wildish et al. 1988; Minchin 1991; Parsons and Dadswell 1992 1994; Shellfresh Farms Ltd. 1993; Côté et al. 1993; Barbeau et al. 1994; Claereboudt et al. 1994a).

Selection of type of culture gear to use with sea scallops depends largely on the type of end product desired. Styled after the Japanese practice (Taguchi, 1977), scallops are usually raised in intermediate culture as juveniles in pearl nets, followed by a choice of final growout methods including suspended culture in cages such as pearl nets, lantern nets, or Shibetsu nets, ear hanging, or bottom culture (Naidu and Cahill 1986; Young-Lai and Aiken 1986; Wildish et al. 1988; Parsons and Dadswell 1992). For the production of juveniles, 50-70 mm, intended for sale as whole, live 'princess' scallops, the final growout stage is not needed. The use of pearl nets, as in intermediate culture, is appropriate to raise scallops to this market size. In this experiment, production of two product types was targeted - large, whole scallops intended for the live 90-110 mm market, traditional meats for the premium priced 20/30 count (#/lb) North American market (ARA Consulting Ltd 1993), and for meats with roe. Production of both these products requires growout beyond the 'intermediate stage'.

Rearing trials were carried out using two types of suspension culture gear - pearl nets and lantern nets, with initial stocking density varied for both gear types. Sea scallops grew well in both gear types and at all densities selected. Significant relationships among growth (in shell height, total weight and meat weight), stocking density, and gear type were found. For both gear types, final shell height, total weight, and meat weight all decreased as density increased. At comparable densities, shell height, total weight, and meat weight were all greater in pearl nets rather than lantern nets. However, no significant differences in survival were found among gear types or stocking densities. Similar relationships in growth and stocking density have been reported elsewhere for sea scallop juveniles in intermediate culture (Dadswell and Parsons 1991; Parsons and Dadswell 1992; Côté et al. 1993), for large sea scallops in lantern nets (Naidu and Cahill 1978), and for other scallop species such as the Japanese scallop, *Patinopecten yessoensis*, and the bay scallop, *Argopecten irradians* (Duggan 1973; Imai 1977; Rhodes and Widman 1980, 1984; Ventilla 1982). Although it is difficult to compare growth rates and size at age data between different studies and locations, the growth rates observed in this study are similar to those reported for sea scallops grown elsewhere in Atlantic Canada (Wildish et al. 1988; Dadswell and Parsons 1991, Côté et al. 1993; Parsons and Dadswell 1992, 1994).

Abnormalities in shell shape were extremely rare in this study, in contrast to stocking density studies with other scallop species such as *Argopecten irradians* and *Patinopecten yessoensis* (Rhodes and Widman 1984; Aoyama 1989). This observation, coupled with the lack of relationship between density and survival, indicates the high stocking densities used did not cause undue duress to the scallops. Suspended culture gear is an excellent substrate for a variety of fouling organisms which negatively impact on growth of cultured stock by reducing water flow through the cages or by directly competing with the culture animals for food or space (Mallet and Carver 1991; Parsons and Dadswell 1994; Claereboudt et al. 1994a). However, only minimal levels of fouling were observed throughout this experiment. Therefore, the depressed growth rate at higher densities is likely due to decreased localized food concentrations caused by the water filtering action of the scallops themselves. Suspension feeding bivalves at high densities are known to deplete their food supplies (Fréchette and Bourget 1985; Peterson and Beal 1989), particularly in situations of low currents in localized areas (Wildish and Kristmanson 1985; Wildish and Saulnier 1993).

Density is probably the single most important factor affecting sea scallop growth rate in culture (Couturier et al. 1995). The combination of temperature and food availability probably accounts for most of the variability in growth rate between sites (Thompson and MacDonald 1991). Increasing food depletion with increasing density was also probably responsible for the reduced total and meat weights observed in both gear types (Claereboudt et al. 1994b). Although no observations were made of water flow rates through the cages, the reduced growth rate in lantern nets compared to pearl nets at comparable stocking densities may be due to greater restriction of water flow around and through the cages, and hence reduced food availability to the scallops, particularly those in the middle trays of each lantern net. In other studies, pearl nets were found to reduce water flow by 46-61% (Claereboudt et al. 1994b). No similar measurements are available for lantern nets.

The lack of significant relationships between survival and density have also been reported (Parsons and Dadswell 1992) although this appears to be somewhat unusual considering most of the above scallop studies on survival and density. Previous studies on intermediate stage culture of sea scallops reported high survival rates (> 90%) (Parsons and Dadswell 1992). Most of the observed mortality when culturing scallops appears due to improper handling (Ventilla 1982; Wildish et al. 1988; Parsons and Dadswell 1992). The high survival rates observed in this study may be attributed to the minimal levels of gear fouling and no re-sorting during the experiment which reduced handling.

The stocking densities used in this study and in other studies on sea scallops (Parsons and Dadswell 1992) produced situations where floor space utilization exceeded 100%. This is well beyond the 33% level recommended as the basis for defining stocking densities and thinning schedules for Japanese scallop culture (Imai 1977; Taguchi 1977). The fact that such high densities resulted in no increase in mortality rates may have important implications for commercial culture. Since high densities still may give acceptable growth and survival performance, and most mortalities will occur at times when scallops are handled, this would suggest the recommended practice of frequent thinning of stock should be reviewed with a view to reducing the number of times thinning is carried out. The frequency of thinning may be determined more by inter-site variation in the severity of gear fouling than by the need to reduce stock density. Claereboudt et al. (1994a) determined shell height was not appreciably affected by regular elimination of fouling from pearl nets, but meat weight was significantly increased. Since labour costs are an important component of overall production costs (Atlantecon 1992; Parsons and Dadswell 1994), any reduction in farm labour by modifying suggested thinning schedules would improve the economic viability of scallop aquaculture.

To keep production costs down, the type of gear and culture techniques selected should produce a marketable product in as short a time as possible. In this experiment, final growout at three of the five densities selected produced the intended product (a 90^+ mm scallop with meats in the 20/30 count per pound range) using pearl nets (Table 5). A 90^+ mm scallop is preferred for the large, whole scallop market (T. Mills, Thimble Bay Farms, Ltd., pers. comm.) while the larger 20/30 count meat has consistently received a price premium in the North American market (ARA Consulting Group Inc., 1993). The two higher densities produced a 20/30 count meat but the mean shell height was < 90 mm. Only the lowest stocking density produced the desired product in lantern nets after one year, although the two lowest densities produced a 20/30 count meat. Production of 100^+ mm scallops, or those with greater meat count rating would require growout for at least another 4-6 months in either pearl nets or lantern nets.

It is important to note that total weight was actually higher in May than in September, irrespective of density or gear type, even though the scallops in May were 4-9 mm smaller in shell height than in September. The September samples were taken shortly after spawning so the gonad weight was probably at a seasonal low. Scallops undergo pronounced seasonal changes in tissue weights, including the meats and roes (Robinson et al. 1981; Epp et al. 1988; Faveris and Lubet 1991; Couturier and Newkirk 1991) and growth rates in both shell height and soft body tissues may vary seasonally (Couturier and Newkirk 1991; Côté et al. 1993). This has obvious commercial ramifications since production of 'meats with roe' will be possible only during the spring to summer period. Also, if large, whole scallops are sold on a price per unit weight basis rather than per individual, harvest weight, and therefore sales income, will be maximized in the spring and summer.

Based solely on the growth rates observed in this experiment, pearl nets rather than lantern nets appear to be a better choice of production gear for suspended sea scallop culture of large size scallops. However, cost of production is determined by many factors other than growth rate such as capital cost of equipment, labour, gear handling times, etc. Parsons and Dadswell (1994) determined that although the initial capital cost of pearl nets were much lower compared to lantern nets, when handling times and their associated labour costs were factored in, lantern nets and Shibetsu nets gave the lowest cost of production. However, their analyses were for intermediate culture of juveniles and did not account for overall optimization of equipment usage for successive year classes of new stock arriving on the farm. For example, keeping scallops an extra 4-6 months to reach minimum size of 90^+ mm would require purchase of a duplicate set of lantern nets if production was geared towards the 90^+ mm scallop. Clearly, selection of gear type and culture strategy is affected by the choice of intended product.

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Table 1. Initial stocking densities and number of sea scallops per pearl net or lantern net tray at experimental startup in September, 1991.

		PEARL NET			LANTERN NET		
DENSITY	NOMINAL % FLOOR SPACE USED	#/NET	# OF NETS	#/100 cm^2	#/NET	# OF NETS	#/100 cm^2
D1	20	6	8	0.52	10	5	0.51
D2	35	10	6	0.87	16	3	0.82
D3	50	14	4	1.21	23	4	1.17
D4	65	18	4	1.56	30	4	1.53
D5	85	25	4	2.16	40	3	2.04

Table 2. Mean daily growth rates (in shell height) from September, 1991 to September, 1992 for sea scallops stocked at five densities in pearl and lantern nets.

		SEP 91 - MAY 92 (8 MONTHS)		MAY 92 - SEP 92 (4 MONTHS)		SEP 91 - SEP 92 (12 MONTHS)	
NET TYPE	DENSITY	TOTAL GROWTH[1] (mm)	GROWTH RATE[1] (mm/day)	TOTAL GROWTH[1] (mm)	GROWTH RATE[1] (mm/day)	TOTAL GROWTH[1] (mm)	GROWTH RATE[1] (mm/day)
PEARL	D1	13.9	0.057	8.9	0.073	22.7	0.062
	D2	11.5	0.047	7.2	0.060	18.7	0.052
	D3	14.3	0.059	7.8	0.065	22.1	0.061
	D4	9.2	0.038	7.8	0.064	16.9	0.047
	D5	8.1	0.033	6.0	0.050	14.1	0.039
LANTERN	D1	10.4	0.043	6.6	0.055	17.0	0.047
	D2	9.6	0.040	6.6	0.055	16.3	0.045
	D3	6.1	0.025	5.8	0.048	11.9	0.033
	D4	7.8	0.032	4.7	0.039	12.5	0.034
	D5	5.8	0.024	3.6	0.029	9.4	0.026

[1] Total growth and growth rates are means of all replicates within each gear type and density

Table 3. Per cent survival from September, 1991 to September, 1992 for sea scallops stocked at five densities in pearl and lantern nets.

NET TYPE	DENSITY	# STOCKED SEP 91	# ALIVE[1] MAY 92	% SURVIVAL[1] SEP-MAY	# ALIVE[1] SEP 92	% SURVIVAL[1] MAY-SEP	% SURVIVAL[1] SEP-SEP
PEARL	D1	6	6	100	6	100	100
	D2	10	10	100	9.7	97.4	97.4
	D3	14	14	100	14	100	100
	D4	18	18	100	17.8	98.7	98.7
	D5	25	24.1	96.2	23.3	96.7	93.2
		$\bar{x}$ SURVIVAL (ALL DENSITIES) =		99.2		98.6	97.9
LANTERN	D1	10	10	100	10	100	100
	D2	16	14.9	93.2	14.9	100	93.2
	D3	23	23	100	23	100	100
	D4	30	29.5	98.4	29.11	98.6	96.8
	D5	40	40	100	39.7	99.2	99.2
		$\bar{x}$ SURVIVAL (ALL DENSITIES) =		98.3		99.6	97.8

[1] # Alive and % survival are means of all replicates within each gear type and density

Table 4. Per cent net tray floor space utilization from September, 1991 to September, 1992 by sea scallops stocked at five densities in pearl and lantern nets.

		% FLOOR SPACE UTILIZATION		
NET TYPE	**DENSITY**	**SEP 1991**	**MAY 1992**	**SEP 1992**
PEARL	D1	20.5	29.2	35.9
	D2	37.0	49.5	56.7
	D3	46.9	67.9	81.1
	D4	63.4	80.5	95.4
	D5	91.5	108.2	121.0
LANTERN	D1	21.3	27.9	32.5
	D2	33.4	40.0	46.8
	D3	49.1	57.7	66.5
	D4	60.1	72.8	80.5
	D5	81.8	95.6	103.8

Table 5. Shell height and meat count (North American market standard) achieved after one year in both pearl nets and lantern nets for five different stocking densities.

	DENSITY LEVEL				
GEAR TYPE	D1	D2	D3	D4	D5
PEARL	Meats are 20/30 count Shell height 90^+ mm			Meats are 20/30 count Shell Height <90 mm	
LANTERN		Meats are 20/30 count; Shell Height <90 mm	Meats are 30/50 count Shell height <90 mm		

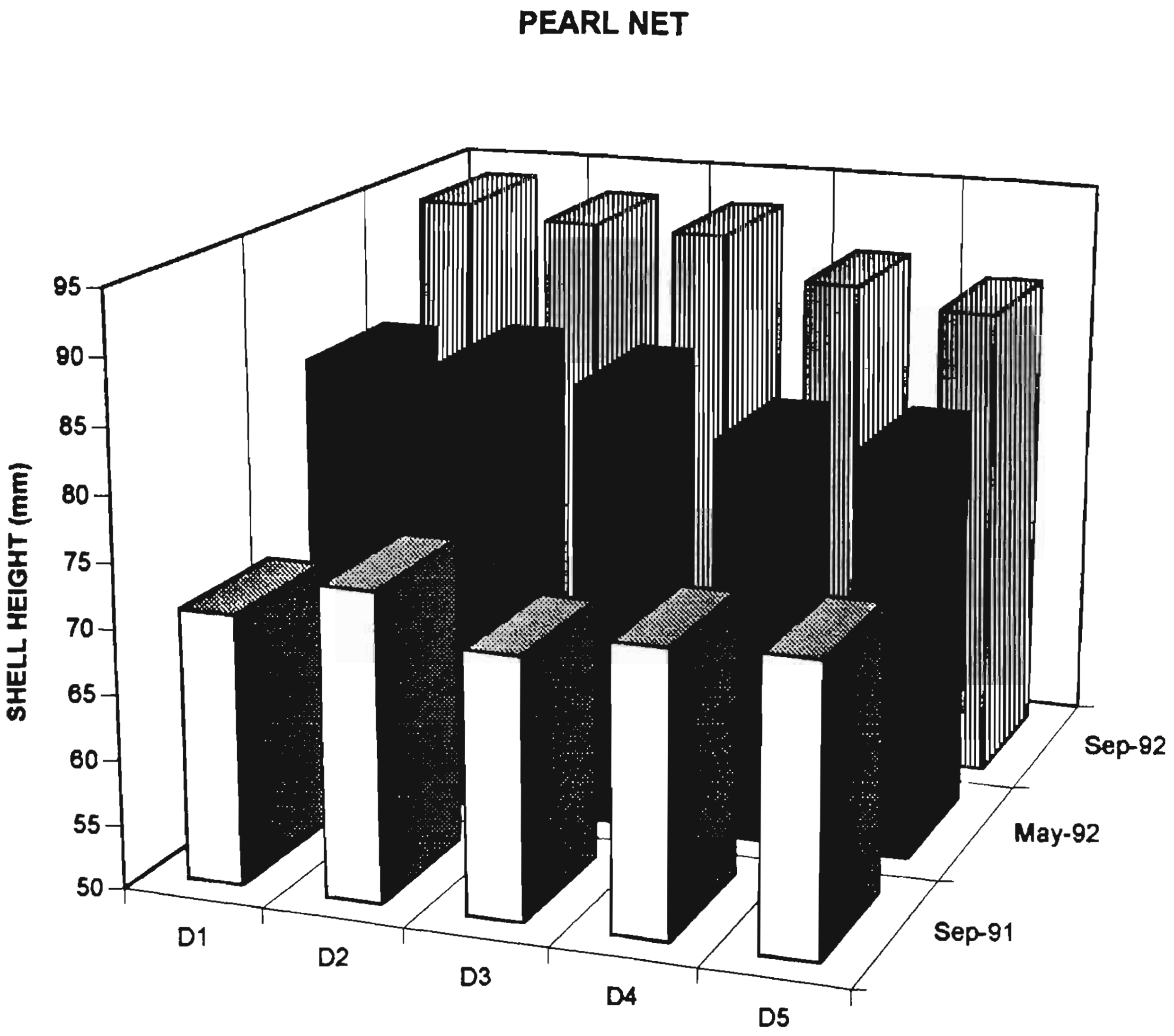

Figure 1. Growth in shell height from September, 1991 to September, 1992, for sea scallops stocked at 5 densities in pearl nets.

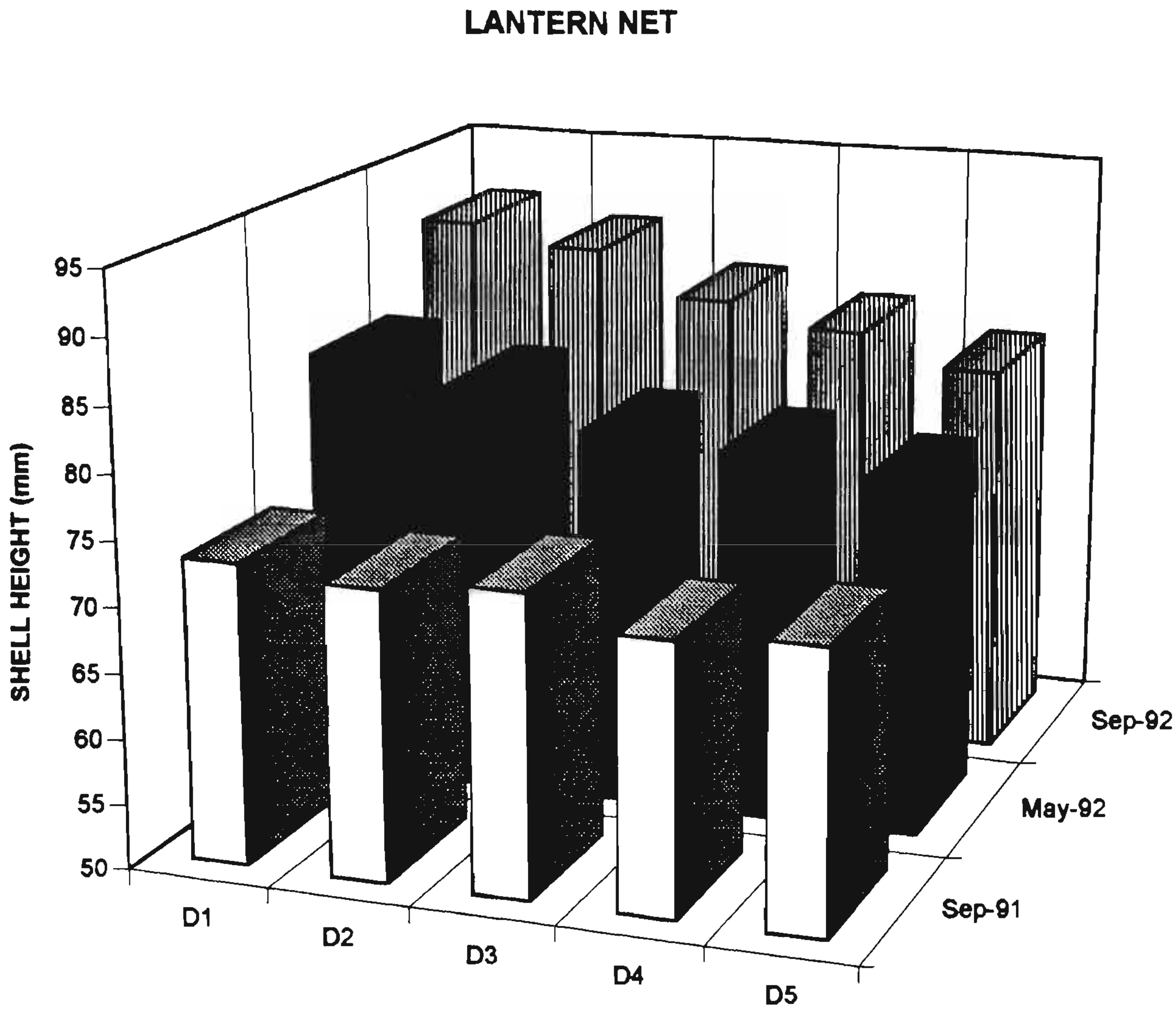

Figure 2. Growth in shell height from September, 1991 to September, 1992, for sea scallops stocked at 5 densities in lantern nets.

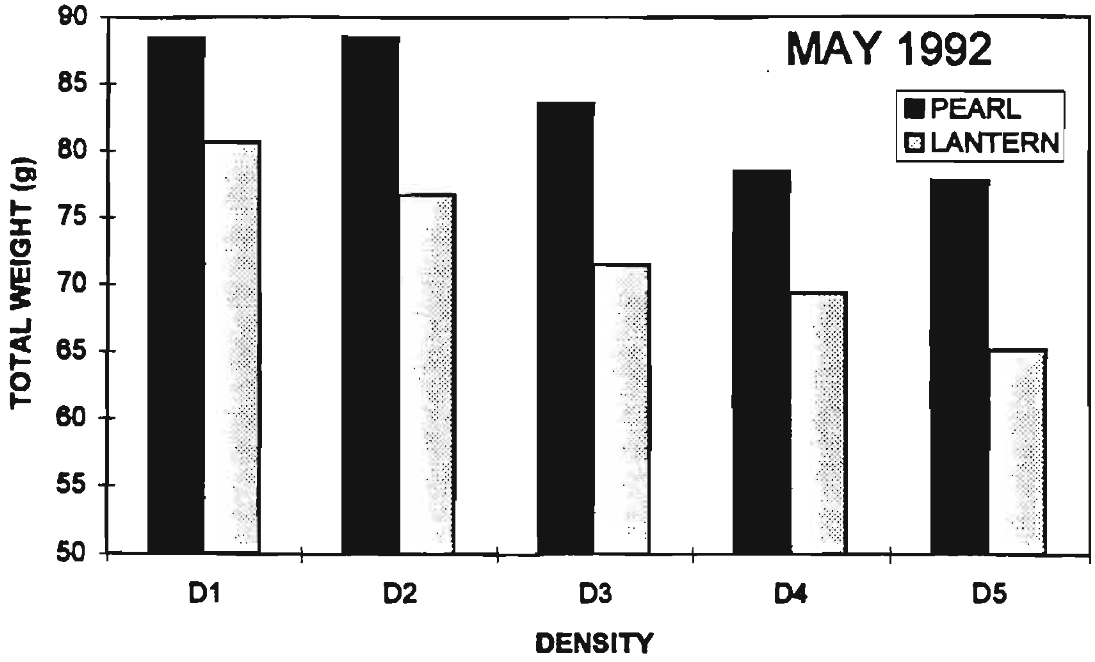

Figure 3. Total weight in May, 1992 for sea scallops stocked at 5 densities in pearl nets and lantern nets.

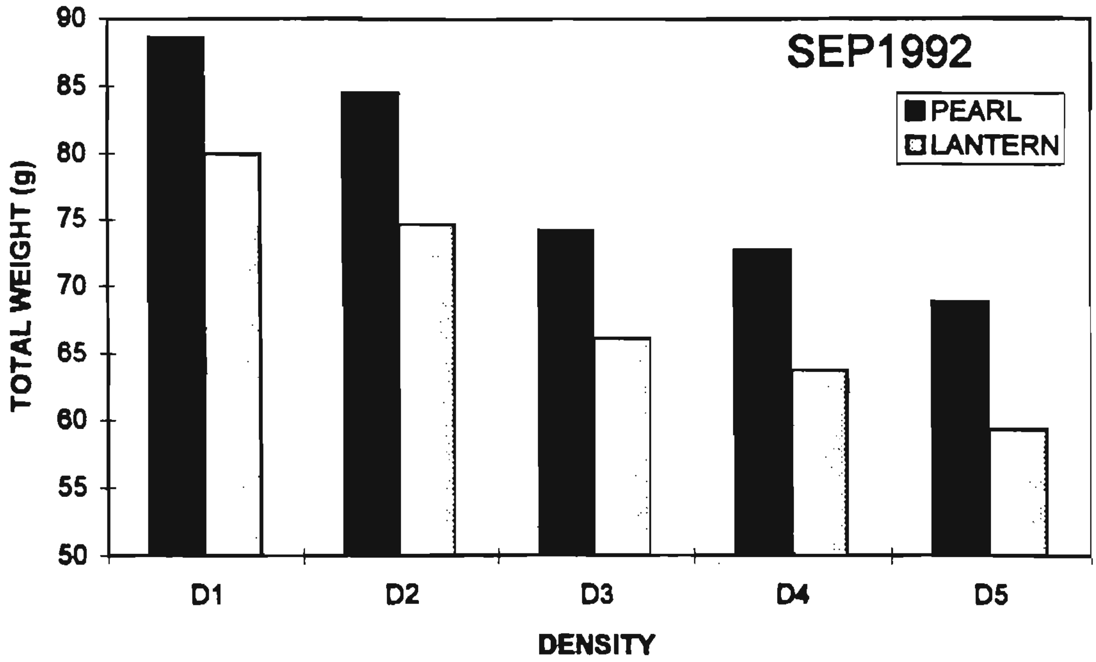

Figure 4. Total weight in September, 1992 for sea scallops stocked at 5 densities in pearl nets and lantern nets.

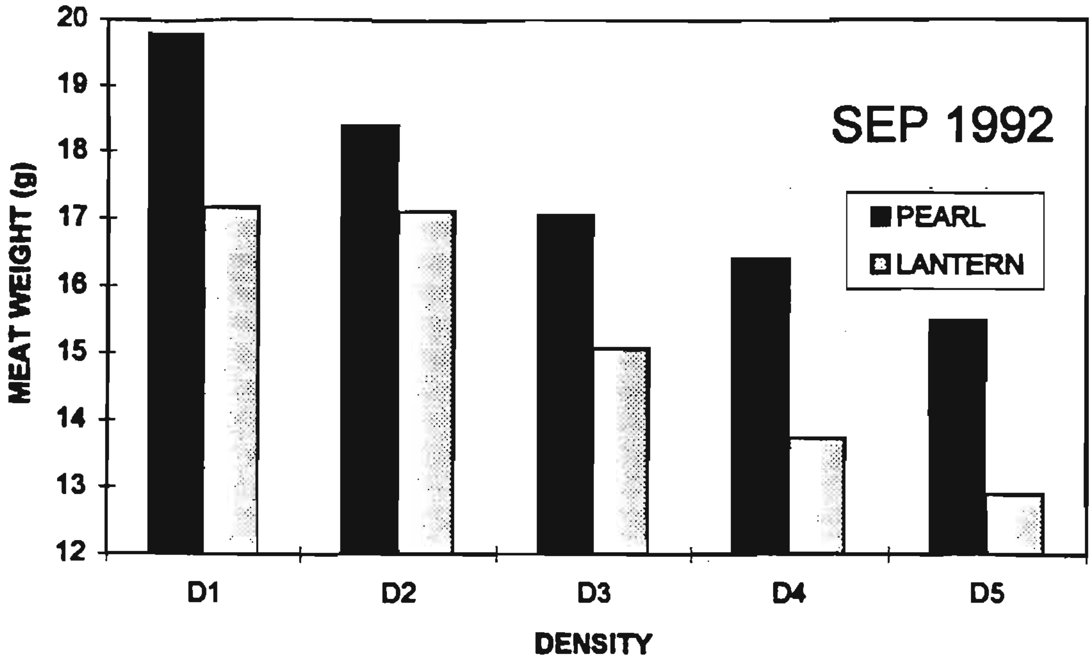

Figure 5. Meat weight (adductor muscle) in September, 1992 for sea scallops stocked at 5 densities in pearl nets and lantern nets.