ELSEVIER

Aquaculture 189 (2000) 73–84

Aquaculture

www.elsevier.nl/locate/aqua-online

Scallop growout using a new bottom-culture system

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Received 4 March 1999; received in revised form 15 February 2000; accepted 25 February 2000

Abstract

A new bottom-culture system was tested at a commercial level to grow catarina scallops (*Argopecten ventricosus*) in the Rancho Bueno tidal channel in Bahia Magdalena, Mexico. The system consisted of a 50 × 1-m sleeve of 19-mm mesh polyethylene netting placed on the sea floor of selected growout areas. A total of 448 sleeves were deployed at various times from October 1994 to April 1995 in four zones from the mouth to the head of the tidal channel. Each sleeve contained 10,000 scallops (initially 32 mm shell height) at a density of 200 scallops/m^2. Fifty-four percent of the spat were produced in a hatchery and the rest were collected using onion-bag collectors. Hatchery and wild spat were deployed separately. Water parameters were measured monthly in each zone: temperature, salinity, dissolved oxygen and total suspended solids. There were better water conditions towards the mouth of the channel. The scallops were harvested from 27 July to 18 August 1995: a total of 2.87 million scallops from the original 4.48 million. Their mean shell height was 56.2 mm and the mean weight of their adductor muscles was 6.8 g. The production was 19.3 t of adductor muscles. Statistically significant differences in mean shell height and mean adductor weight were found between scallops grown in different zones, but no statistically significant differences were found comparing yields from hatchery vs. wild scallops. To find the best culture conditions, a scallop relative value (SRV) was calculated by multiplying survival by adductor muscle weight and relative market price, and dividing by the growout duration. There were higher SRVs for scallops cultured in zones closer to the channel mouth. The highest SRV was found in a group from this zone, with 86% survival, 6.25 g mean adductor weight, and a growout duration of only 3.6 months. A new successful method for

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0044-8486/00/$ - see front matter
PII: S0044-8486(00)00362-8

growing scallops in shallow areas is, thus presented here. It gave better results than suspension methods tested in the same area.

Keywords: Argopecten ventricosus; Culture; Scallop; Mexico; Benthos; Technique

1. Introduction

The current industrial method of culturing scallops in China and Chile uses lantern nets as growout devices. This method, developed for the scallop *Patinopecten yessoensis* culture in Japan, is profitable where labor is inexpensive, as in China, and where the final product is highly valued, such as the Chilean scallop (*Argopecten purpuratus*) in the French market. In searching for more economically effective methods, the Japanese are shifting gradually to the sowing method, which consists of releasing high numbers of spat in highly productive areas where predators like starfish, sea urchins, and octopus have previously been removed (Ito, 1991). The sowing method is therefore only applicable to those areas with high seston concentrations and with low natural predation, or where predator control is permitted. In Japan, recapture of scallops varies from 5.5% to 98% during 2 to 3 years of culture, and depends on seed input (Ito, 1991).

In Mexico, lantern nets have been destroyed by fish (Tripp-Quezada, 1985) and sowing is not appropriate because predation is high (Maeda et al., 1992). A good suspension gear for scallop culture in Mexico is the Nestier tray (Maeda-Martínez et al., 1997); but, because of the current low price of small scallop meat, and the high costs of labor and the gear, profit still remains low. Apart from the sowing approach, only a few attempts have been made to develop other profitable methods for bottom-culture growout. Experimentally, Velez et al. (1995) cultured *Euvola ziczac* in bottom cages and several researchers in Mexico (Félix-Pico et al., 1989) tested a modular enclosure to confine the scallops. Maeda-Martínez and Ormart-Castro (1995) developed an experimental bottom-culture system that produces high growth rates and survival, and requires inexpensive gear and low maintenance during operation. This system remains to be tested commercially.

This study describes the results of a commercial culture project for the catarina scallop, *A. ventricosus*, in four growout zones at Rancho Bueno, Bahia Magdalena, Mexico, using a new system. An index of scallop relative value (SRV) that accounts for survival, adductor weight, relative market price, and the growout duration was used to find the culture conditions that produced maximum economic yield. Although the project did not follow an experimental protocol, comparative performance of groups of scallops sown in the same or in different zones and using wild or hatchery produced spat is given.

2. Materials and methods

2.1. The growout system

The growout system consisted of 19-mm mesh of high-density polyethylene (HDPE) netting sleeves of 50×1 m dimensions (Fig. 1), placed on the sea floor of selected

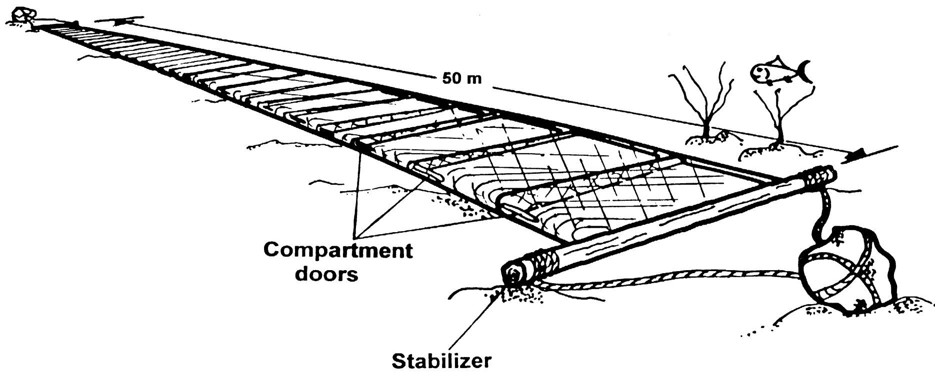

Fig. 1. Growout device employed for bottom culture of catarina scallop (*A. ventricosus*).

growout areas. To achieve an even distribution of the scallops, the sleeves were sectioned into 50 0.2-m^3 (1 m^2 $\times$ 0.2 m height) rhomboid compartments. The divisions of the compartments were made with strips of the same mesh, fixed with u-shaped galvanized staples every meter. The strips were introduced into the sleeves through 0.3-m longitudinal incisions that served as the compartment doors. The narrow ends of the compartments ended in the doors, serving as funnels that facilitated the harvest of the scallops. A wooden 1.5-m post acting as a stabilizer was tied transversally to each end of the sleeve with a polyethylene rope. The anchors of each sleeve were two 10-kg rocks tied with ropes to each stabilizer as shown in Fig. 1. A small signal buoy was tied to one of the rocks.

Casting and recovery operations of the system were done from a 6.9-m boat, without the need of diving. Before deployment, the sleeves were rolled and placed on a reel mounted on the boat (Fig. 2), which already contained the screened scallops of 32-mm mean shell height. A total of 200 scallops per compartment were loaded, and the sleeve was cast in the direction of the water current to avoid entanglement. Every 15 days, the gear was serviced by turning the sleeves over during ebb tide to get rid of fouling organisms and to avoid excessive sand deposition.

2.2. The commercial project

A total of 448 sleeves divided into 12 lots (= groups of scallops each of the same date of sowing and culture zone) were deployed from October 1994 to April 1995

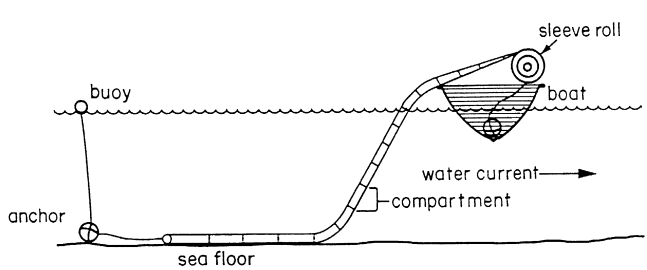

Fig. 2. Casting procedure of growout device for scallop culture.

Table 1
Total harvest, final shell height and meat weight, meat grade, survival, and relative price and value of catarina scallops (*A. ventricosus*) grown at Rancho Bueno, Mexico
H = Hatchery; W = Wild; lb = 0.454 kg.

Zone	Lot	Sowing date	Spat origin	Growout duration (days)	No. of sleeves	Scallops sown ×1000	Meat harvest (kg)	Final shell height (mm) (mean ± sd)	Final meat wet weight (g)	Meat grade (meats/lb)	Survival (%)	Relative price	Relative value
1	1	10/94	H	319	76	760	428	57.4 ± 3.8	8.54	40/60	65.9 ± 4.8	1.74	3.1
	2	10/94	H	299	79	790	4782	57.7 ± 3.6	8.27	40/60	73.2 ± 7.4	1.74	3.5
	8	02/95	H	185	8	80	494	56.4 ± 3.0	7.14	60/80	86.5 ± 0.2	1.10	3.6
	11	04/95	H	109	3	30	161	52.5 ± 2.6	6.25	60/80	86.1 ± 0.5	1.10	5.4
2	3	10/94	H	278	28	280	1414	56.5 ± 3.4	7.84	40/60	64.4 ± 2.8	1.74	3.2
	6	01/95	W	206	95	950	5026	56.8 ± 2.6	7.12	60/80	74.3 ± 9.6	1.10	2.8
	9	02/95	H	183	22	220	1172	57.4 ± 3.3	7.32	60/80	72.8 ± 2.0	1.10	3.2
3	4	12/94	H	240	9	90	409	58.2 ± 3.7	7.06	60/80	64.3 ± 0.5	1.10	2.1
	5	12/94	W	224	97	970	4361	57.9 ± 3.9	6.97	60/80	64.5 ± 17.0	1.10	2.2
	10	02/95	H	172	3	30	105	55.7 ± 3.1	4.90	80 over	71.8 ± 0.1	1.00	2.0
	12	04/95	H	118	16	160	500	52.4 ± 2.9	4.40	80 over	71.1 ± 0.5	1.00	2.6
4	7	01/95	W	186	9	90	422	55.6 ± 2.9	5.83	60/80	60.4 ± 0.6	1.10	2.1
Totals and averages					448	4480	19,274	56.2 ± 3.2	6.80		71.2 ± 3.8		

(Table 1) in four growout zones in the tidal channel, Rancho Bueno, at the southern end of Bahia Magdalena on the Pacific Coast of the Baja California Peninsula (Fig. 3). Each sleeve contained 10,000 scallops. Fifty-four percent of the spat were produced in a hatchery, following the method of Maeda-Martínez et al. (1995), and the rest were collected using onion-bag collectors. Hatchery and wild spat were deployed in different lots (Table 1). The nursery stage was conducted in suspended Nestier trays (Maeda-Martínez et al., 1997) at 1000 scallops/m^2 for 4 months for wild spat or 6 months for hatchery-produced spat. The scallops were screened to an even size (32.4 ± 2.6 mm shell height) before they were loaded into the sleeves.

A detailed description of water conditions in Bahia Magdalena is given by Maeda-Martínez et al. (1993). Briefly, Rancho Bueno is a tidal channel 8-km long, 0.5-km wide and 5-m maximum depth with strong currents (higher at the mouth than at the head) caused by a 2.25-m tidal range in the area (Mendoza-Salgado and Lechuga-Devéze, 1995). This area is influenced by the California Current carrying cold water during most of the year (Alvarez-Borrego et al., 1975; Lynn and Simpson, 1987). Bathymetry is uneven along the channel, with flat intertidal and subtidal areas, and primary and secondary channels. Sediment varies from sand at the mouth to mud at the head. Flat subtidal areas are found along the channel and account for approximately 42 ha of the total area. Four sections distributed along the channel were marked with buoys and were used as growout zones (Fig. 3). Average depths at extreme ebb tide were 0.5, 0.75, 0.5, and 0.75 m in zones 1, 2, 3, and 4. Monthly measurements of water temperature, salinity, dissolved oxygen and total suspended solids were taken throughout the study. Temperature was measured with a cuvette thermometer and salinity with a hand

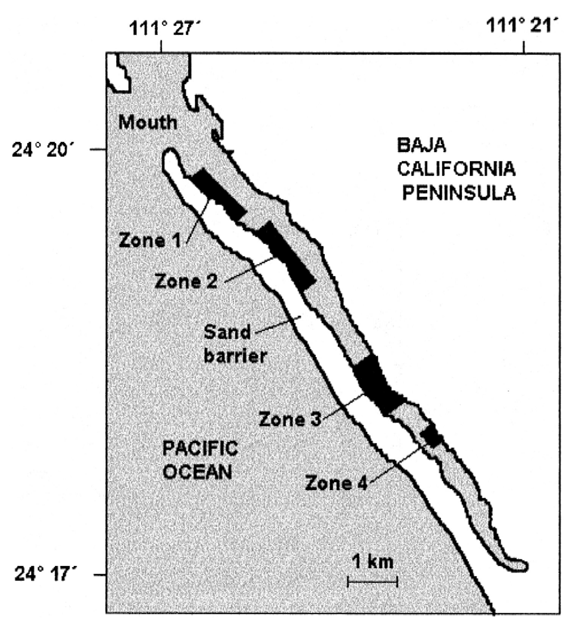

Fig. 3. Growout zones in Rancho Bueno, Mexico.

refractometer. One sample (0.5 l) of seawater was taken at 20- to 30-cm depth at each station every month, and was stored in polyethylene bottles. The whole sample was filtered through a GF/C membrane and the filtrate analyzed for total suspended solids according to APHA–AWWA–WPCP (1980). Dissolved oxygen was measured using a microWinkler miniaturized titrator method (Maeda-Martínez, 1985).

A sample of 50 scallops was taken periodically between January and harvest day from the lots under culture, and the shell height and wet weight of adductor muscle were measured. From 27 July 1995 to 18 August 1995, all the scallops were harvested. Once on the beach, the scallops were shucked by hand and the adductor muscles separated from the rest of the animals. Average shell height and meat wet weight from a pooled sample of at least 50 harvested scallops from all the sleeves of a given lot were measured, and the total meat weight harvested was recorded. Total growth was calculated by subtracting final shell height from the initial shell height. Lot survival was calculated as follows:

$$\text{Survival}\,(\%) = \frac{\text{Number of meats harvested}}{\text{Number of scallops sown}} \times 100$$

where

$$\text{Number of meats harvested} = \frac{\text{Total adductor wet weight harvested (g)}}{\text{Mean adductor wet weight (g)}}$$

and

$$\text{Number of scallops sown} = 10{,}000 \text{ scallops per sleeve} \times \text{No. of sleeves}$$

To determine the economic yield of the lots, the relative value (SRV) of the scallops was calculated using the following expression:

$$\text{SRV} = \frac{\text{survival} \times \text{adductor wet weight} \times \text{relative price}}{\text{growout duration (days)}}$$

Because in commodity markets scallops are valued according to the number of meats per unit weight (per pound (lb) = 0.454 kg), the relative price of a given lot was calculated depending on the weight category, relative to the 80-over grade. Thus, the lower the counts per pound, the higher the price. In this work, relative price was calculated using the Urner Barry's Publication price list of September 1995, where 80-over, 60–80 and 40–60 scallops/lb, were valued at 2.85, 3.15, and 4.95 US Dollars/lb, respectively. Therefore, relative prices were 1.0, 1.1, and 1.74 for 80-over, 60–80, and 40–60 scallops/lb.

Final shell height and final meat weight were used to compare several lots sown on similar dates, to test for variability within the same zone (1 vs. 2), differences between growout zones (6 vs. 7, 8 vs. 9, 8 vs. 10, 9 vs. 10, and 11 vs. 12), and to compare the performance of wild against hatchery-produced spat (4 vs. 5). Comparisons were made with a Student's *t*-test.

3. Results

3.1. Environmental variables

Mean water temperature varied between 19.1°C (February 1995) and 28.7°C (August 1995) at the four growout zones (Fig. 4). Mean temperature was higher towards the head of Rancho Bueno throughout the year (Fig. 4), probably as a result of the shallow conditions. The mean temperatures at zones 1, 2, 3, and 4 were 22.6°C, 23.1°C, 23.7°C, and 24.4°C, respectively. This gradient, however, was only present during 7 months (March 1995 to September 1995), and was higher when the extreme temperatures of June 1995 (lowest) and August 1995 (highest) occurred. From October 1994 to February 1995, the thermal gradient between zones was not present.

Salinity remained steady throughout the year at 37‰. Dissolved oxygen varied within a range of 3.8 and 5.2 ml/l in the four zones. These data, converted to O_2 saturation, indicate that the sea water in Rancho Bueno was close to O_2 saturation throughout the year: between 88% and 94%. Total suspended solids fluctuated within a range of 2 and 8 mg/l, almost throughout the year, except during two small periods (June–July 1995 and October–November 1995) when values were notably higher, up to 17 mg/l.

There were clear horizontal gradients of the last two variables, dissolved oxygen and total suspended solids, from the mouth (zone 1) to the head (zone 4) throughout the year. Dissolved oxygen was higher at the mouth than at the head, while total suspended solids were highest at the head.

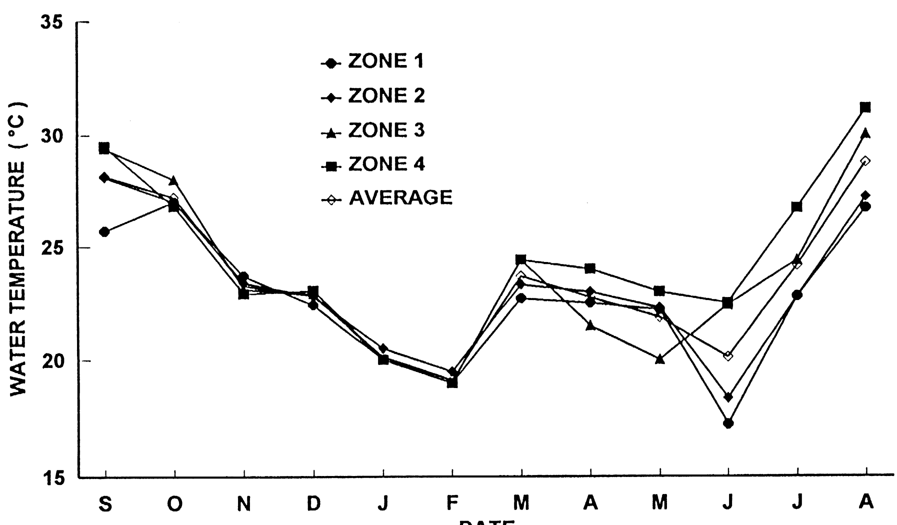

Fig. 4. Monthly temperature at the four growout zones in Rancho Bueno from September 1994 to August 1995.

3.2. Scallop growout

A total of 19,300 kg of meat was harvested during 23 days from 27 July 1995 to 18 August 1995 from all lots (Table 1). Mean final shell height was 56.2 ± 3.2 mm with a minimum of 52.4 ± 2.9 mm in 118 days (lot 12) and a maximum of 58.2 ± 3.7 mm in 240 days (lot 4). Final adductor muscle wet weight varied from 4.40 in 118 days (lot 12) to 8.54 g in 319 days (lot 1), with a mean value of 6.8 g. Mean survival was 71.2 ± 3.8%, with the lowest 60.4 ± 0.6% (lot 7) and the highest 86.5 ± 0.2% (lot 8).

Regression analysis of shell height against growout duration, indicated that the shell height varied directly and significantly with growout period ($P < 0.05$) ($r = 0.71$; $n = 12$), as did muscle wet weight ($P < 0.05$) ($r = 0.77$; $n = 12$). However, survival vs. growout duration ($r = -0.47$; $n = 12$) was not significant ($P > 0.05$), although the correlation was negative as expected.

There were no significant differences between shell height of scallops sown in the same zone ($P > 0.05$). When comparisons were made between lots sown in different zones, differences in shell height were significant only in lots 9 (zone 2) vs.10 (zone 3), and in lots 6 vs. 7 grown in zones 2 and 4 ($P < 0.05$). No significant differences were found in lots 8 vs. 9, 8 vs. 10 and 11 vs. 12, which indicates similar growth in zones 1 and 2, and in 1 and 3. However, significant differences ($P < 0.05$) were found between lots 9 vs.10, grown in zones 2 and 3, and there is no ready explanation for this. Final shell height of scallops produced in the hatchery (lot 4) vs. that of wild scallops (lot 5) were not statistically different ($P > 0.05$).

For adductor muscle wet weight, similar results as for shell height were obtained, except that significant differences ($P < 0.05$) were found between lots grown in zones 1 and 3 (lots 8 vs. 10 and 11 vs. 12). There were no significant differences ($P > 0.05$) within the same zones, between zones 1 and 2, and between scallops of different origin.

Table 1 also shows the relative value of scallops from different lots. The highest relative values were obtained in lots closer to the mouth of Rancho Bueno, declining

Table 2
Linear regression parameters of meat wet weight vs. growout duration of different lots of catarina scallops (*A. ventricosus*)
a = intercept; b = slope.

Zone	Lot	Sowing date	*a*	*b*	*r*	*n*	Calculated meat weight at day 109
1	1	October 1994	0.31	0.030	0.93	6	3.66
	2	October 1994	0.80	0.026	0.97	3	3.74
	8	February 1995	2.93	0.024	0.94	4	5.61
	12	April 1995	3.20	0.027	1.00	2	6.25
2	3	October 1994	1.12	0.020	0.94	4	3.89
	6	January 1995	3.35	0.020	0.93	4	5.96
	9	February 1995	3.60	0.021	0.91	3	5.99
3	4	December 1994	2.71	0.010	1.00	4	4.22
	5	December 1994	1.78	0.029	0.88	4	4.99
	10	February 1995	3.61	0.009	0.78	4	4.69
	11	April 1995	3.16	0.007	1.00	2	4.00
4	7	January 1995	3.01	0.017	0.91	4	4.91

gradually towards the head. The highest relative value of 5.4 was obtained in lot 11 from zone 1, which produced a mean size of 6.25 g adductor muscle wet weight in only 109 days.

To determine if this result persists despite scallops being sown in a different month than April, a correlation analysis was made between growout time and adductor muscle wet weight using the data from samples taken from January 1995 to harvest from all lots. Results indicate that sowing date is critical to produce the highest adductor muscle wet weight possible (Table 2). In zone 1, scallops sown in April 1995 produced heavier meats (6.25 g) than those sown in February (5.61 g) or in October (3.66 and 3.74 g). In zone 2, a similar pattern was observed. However, in zone 3, meat weight was not apparently affected by sowing date (Table 2).

4. Discussion

A new alternative system for scallop growout has been described in this paper. The system allowed us to harvest more than 19 t of scallop meat and to evaluate the effect of the environment on scallop yields. A study is needed to compare the economic aspects of the different systems available, although we anticipate that sleeves have several advantages over lantern nets and Nestier trays. The latter devices have previously been evaluated on the same scallop in Bahia Magdalena by Tripp-Quezada (1985) and Maeda-Martínez et al. (1997). Advantages of sleeves include lower gear maintenance and operation costs. Additionally, it seems that the product harvested from the sleeves is far heavier than that obtained in trays over the same period of time and at similar densities. Performance in lantern nets cannot be compared because of high densities ($400/m^2$) used by Tripp-Quezada (1985). Maeda-Martínez et al. (1997) harvested 3.78 ± 0.01-g meats (fresh weight) from 55.7 ± 0.05-mm shell height scallops grown at a density of 150–250 $scallops/m^2$ in trays for 200 days, in zone 3 of this study area. In the present work, 4.9-g meats were harvested from scallops of the same size (55.7 ± 3.1 mm) belonging to lot 10, grown in zone 3, in only 172 days. This can probably be explained by the higher flow of water (which contains the food) passing through the holes of the sleeves (19 mm) compared to those of the Nestier trays (6- and 8-mm diameter at the lateral and bottom faces). Plankton stratification is not likely to be the cause, because of the shallow water in the area.

Average survival in the sleeves was 71.2 ± 3.8% with a minimum of 60.4% and a maximum of 86.5%. Mortality was not related to growout zone, but it correlated with growout duration. Survival figures are low when compared with the results in suspension culture (> 90%) (Maeda-Martínez et al., 1997), probably caused by the escape of scallops. During casting, scallops were frequently seen falling out of the sleeves through compartment doors that were not properly stapled. These scallops were not recovered and therefore contributed to mortality figures. Another cause of mortality was produced by excessive sand and mud deposition on the scallops in certain portions of the sleeves. This was probably caused by irregular water currents occurring in the growout zone and from insufficient maintenance. Mortality was never related to predation.

Growth and yield differences between zones can be explained by differences in water current velocity and, possibly, temperature. Wildish et al. (1987) demonstrated a unimodal response of specific daily growth rates in the giant scallop, *Placopecten magellanicus*, to water velocity. Optimum flow for this species was ~4 cm/s. Above and below this value, the specific daily growth was lower. Current velocity was not measured in Rancho Bueno, but it is clear that water currents in this site are higher towards the mouth than at the head, producing the higher scallop growth obtained in this study. Within certain limits, a higher flow will not allow a seston depletion for downstream animals, producing an even distribution of food within all individuals of the population. This applies where the benthic boundary layer intersects the surface (Wildish and Kristmanson, 1997), and it may occur in the shallow waters of Rancho Bueno. Further research is needed to confirm this hypothesis. Temperature is one of the most important factors controlling growth in poikilotherms, including bivalves (Bayne, 1976). In a recent study on the upper lethal tolerance to temperature (LT_{50} at 96 h = 29°C) and the optimum temperature (19–22°C) of the catarina scallop population of Bahia Magdalena (Sicard et al., 1999), it was concluded that the population studied belonged to a subtropical form, rather than being tropical as believed by Villalaz (1994). This suggests why the highest yields were obtained in the colder zones towards the mouth of Rancho Bueno where a greater mixing with the cold water from the Pacific Ocean occurs. As the water flows into the lagoon carried by tidal currents, water is warmed because the shallow conditions allow a greater heat transfer from the sun.

Differences in growth and yields cannot be explained by the variations in salinity, dissolved oxygen and total suspended solids occurring at the different zones. In Rancho Bueno, salinity (37‰) and dissolved oxygen (88–94% saturation) fell within the optimum values reported for the catarina scallop in the literature: 37‰ (Singnoret-Brailovsky et al., 1996) and 83–100% oxygen saturation (Sicard et al., 1999). Although the effect of total suspended solids on the catarina scallop growth and survival is not known, tissue and shell growth rates of juveniles of a close relative to the catarina scallop (*A. irradians*) were unaffected by natural sediment concentrations between 5 and 44 mg/l fed in combination with an algal diet (Korol, 1985). In Rancho Bueno, total suspended solids varied between 3.22 and 17 mg/l and therefore, it is unlikely that growth in *A. ventricosus* was affected by total suspended solids.

As was expected, shell growth and meat weight in the catarina scallop correlated with growout time. To determine the best harvest time, we calculated the relative value of scallop meats considering survival, adductor wet weight, relative price of the meats, and the duration of the growout phase. Higher SRV was obtained towards the mouth of Rancho Bueno, with the highest value from scallops sown in April in the mouth of Rancho Bueno and grown for only 109 days (3.6 months). Because of the existing effect of sowing season on final results, this combination of factors, especially the zone and sowing season, are recommended. The effect of sowing date on yields cannot be explained with the data available and a specific study is needed. However, it seems important that during this period the average temperature in zone 1 (21 ± 1°C) fell within the optimum temperature range (19–22°C) found by Sicard et al. (1999) in the same scallop population.

With our results, the optimum production cycle of catarina scallop would be using wild spat for 249 days or 8.3 months (60 + 80 + 109 days for spat collection, nursery, and growout, respectively) provided an appropriate area is selected and sowing is done at the right time. Areas similar to the mouth of Rancho Bueno are common not only in Bahia Magdalena, but also in the protected areas of the west coast of Baja California Peninsula including Laguna San Ignacio, Guerrero Negro, and Laguna Ojo de Liebre. Timing of this cycle in Bahia Magdalena is possible using hatchery or wild spat. As hatchery spat are smaller, the cycle has to be extended one extra month for hatchery spat.

Wild spat can be collected in large numbers (250 animals/collector) (Felix-Pico, 1991; Maeda-Martínez et al., 1993) if collectors are placed in January. The number of spat/collector would be increased if adult populations are maintained under culture in the same area (Ito, 1991; Maeda-Martínez et al., 1993). From personal observations, the spat harvested from collectors kept in the water for 2 months will measure more than 5-mm shell height, which are large enough to go to the nursery stage in Nestier trays. By using this gear, Maeda-Martínez et al. (1997) have demonstrated that 5-mm spat can be grown up to a mean size of 34 mm in suspension in 80 days. The use of sleeves with a smaller mesh for the nursery stage remains to be investigated. In this way, the suspension gear (including the Nestier trays, buoys, and ropes), which is expensive to buy and operate, could possibly be eliminated.

We have demonstrated that the sleeve method is appropriate for shallow areas. However, it appears that the system could work well in deeper places. In shallow conditions, operations are easy using only labor, but scallops are exposed to a variable environment, possibly stressing them. In contrast, in deeper areas ($>$ 30 m) of Bahia Magdalena, more stable temperatures and lower fouling loads occur (Tripp-Quezada, 1985), thus reducing the costs of maintenance. However, special machinery for casting and recovering the sleeves would have to be developed.

Acknowledgements

The authors thank Cultivos Técnicos del Mar Sudcaliforniano, S.A. de C.V. for providing the facilities to do the present study, in their concessioned area, Rancho Bueno, B.C.S. We thank Dr. Ellis Glazier for editing the English language text.

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