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Spat Settlement and Growth of Yearling of the Pearl Oyster *Pinctada radiata* in Bahrain Water

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ABSTRACT. Pearl oyster spat *(Pinctada radiata)* settlement under different environmental conditions was studied at several locations around Bahrain during 1989. A variety of spat collectors were tested and evaluated. Collectors made from empty oyster shell, nylon rope, coir rope type, steel wire, plastic baskets, wooden frams and cement coated oyster cages were laid during July 1989 at Fasht Al-Jarim, Khor Fasht, Sitra Beacon, Buoy No. 3 and Ras Hayan. Spat settlement took place over a long period (July to November 1989) as evident from occurrence of small-sized oysters each time collectors removed but intense spat settling was recorded throughout August 1989 giving indirect evidence that spawning commenced toward end of July 1989, and August 1989. Although settlement was reported on a wide range substrates, empty oyster shells enhanced maximum settlement (80 spat per oyster shell) indicating that ready to sit larvae exhibited some degree of substrate preference by settling primarily on rough surfaces such as empty shells. Moreover most of the settlement took place in the mid-depth (0.5-1.5 m) region. However, based on average of 50 spat per shell, a total of 1 million spat could be conveniently collected using collectors made of empty oyster shells during settlement season. Spatial differences in spat settlement was recorded with Fasht Al-Jarim exhibiting heaviest settlement of larvae drifted from offshore oyster beds, in the north and northwest areas of Bahrain. Seasonal changes in pattern of post settlement growth was found to be closely related to changes in water temperature, as indicated by Spearman's correlation coefficient $r = 0.5$ at $p < 0.05$. After settlement in summer (July-August 1989) the spat showed accelerated rate of growth (0.204-0.248 mm/day) until the following

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winter (December-January) when growth has slowed down but at steadily rate mainly as a result of drop in water temperature from 27-33 °C to 17-18 °C, respectively. Eighteen months after settlement a shell length of 57.69 mm was attained, and there was an indication that growth slowed down during the second year.

Seven species of pterid bivalve occur around Bahrain namely *Pinctada radiata, P. margaritifera, P. maculata, P. rutila, P. sugillata, P. nigra, P. anomioides* and *Pinctada* sp. (Khamdan 1988). *Pinctada radiata* is the most common pearl oyster and constituted the main source of state income before the discovery of oil in the ninteen thirties. Most of the prime oyster beds are located approximately 25-30 nautical miles offshore.

Despite the existence of popular Arabic literature on the pearl fishery of the Arabian Gulf, few scientific works have been published. Lorimer (1915) described major pearl oyster banks and estimated the value of pearls exported for the period 1873 to 1905. Bowen (1951) gave a full account of pearl diving techniques and commented on various aspects of the industry. Bahrain is among the few places in the world where wild oysters occur in large numbers in offshore areas.

Recently, interest in the revival of the natural pearl industry has led to several surveys of the major oyster beds (Nayar *et al.* 1993). Experimental trials of pearl culture have been attempted (Nayar *et al.* 1993). Mahasneh *et al.* (1992) assessed organic and inorganic pollutant levels in pearl oyster populations at different sites around Bahrain before and after the Gulf War. In Kuwait, Al-Mattar *et al.* (1984) monitored the landing statistics of the pearl oyster market. In addition, Al-Mattar *et al.* (1993) described aspects of pearl fishery resource and suggested management strategies.

Spat collection is a technology by which the very young oyster are collected by providing suitable spat setting material at appropriate times and at suitable places. In all the countries where some of the bivalve molluscs, such as oyster, pearl oysters or mussels are cultured, spat collection is carried out. This is essential as it affords a much simpler and easier method of capturing the young ones and enabling them to grow into adult bivalves.

The present investigation was undertaken in order to determine extent, duration and intensity of spat settlement in the nearshore areas of Bahrain using methods based on locally available low cost materials. In addition, growth rate of newly settled spat under field conditions was monitored.

Materials and Methods

1. Type of collectors

Different types of spat collectors made from cheap and locally available materials were constructed as outlined below:

a) Empty oyster shell strings

Pearl oyster shells perforated with an electric drill were strung on a 4 metre copper wire (2 mm thick) covered by a plastic casing. A plastic tube 1.5 cm long and 1 cm diameter was used as a spacer in order to keep the shells apart. A brightly coloured plastic tubing was used to retrieve them from the water for repeated use. About 200 oyster shells could be used on a string of 4 m long.

b) Wooden frames

A rectangular frame (2.5 x 1 m) was constructed from wooden sticks. The frame was divided into grid by fixing 7 and 15 sticks across length and breadth of the frame. The frames were coated with bitumen for protection against fouling and boring organisms (tube worms, barnacles and boring sponges) and also to provide a clean surface for pearl oyster settlement. Two frames were tied together to form a single unit. At one end concrete blocks were tied to give enough weight in order to sink in water when it was suspended from above the water surface.

c) Loosely woven nylon ropes

Nylon ropes (2.5 mm diameter) were cut into pieces 4 m long and were untwisted to make them loosely woven ropes and to increase surface area for spat settlement. The ropes were hung from one end and a concrete block was tied at the other end in order to keep them vertical when suspended in the water.

d) Cement coated cages

Oyster cages (40 x 40 x 10 cm) were fabricated using 6 mm iron rods coated with antifouling paint and covered with synthetic mesh netting of 1 cm. The cages were dipped in a thin sand-cement mixture. When dry, the cement formed a rough coating of about 2 mm thickness over all parts of the cage. The cement also provided a base upon which the pearl oyster larvae could settle.

e) Steel wire rope

Old steel wire (2.5 cm diameter) was cut into lengths of 4 m and suspended vertically in the sea water.

f) Baskets collectors

Rectangular plastic baskets (40 x 28 x 23 cm), normally used for transporting fruits, were used as spat collectors.

2. Placement and examination of collectors

Based on gonadal examination and plankton analysis at major oyster beds, Nayar *et al.* (1993) observed that spawning had commenced by the end of June 1989. Consequently, spat collectors made of wooden frames, empty oyster shells, steel wire and ropes, were laid on 9 July 1989 at different locations (Fasht Al-Jarim, Khowr Fasht, Sitra Beacon, Buoy No. 3 (navigational structure and Ras Hayan). At Fasht Al-Jarim, (Fig. 1) and Khowr Fasht collectors were tied from sides of a coast guard barge. At Buoy No. 3, the collectors were tied to an underwater structure of the Buoy itself. At Ras Hayan, collectors were strung from a raft floated by empty drums. Collectors were examined on different occasions, *i.e.* 7, 16 and 38 days, respectively, and then every two weeks for 18 months. On each occasion collectors examined spat were removed and their shell dimensions were recorded using a vernier caliper. A calibrated eye piece micrometer fitted to a stereomicroscope was used to measure spat less than 1 mm long.

3. Sea water temperature

Surface water temperature records of the study site was obtained from the Meteorological Office which measures the temperature on a daily basis.

Results

Spat setting

Pearl oyster spat were found to be present on most of the collectors. Examination of collectors laid at Fasht Al-Jarim showed that spat settlement took place, but its more on empty shells than on nylon rope and wooden frames. The first record of settlement was observed at the end of July 1989, and new settlement took place throughout August and thereafter intermittently until November 1989. Table 1 shows shell increment of different days after settlement. New oyster spat were found each time the collectors were examined indicating that settlement was continuous. On several occasions oysters as small as 0.2 to 0.3 mm were found on collectors. Moreover, spat of 4 different unidentified bivalve spp. were found on the collectors, indicating that their spawning coincided with spawning of the pearl oyster. Oyster spat were easily identified and separated because of the characteristic shape and growth processes.

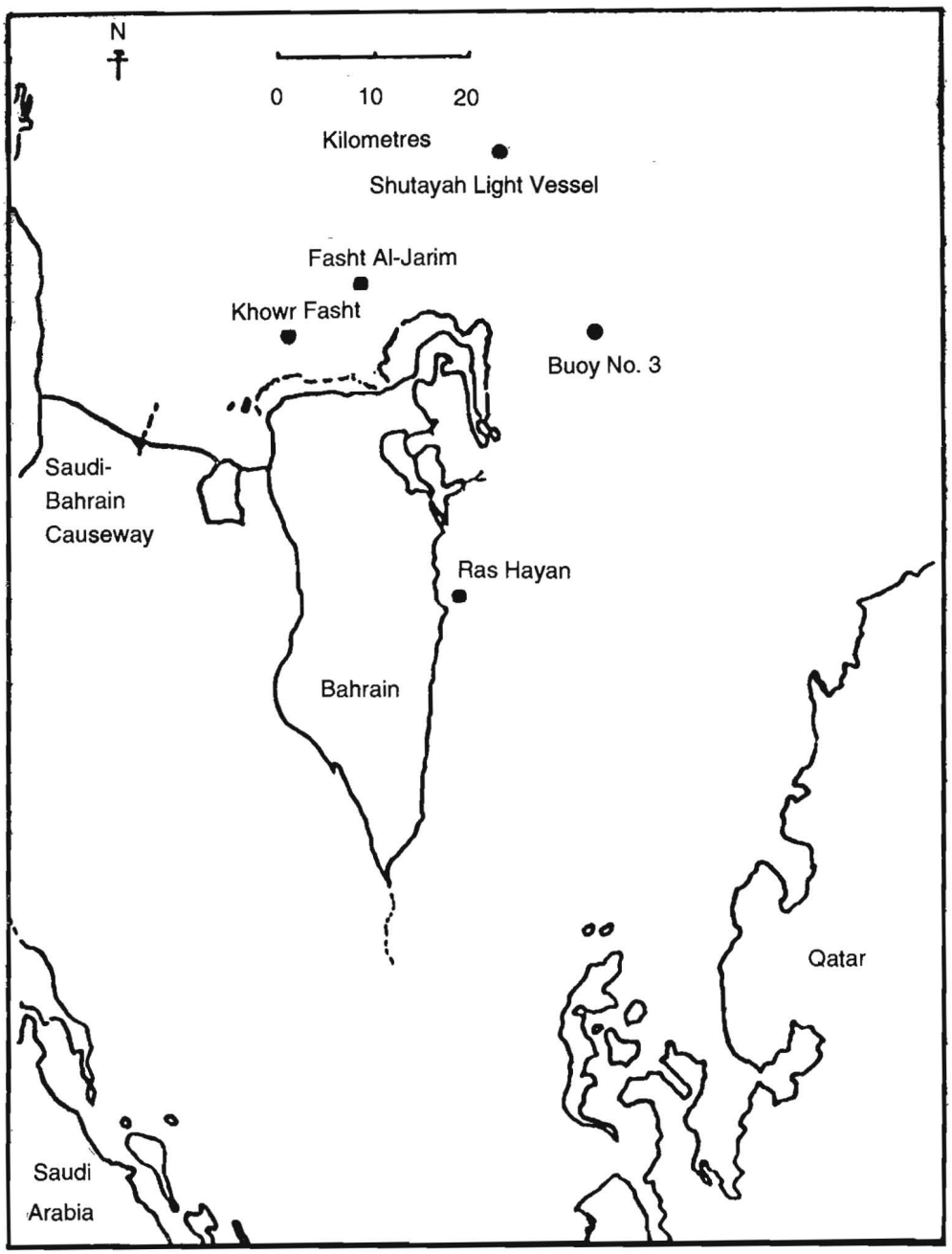

Fig. 1. Map showing the different sites selected for laying spat collectors.

Table 1. Sizes of pearl oyster spat (Mean ± S.E.) within 2 months of setting up shell collectors at Fasht Al-Jarim

Days after settlement	Number of individuals	Mean length (mm)	Standard error (± S.E.)	Minimum length (mm)	Maximum length (mm)
7	47	1.44	0.09	0.204	2.96
16	175	3.20	0.25	1.04	9.94
38	36	9.43	0.26	3.1	1.89
55	150	11.14	0.20	6.3	19.9

The settlement was not heavy at Khowr Fasht, but at Fasht Al-Jarim the settlement was profuse on empty oyster shell and steel ropes. Some of the shells had a maximum of 80 spat settled on them.

Spat collectors laid at Sitra Beacon and Ras Hayan did not reveal settlement of spat on any of the collectors.

Growth of Spat

As the spat settlement was good on empty oyster shell at Fasht Al-Jarim, the details given below are based on the observation made at that location.

Oyster spat removed from collectors were placed in cages and their growth increment was monitored at regular intervals for one year. Table 2 depicts mean length of oyster spat and water temperature recorded on different sampling dates. The spat had grown rapidly from an initial average length of 11.13 mm to 35.19 mm during the September-November period, whereas slow rate of increment had been observed from the December-February period. Around April-May the growth rate started to accelerate and a high growth rate was achieved in the summer months. Water temperature during the study period showed wide fluctuation mainly between summer and winter seasons. In summer, the average temperature rises as high as 33 °C, whereas it declines to an average of 16 °C in winter. Other environmental factors such as salinity, dissolved oxygen and pH were not expected to vary between seasons (Nayar *et al.* 1993). In order to assess the effect of temperature on the growth of the pearl oyster, the increment in the shell length between two successive sampling periods was calculated and extrapolated to mean growth rate per 30 days. Similarly, the mean water temperature was calculated. The inter-relationship between the mean water temperature and the mean growth rate per 30 days was calculated (Table 2) and found to show a significant positive correlation as indicated by spearman's correlation coefficient ($r = 0.51$ at $P < 0.05$).

Table 2. Data obtained from growth experiment of pearl oyster maintained in cages at Fasht Al-Jarim from September 1989 to March 1991

Sampling dates	No. of individuals	Mean shell size (mm)	Standard error (± S.E.)	Mean growth* per 30 days (mm)	Mean* water temp. (°C)
03/09/89	150	11.13	0.20		
17/09/89	145	14.31	0.23	6.80	32.7
02/10/89	145	20.90	0.39	13.80	30.6
16/10/89	145	26.90	0.46	12.86	27.0
30/10/89	145	31.25	0.50	9.96	27.4
18/11/89	145	35.19	0.49	6.22	26.2
03/12/89	141	37.94	0.63	2.75	24.4
21/12/89	141	40.01	0.59	2.09	20.0
04/01/90	139	41.02	0.61	2.33	18.5
03/02/90	133	43.61	0.62	2.98	17.6
12/03/90	130	45.75	0.65	1.74	17.6
11/04/90	126	48.35	0.62	2.69	20.7
14/05/90	126	51.49	0.51	2.85	25.9
12/08/90	111	57.59	0.52	2.00	32.2
10/10/90	106	61.82	0.54	2.15	32.7
21/11/90	105	64.76	0.53	2.10	28.0
12/12/90	97	67.16	0.51	3.40	22.4
13/01/91	97	67.39	0.51	0.22	16.7
16/02/91	92	69.27	0.49	1.65	16.1
20/03/91	91	70.06	0.49	0.73	

*Highly significant correlation was found between mean growth per 30 days and mean water temperature ($R = 0.51$ at $P < 0.05$).

Discussion

For good settlement, emphasis should be given to: season for laying the spat collectors, location where the spat collectors are to be laid and the appropriate types of spat collectors to be used. The observations carried out in this study clearly highlighted some aspects of spat settlement of the pearl oyster *Pinctada radiata* in offshore oyster beds located in the north and north west of Bahrain drift with the current toward Fasht Al-Jarim, more so than from the nearby Khowr Fasht area. The role played by currents in dispersal of planktonic larvae of pearl oysters is discussed by earlier workers (Malpas 1929, Devanesan and Chidambaram 1956).

Although some spat setting took place on different types of collectors, the empty oyster shell string was the most ideal substrate for artificial collection of spat since there was profuse spatfall on them. However, comparison between collectors should be treated with caution because of differences in surface area.

The settlement was observed from 0.5 m to a depth of about 1.5 m. In the middle region more than 80 oyster spat were counted per shell and at the top and bottom regions it was about 40 spat per shell. Considering that the average number of spat to be about 50 per shell, it could be calculated that a single string of empty oyster shell could collect about 2,500 spat. This suggests that by providing 400 of such shell strings, it may be possible to collect about one million spat during a spat setting season assuming that the mortality rate due to fouling and predation is negligible.

Reed (1966) modified spat collectors used by Crossland (1957) which were made of floating frames with shelves and was ideal for collection of up to 25,000 *Pinctada margaretifera* spat per collector in Dongon Bay in the Red Sea. In India, work has been carried out in the technology of spat collection of edible oysters, pearl oysters and mussels by the Central Marine Fisheries Research Institute for a number of years (Achari 1980, Appukuttan 1987, Mahadevan and Nagappan 1976, Nayar and Mahadevan 1980 and 1983).

The type of substrate is commonly known to play an important role in modifying the pattern of setting and metamorphosis of pelagic larvae of benthic animals (Becascu 1972).

At Vizhinjam it was found that frilled nylon ropes were suitable for pearl oyster spat collection (Achari 1980 and Appukuttan 1987) while at Tuticarin nylon twine meshed cages appeared to be the best suitable material for spat collection (Nayar *et al.* 1978). Loosanof (1958) has suggested the use of plastic materials for spat collectors. In Papua New Guina, plain nylon ropes were found to be very good spat collectors for the spat of the black lip oyster (Lock 1982). Spat collectors made of polythene sheets, protected against predators by plastic net bags, gave encouraging results in French Polynesia in the collection of *P. margratifira* spat (Aquacop 1982).

In nature pearl oyster settlement occurs on a wide range of substrates. For example, settlement on macrophyte mainly *Halodule uninervis* occurred in large numbers, and the life cycle of the pearl oyster is closely related to the survival and death of the seagrass (Basson *et al.* 1977). Settlement was also achieved on algae such as *Hormophysa* sp. and *Sargassum* sp. (Khamdan 1988). Moreover, oyster spat

exhibits greater ability of alternate attachment and detachment on seagrass than older individuals (Basson *et al.* 1977). Al-Shamlan (1987) described pearl diving techniques and traditional pearl fishery according to an interview he had with old pearl divers, who explained that divers suffered hand injuries as a result of pearl oyster settlement on anchor rope. In Bahrain, field observations revealed that settlement took place on steel wire, wooden sticks and rocks. It seems that pearl oysters show some degree of substrate preference given the chance, but it could settle primarily on hard substrate if available, otherwise on any objects it encounters at the time of larval metamorphosis and spat setting.

This study provides the first evidence of post settlement growth pattern of pearl oyster around Bahrain. Profuse settlement of spat on empty oyster shell set up at Fasht Al-Jarim enabled us to follow seasonal changes in the growth pattern of pearl oysters from settlement up to more than one year. Monitoring is still in progress for growth and longitivity of the oyster life under high temperature and salinity conditions which prevail in the marine environment around Bahrain.

Growth was found to be rapid and variable during the first two months after settlement. Within seven days of setting up the collectors, the spat had grown to 1.44 mm in length and reached 3.20 mm after 16 days, recording a post settlement growth rate of 0.204 mm per day. Over 38 days, the spat grew to an average length of 9.43 mm indicating a daily growth rate of 0.248 mm per day, which is higher than the growth in earlier days. It seems that post settlement growth of pearl oysters in Bahrain waters is higher than growth rate in India reported by Algarswami *et al.* (1983) primarily due to higher water temperature and salinity which characterize Bahrain marine environment.

It is tempting to conclude that the high post settlement growth and the minimum size of spat found on collectors, would indicate that larval period and spatting size are shorter and smaller than reported in Indian waters (Algarswami 1983) mainly as a result of higher water temperature and salinity around Bahrain. Algarswami (1983) found that under laboratory conditions larval settlement of pearl oyster was achieved after 24 days at a temperature range of 28.2 °C and 29.8 °C, and larval period became longer (32 days) when temperature decreased to 24.5 to 27.2 °C. However, the possibility that pearl oyster larvae undergo primary and secondary settlement cannot be ruled out as it was found that the oyster spat can easily be detached from the upper part and attached to the lower part of dying macrophytes in order to avoid drifting shoreward (Basson *et al.* 1977, confirmed by Khamdan 1988).

Growth was also variable on seasonal basis. Initially growth was rapid during

the September-November period when the temperature was high (27-33 °C) but oysters grew slowly and steadily throughout winter months December-March when the temperature was decreasing (17-18 °C). However, around April/May growth rate had accelerated and continued throughout the summer months. There is an indication that growth rate was beginning to fall during the second year in general, and second winter in particular. Nayar *et al.* (1993) concluded that the growth rate of pearl oyster was faster during June-October than in other months.

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إستقرار ونمو صغار محار اللؤلؤ (*Pinctada radiata*) في مياه البحرين

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تمت دراسة إستقرار صغار محار اللؤلؤ (*Pinctada radiata*) في مناطق مختلفة حول البحرين . وقد أستخدمت مجمعات متنوعة مثل أصداف محار وحبال نايلون وحبال حديدية وسلال بلاستيكية وإطارات خشبية وأقفاص محار مطلية بالأسمنت ، وذلك لغرض تقيمها لمدى ملاءمتها لتجميع صغار محار اللؤلؤ خلال يوليو ١٩٨٩ وقد تم وضعها في أماكن متفرقة مثل فشت الجارم وخور فشت وعوامة سترة رقم ٣ وراس حيان . وعلى الرغم من أن إستقرار المحار قد أستمر لمدة طويلة (يونيو إلى نوفمبر ١٩٨٩) إلا أن أكثر كثافة إستقرار قد لوحظت خلال شهر أغسطس ١٩٨٩ . كما وجد أن إستقرار صغار المحار قد تم على أسطح متنوعة . سجلت أصداف محار اللؤلؤ أعلى معدل أستقرار (٨٠ محارة لكل صدفة) مما دل على قدرته على تفضيل الأسطح الخشبية . وطبقاً إلى متوسط ٥٠ محارة صغيرة لكل صدفة فقد تبين أنه بالإمكان تجميع مليون محارة صغيرة بإستخدام مجمعات أو مصائد (عدد ٤٠٠ مجمع) مكونه من أصداف محار خلال موسم الإستقرار . دلت الدراسة إلى وجود إختلافات في معدل إستقرار صغار المحار من منطقة إلى أخرى . فقد لوحظ أن منطقة فشت الجارم تعتبر من أنسب المناطق لتجميع صغار المحار وربما

يرجع ذلك لوقوعها في مجرى التيارات البحرية التي تحمل يرقات ناتجة من مغاصات اللؤلؤ الواقعة في شمال وشمال غرب البحرين . بينت الدراسة أن الاختلاف الموسمي لمعدل نمو صغار المحار مرتبط بمعدل الإختلاف في معدل درجات حرارة البحر . سجل أعلى معدل نمو خلال الصيف حيث كانت درجة الحرارة ٢٧-٣٣°م بينما أقل نمو كان خلال الشتاء حيث أنخفضت الحرارة إلى ١٧-١٨°م . بعد ١٨ شهراً من إستقرار يرقات المحار وجد أن متوسط طول المحار يصل إلى ٥٧,٩٦ مم ولكن النمو تباطأ خلال السنة الثانية .