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GROWTH AND SETTING OF CULTURED OYSTER (*CRASSOSTREA GIGAS* THUNBERG) IN PUTAI BAY

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Yao-Sung Lin and Min-Hwang Liang (1982) Growth and setting of cultured oyster (*crassastrea gigas* Thunberg) in Putai Bay. *Bull. Inst. Academia Sinica* **21**(2): 129-143. This research was conducted to study the biological aspects of cultured oyster and the problems encountered in spat collection in Putai Bay. One randomly-chosen oyster string was removed monthly from each set of the raft, rack of vertical type, and rack of horizontal type culture system, respectively, for biological measurements and examination of gonad development. Additionly, distribution of larva and the intensity of setting were also investigated at eight stations in the oyster culture areas.

Maximum growth was observed in oysters from the raft culture system, then followed in order by individuals from the vertical racks and horizontal racks. This was due to difference of immersion hours of oysters under different culture systems. In the raft system, the oyster attained 4.8 cm in mean shell height within 6 months of culture period.

Gonad development conditions varied with individuals, season and culture methods. Oysters accumulated gonad materials cyclically and spawned repeatly once they reached maturity. During March 1980 to mid-April 1981, at least 8 spawning activities occurred among oysters in the horizontal rack system. Spat collection also indicated that oyster setting occurred all the year round.

The density of oyster larva was most abundant at stations near the raft culture area, whereas the setting was heavier at stations near the Yensui Stream. Vertical distribution of the spatfall indicated they were concentrated mainly in 1-3 m below the high-water mark. Mature oyster larvae set more readily on upper than lower part of the concave surface of roofing board collector. Fouling organisms and suspended mud particles greatly affect setting of oysters. The importance of the slow-growing oysters in the horizontal rack systems as seed producer was discussed.

Crassostrea gigas, the Pacific oyster, is the most important cultured bivalve in Taiwan. According to the latest Fisheries Year Book published by Taiwan Fisheries Bureau, the annual production of oyster meat reached a high of 20629 mt in 1980.

Many studies concerning the growth rate of cultured oysters, their predators and spat have been conducted in Taiwan[5,11~14,20,23,25]. However, no study on the distribution and abundance of planktonic oyster larvae has been done. Although the distribution of free-swimming larvae and setting of young *Crassostrea gigas* have been investigated intensively abroad[2,6,9,10,16~18], their results may not be applicable to the situation in subtropical areas such as Taiwan. With rapid expansion of oyster farming areas in Taiwan, it is important to meet the ever-increasing demand. A clearer understanding of the time of oyster spawning, distribution of larvae and spats, and seasonal variation in the intensity of setting in oyster culture area in Taiwan is needed for more efficient spat collection.

In recent years the oyster culture area in Putai Bay has been expanded from the tidal flat into the drainage canal or sea route, and further to the offshore district. The yield of oyster meat tripled in recent years; it increased from 2883 mt in 1977 to 8700 mt in 1980, and that location has become the most important oyster farming area in Taiwan. However, collecting enough spat has been a problem for the oyster growers in Putai Bay in the past few years.

This study was conducted to investigate the growth rate of oysters among different culture systems, gonad development, distribution of planktonic larvae, and setting of seed to provide basic information about the time and intensity of spawning and setting in Putai Bay.

MATERIALS AND METHODS

General background

The oyster culture area in Putai Bay is scattered among the tidal flat, along the sea route or drainage canal, and in the offshore district within the boundary of Waisantinchou sandbar where water is 5-10 m in depth during low tide (Fig. 1). At present, the raft, rack of vertical type, and rack of horizontal type methods are widely employed for oyster culturing in this area. In the vertical rack system, oyster strings hang vertically from bamboo frames, whereas in the horizontal type, oyster strings stretch between two horizontal bamboo poles. The latter is commonly practiced in the tidal flat, the former usually located in estuaries or along the sea route where the water level ranges from 0-4 m during low tide. The raft culture method was adopted by local oyster growers fairly recently. Success in a first trial of the system in deep water area in 1976 stimulated rapid expansion of this culture method in Putai. The number of raft systems increased rapidly from 600 sets in 1977 to 6000

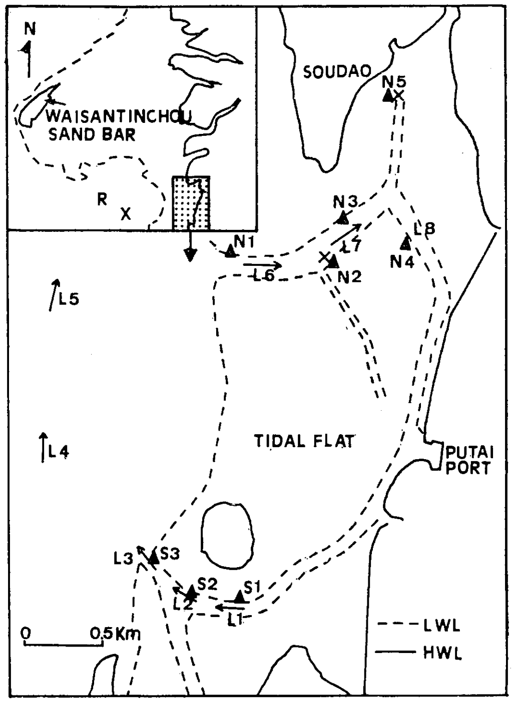

Fig. 1. Locations of spat (▲), larva (-) and adult oyster (×) sampling areas in Putai Bay. LWL and HWL are abbreviations for low water mark and high water mark of spring tide, rspectively.

sets in 1980, and the culture area of the raft system has expanded from nil in 1975 to the current 3000 ha. within the Waisantinchao sand bar. In addition, some long-line culture systems have been used among the raft culture since 1979.

In Putai, oyster growers usually collect the spat during September-December and begin the culture in January. The duration of culture period varies with the methods. Oysters in raft systems is harvested before July to avoid losses during the typhoon season, but some of them may be transferred to horizontal racks to continue culturing before marketing. The majority of the vertical rack cultures is harvested before September so that space could be used for spat collections. Horizontal rack cultures are carried on for a rather long period, generally for 10-18 months.

Growth and gonad condition

Oysters were collected from three sampling stations (R, N2 and N5 in Fig. 1) to monitor the growth rate and gonad development of oysters among the raft, rack of vertical type, and rack of horizontal type culture systems. Station R was located in the raft culture district 5 km west of Putai Harbor; station N2 was located along the sea route in the northern part of Putai Bay where vertical rack cultures are practiced; and N5 was within the horizontal rack culture area to the east of Soudao. In 1979, spat were distributed to the respective culture systems in late December, and samples were obtained from each culture system every month from December 31, 1979 to shortly before the end of the culture period for each system.

On each sampling date, one randomly-chosen oyster string was obtained from each station for examination. The oysters from each string were divided into subgroups every 3-4 cultches according to their vertical position on the string for comparison of growth rate at varied depths. However, no differentiation into subgroups were made on strings from the horizontal rack systems. Shell height of oysters from each string was measured to the nearest 1.0 mm (shell height is the distance between the umbo and the ventral valve margin). Gonad conditions were arbitrarily classified into four categories following the suggestions of Imai and Sakai[6]: A—body with large amount of gonad tissue, in which most of the digestive diverticulum was not observed; B—less than 50% of the digestive diverticulum can be observed; C—more than 50% of the digestive diverticulum can be observed; D—oyster was in a state of water oyster and almost the entire digestive diverticulum is exposed. The percentage of oysters belonging to each category on each sampling date were calculated. Once the genital product was discharged, the gonad condition of the oyster would probably shift from categories A and B to C and D. Subsequently, the spawning periods could be detected from the change in the percentage of the above mentioned four categories between consecutive sampling dates.

Larva distribution

To investigate the distribution of oyster larva in the water of Putai Bay, plankton samples were obtained at eight stations (L1-L8 in Fig. 1) every 6-10 days during September-November, 1980. Horizontal tows were made at 0-1.0 m (surface water) and 1.5-2.5 m (middle water) using two 55 μm nets with 30 cm openings and a length of 110 cm. Tows were for two minutes at approximately 40 m per minute except for the first two sampling dates when tows were for five minutes. The volume of water filtered was calculated by multiplying the area of the net mouth by the distance of the tow. On each smpling date, the first tow was made at station L1 one hour before the highest tide and subsequent samples were taken at stations L2-L8 following directions shown in Fig. 1. Completation of sampling at station L8 usually was an hour after the highest tide. Stations L1-L3 were near the drainage canal of Yensui Stream, stations L4 and L5 were in the open marine waters near the raft culture area, and stations L6-L8 were located in the north sea route of Putai Bay. Plankton specimens were fixed in 4% formalin. One ml subsamples were drawn from each sample with a Hensen-Stempel pipette. Three 1 ml subsamples were examined under stereo-microscope to enumerate larval stages of oysters. The shell height was measured with an ocular micrometer and the oyster larvae were arbitrarily divided into three developmental stages according to their size: small ($<150\ \mu$m), medium (151-250 μm) and large ($>250\ \mu$m).

Setting study

The spat collection study was conducted from October, 1979-September, 1981. In the first year spat was collected at five stations (N1-N5) in the sea route of north Putai Bay. From September, 1980 on, three additional stations (S1-S3) near the drainage canal of Yensui Stream in southern Putai Bay (Fig. 1) were also included in the study.

Oyster shells 6-7 cm in height were fastened 20 cm apart on nylon strings (0.25 cm in diameter). Total length of the completed collector strings varied with the immersion depth during the high tide at each station. It was 7 m at station N2, about 4-5 m at station N1, N3, S2 and S3, and only 3 m at stations N4, N5 and S1. A 1 kg weight was fastened to the bottom end of a string to keep it perpendicular to the water level. Once or twice a month, a shell string was attached to a bamboo rack at each sampling station to observe setting. On the next trip, these strings were retrieved and replaced by clean shell strings. From September, 1980 on, strings composed of sanded plastic roofing board (150×75 mm) as spat collectors were also used at these stations. The roofing boards were spaced 33 cm apart on the string. Later we combined the above two types into one system so that the shells and the roofing boards were in alternate positions on the same string. The last type of collector strings were from November 30, 1980 until the end of the experiment.

The retrieved collector strings were air-dried, and the number of oysters on each collector counted under the stereo-microscope. The appearance of barnacles and other fouling organisms were also recorded.

RESULTS

Growth

Growth rates of oysters varied with culture methods (Table 1). Until early March, 1980, little difference in the growth rate of oysters among the three culture systems were observed, but after March, variations in growth rate of these oysters became more evident as time proceeded. The greatest growth was observed among oysters from the raft culture system, then followed in order by individuals from rack of the vertical type and from rack of the horizontal type. In late June 1980, oysters from the first culture system had grown to 4.8 cm in shell height, whereas the same measurement for those from the latter two culture systems was only 4.3 cm and 3.8 cm, respectively. Another one or two months would be required for oysters in the rack systems to

TABLE 1
Comparison of mean shell height (in cm) of oysters under different culture methods in Putai Bay

Date	Raft		Rack (Vertical)		Rack (Honzontal)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1979. Dec. 31	2.1	0.8	2.0	0.8	2.0	0.8
1980. Jan. 13	2.6	0.8	2.6	0.6	2.5	0.6
Feb. 24			2.1	0.8	2.5	0.9
Mar. 10	2.8	0.8	2.6	0.8	2.5	0.6
Apr. 7	3.2	1.1	2.6	1.0	2.9	0.8
May 12	4.2	1.3	3.7	1.4	3.3	1.1
Jun. 21	4.8	1.4	4.3	1.3	3.8	1.0
Jul. 23			4.9	1.5	4.2	1.2
Aug. 14			5.2	1.4	5.0	1.2
Sep. 19					5.4	1.3
Oct. 13					5.6	0.9
Nov. 30					5.8	1.6
Dec. 20					5.8	1.6
1981. Jan. 18					5.4	2.2
Feb. 20					5.3	2.3
Mar. 30					5.9	2.5
Apr. 19					5.4	1.1

attain 5 cm in shell height. After September 1980, only the horizontal rack culture were carried on but those oysters appeared to have stopped growing after mid-September and their size remained fairly constant.

Growth rate of oyster was affected by the daily immersion hours, but not by depth below the water. In the vertical rack culture system, the daily immersion hours for the upper, middle and lower strata were 15–17 h, 18–20 h and 21–23 h, respectively. Comparisons of growth rate of oysters in different strata (Table 2) indicated that, in general, longer submersion time resulted in better growth. On the other hand, comparisons of the growth rate of oysters at depths of 0–0.8 m, 0.9–1.5 m, 1.6–2.4 m, and 2.5–3.2 m under the raft culture system showed no significant difference among different depths (Table 3).

TABLE 2
Comparison of growth in mean shell height (in cm) of oysters with different daily immersion hours under the vertical rack culture system in Putai

Date	Immersion hours		
	15-17	18-20	21-23
1979			
Oct. 31	1.9	2.0	2.0
1980			
Feb. 14	1.9	2.5	2.3
Mar. 10	2.4	2.6	2.7
Apr. 7	2.4	2.6	3.4
May 12	3.4	3.6	4.4
Jun. 21	4.2	4.4	5.1
Jul. 23	4.6	4.7	5.4
Aug. 14	5.0	5.5	5.2

TABLE 3
Comparison of growth of oysters in terms of shell height (cm) at four depths under the raft culture systems in Putai

Date	Depth (m)			
	0-0.8	0.9-1.5	1.6-2.4	2.5-3.2
1979				
Dec. 31	2.5	2.0	2.1	2.0
1980				
Mar. 10	3.0	2.9	2.8	2.5
Apr. 7	2.9	3.2	3.3	3.5
May 12	4.3	4.5	4.3	3.8
Jan. 21	5.1	4.4	5.0	4.5

Gonad development and spawning activity

Chronological records on gonad development of oysters in the raft and vertical and horizontal racks from March to August, 1980 are shown in Fig. 2. Apparently gonad development varied greatly with individuals, seasons, and culture methods. Oysters in all stages of gonad development could be

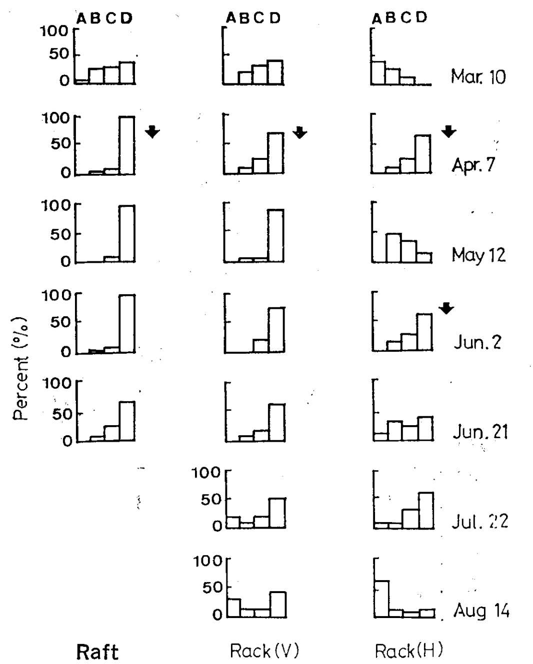

Fig. 2. Gonad condition of oystere in the raft, rack of vertical type (V) and rack of horizonal type (H) culture systems in Putai Bay from March to August, 1980. A, B, C and D represented that 76–100%, 51–75%, 26–50% and 0–25%, respectively, of the gonad capacity filled with ova or sperms. Arrows indicate occurrence of spawning occurred.

found on most of the sampling dates. On March 10, 1980, although the mean shell height was only 2.7 cm, some oysters already had fully-developed gonads. The percentage of oysters with fully mature gonads (stage A) in the horizontal rack system was much higher than those from the other two culture systems. In the subsequent sampling date (April 7, 1980), the majority of the oysters was in stages C and D, suggesting that spawning activity had occurred between these two dates. A second minor spawning activity between May 12 and June 2, 1980 among oysters in the horizontal rack system was detected. No further spawning activity was observed among oysters in the raft and the vertical rack system until the cultures ended in late June and August, respectively.

After August most of the oysters cultured in Putai Bay were in the horizontal rack systems

TABLE 4

Gonad condition of oyster cultured in the rack of horizontal type during the period from August 19, 1980 to April 19, 1981. A, B, C and D represent that 76-100%, 51-75%, 26-50% and 0-25% of the gonad is filled with ova or sperm material

Date	Ratio (%)			
	A	B	C	D
1980				
Aug. 19	86	3	7	4
Sep. 3*	36	46	18	0
Sep. 10	67	16	17	0
Sep. 19*	36	40	20	10
Oct. 5	70	15	15	0
Oct. 19*	20	30	40	10
Oct. 25	20	42	38	0
Nov. 9*	16	31	33	20
Nov. 30	58	37	5	0
Dec. 20*	2	31	54	13
1981				
Jan. 18	64	28	8	0
Feb. 20*	0	21	30	49
Mar. 20	25	20	15	40
Apr. 19	43	35	19	3

* Spawning occurred.

on the tidal flat. Gonad development and spawning activity were monitored continually until April, 1981 (Table 4). From the change in the percentage of oysters in different gonad development stages between two consecutive dates, we could assume that at least 6 spawning activities had occurred between mid-August, 1980 to mid-February, 1981. This means that these oysters were engaged in cyclic accumulation of gonad materials and spawned repeatedly within the 6 months, therefore, a majority of energy derived from food would be spent on reproduction rather than on body growth. This probably was the main reason why oysters ceased growing after they reached maturity.

Larva distribution

The density of oyster larvae varied greatly with the sampling stations as well as with dates from September to November, 1980 (Table 5). Overall mean densities of the small, medium, and large larvae from all sampling dates and stations were 1546, 23 and 6 individuals per 1000 ℓ, respectively. The drastic decline in the number of individuals from small to medium and large larvae indicated that the larvae suffered a high mortality during their free-swimming stages.

Although the number of larvae obtained at each station varied, the pattern of seasonal abundance was similar for most of the sampling stations. Small larvae were increasing from a mean of 177 per 1000 ℓ on September 3 to a peak of 2130 per 1000 ℓ on September 19. During this period very few medium and large larvae were found in the plankton samples. The peaks of medium and large larvae appeared 1-2 weeks later. After September 19 the abundance of small larvae declined to low levels, but began increasing on October 19 and reached a maximum number of 10009 per 1000 ℓ on October 25. However, very few medium and large larvae were found in later samples, which may suggest that small larvae produced in late October suffered a higher mortality than those occurring in mid-September. Large larvae were more abundant in October than in September and November, suggesting that October was probably the best time for spat collection in 1980.

TABLE 5

Number of oyster larvae (*C. gigas*) per 1000 ℓ of sea water in plankton haul at eight stations in Putai Bay during the period from September to November 1980

Larvae size	September				October					November				Mean*
	3	10	19	29	5	13	19	25	31	9	16	23	30	
Station L1														
Small	13	8	24	137	461	78	187	—	137	833	176	392	1391	375
Medium	0	0	0	0	10	0	0	—	0	0	0	0	0	1
Large	0	0	0	0	10	10	0	—	0	0	0	0	0	1
Station L2														
Small	0	—	566	432	686	167	1804	—	1130	686	98	69	804	628
Medium	0	—	0	78	68	0	10	—	10	10	0	10	0	19
Large	0	—	0	0	10	0	0	—	0	10	0	0	0	2
Station L3														
Small	39	8	110	686	421	205	3665	—	1506	569	186	323	686	819
Medium	0	0	0	274	59	59	10	—	0	20	0	0	10	37
Large	0	0	0	0	29	0	0	—	0	0	0	10	0	4
Station L4														
Small	293	—	4555	813	392	—	6417	—	1068	421	206	363	1529	1606
Medium	0	—	0	353	80	—	0	—	0	10	0	79	0	52
Large	0	—	0	0	59	—	0	—	0	10	0	0	10	7
Station L5														
Small	41	47	4327	460	1038	677	275	7666	629	392	549	225	294	823
Medium	0	4	0	147	58	58	10	20	0	49	0	10	39	31
Large	0	4	0	0	58	29	10	39	0	10	0	0	10	9
Station L6														
Small	20	290	581	274	931	1315	924	6962	1503	755	59	578	333	596
Medium	0	0	0	20	186	30	20	30	30	20	0	0	0	25
Large	0	4	0	0	10	29	0	75	0	0	0	10	0	2
Station L7														
Small	751	1591	4525	254	1519	373	3823	18244	3017	1911	137	255	725	1692
Medium	0	0	0	147	98	69	0	0	0	40	0	0	0	29
Large	0	0	0	0	10	0	0	10	0	0	0	0	0	1
Station L8														
Small	259	870	2351	0	764	294	118	7264	835	1940	216	411	353	724
Medium	0	0	0	0	20	30	0	0	0	20	0	10	0	5
Large	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean														
Small	177	562	2130	382	777	444	2152	10009	1228	937	214	327	764	1546
Medium	0	1	0	127	72	35	6	13	1	21	0	14	6	23
Large	0	1	0	0	23	10	1	31	0	4	0	3	3	6

— data missing.

* Mean: excluding data of sampling dates 13, October 13 and 25.

In general the density of small larvae increased from station L1 to L4 or L5 in September and October. However, this pattern was not observed among plankton samples collected in November. Among the eight sampling stations, the density of small larvae was also quite high at station L7, which was probably related to the existence of turbulent current in

TABLE 6

Mean number of spat per shell per day ($\times 10^{-3}$) obtained at sampling stations during the period from October 1979 to April 1981

Date		Station								
		N1	N2	N3	N4	N5	S1	S2	S3	Mean
1979										
Oct. 13-Oct. 31		38	—	14	—	255				102
Oct. 31-Nov. 12		400	375	104	—	413				323
Nov. 12-Nov. 26		82	182	92	—	47				212
Nov. 26-Dec. 31		170	219	79	24	30				104
Dec. 31-Jan. 13		0	0	0	0	0				0
1980										
Jan. 13-Feb. 2		98	130	44	—	63				84
Feb. 2-Feb. 14		63	67	13	33	112				57
Feb. 14-Mar. 10		4	33	4	6	17				11
Mar. 10-Mar. 24		39	2	7	5	0				13
Mar. 24-Apr. 22		—	65	25	—	0				3
Apr. 22-May 12		0	0	10	—	43				12
May 12-Jun. 2		—	34	17	19	0				19
Jun. 2-Jun. 21		0	0	0	0	0				0
Jun. 21-Jul. 22		—	11	0	0	0				3
Jul. 22-Aug. 14		0	0	0	0	0				0
Aug. 14-Sep. 10		—	537	629	—	—				583
Sep. 10-Oct. 13		88	128	259	208	126			256	222
Oct. 13-Oct. 31		159	328	127	—	41	193	794	495	305
Oct. 31-Nov. 30		182	318	128	82	33	110	366	246	183
Nov. 30-Dec. 21		36	35	28	7	32	9	31	64	30
Dec. 21-Jan. 18		200	400	60	183	—	35	740	375	284
1981										
Jan. 18-Feb. 20		448	520	133	—	223	165	958	—	407
Feb. 20-Mar. 22		433	—	391	153	166	355	1050	1196	532
Mar. 22-Apr. 19		85	195	52	27	18	20	191	179	96
Apr. 19-May 21		175	—	115	45	22	83	465	652	222
May 21-Jun. 19		282	—	—	345	143	148	1278	—	439
Jun. 19-Jul. 26		334	—	480	335	152	25	1115	495	424
Jul. 26-Aug. 12		25	—	239	39	46	13	74	—	73
Aug. 12-Sep. 10		—	—	257	261	521	236	425	408	351
Mean	a	81	110	65	10	58				
	b	204	275	189	123	130	114	624	411	274

a : From October 1979 to September 10 1980.
b : From September 10, 1980 to September 10, 1981.
—: Data missing due to loss of collector.

that area. Large larvae were more abundant at stations L4 and L5 near the raft culture area in open marine waters. This area would be a potential spat collecting ground for the oyster culture industry.

Setting

Although the duration of oyster setting in Putai Bay occurred almost year-round, intensity of setting varied greatly with seasons and locations. Because our experimental spat collection was started in mid-October, 1979, it was not known when the setting season began in that year. The intensity of setting was relatively high from October to December, 1979, but it remained at low or negligible level from January through mid-August, 1980. From June to mid-August, except for a very light setting at station N2, no spat was collected at the other stations (Table 6). Setting intensity increased sharply between mid-August and early Septembr, 1980 and remained elevated, except for a few dips, until the end of the study period in early September, 1981. Oyster growers in Taiwan call the spat collected in January to March "spring spat" in contrast to "autumn spats" which are collected in September to December. Traditionally, only autumn spat are collected for culture. After the 1981 spring spat, unusually heavy setting of the spat was observed during the period from April to early August, which was in great contrast to the neglegible setting intensity during the same period in 1980. However, it did not interfere with the onset of the 1981 autumn spat season. The setting was still rather intensive in that year (Table 6). A similar seasonal pattern was observed on the plastic roofing board (Table 7). Correlation between the mean number of oysters setting on shell collectors and roofing boards between September, 1980 to September, 1981 was 0.93 (highly significant at 1% level).

The intensity of setting varied with the locations. Regardless of whether oyster shells or plastic roofing boards were used as collectors, the setting numbers at stations S2 and S3 were

TABLE 7

Mean number of spat per plastic roofing board (150×75 mm) per day (10^{-2}) at 8 sampling stations during the period September 3, 1980 to April 9. 1981

Date	Station								
	N1	N2	N3	N4	N5	S1	S2	S3	Mean
1980									
Sept. 3-Sept. 13	—	17	4	10	22	—	9	—	12
Sept. 13-Oct. 13	—	39	18	16	10	—	—	37	24
Oct. 13-Oct. 31	15	62	15	47	—	29	80	80	47
Oct. 31-Nov. 30	10	53	2	14	9	21	88	12	26
Nov. 30-Dec. 21	1	19	2	—	3	1	6	9	6
Dec. 21-Jan. 18	18	103	5	35	—	7	124	63	51
1981									
Jan. 18-Feb. 20	87	129	39	—	114	44	270	—	114
Feb. 20-Mar. 22	112	—	35	41	16	129	334	442	159
Mar. 22-Apr. 19	22	48	5	4	6	11	22	22	18
Apr. 19-May 21	20	—	10	7	8	27	34	15	32
May 21-Jun. 19	64	—	—	61	58	47	196	—	85
Jun. 19-Jul. 26	59	—	121	89	90	86	158	135	105
Jul. 26-Aug. 12	3	—	60	7	14	6	23	—	19
Aug. 12-Sept. 10	—	—	59	109	203	89	23	—	97
Mean	37	59	29	37	46	41	105	106	52

always considerably higher than those at other stations. The mean numbers of spatfall per shell per day for the period September 10, 1980 to September 10, 1981 were 0.62 and 0.41 at stations S2 and S3, respectively, but the range was only 0.11–0.28 for the other six stations (Table 6). The mean number of spatfall per roofing board per day was 1.05 and 1.06 at stations S2 and S3, respectively, which was also significantly higher than the range of 0.29–0.59 observed at other stations (Table 7). These results indicated that spatfalls were rather uneven among different locations.

Unevenness in distribution of oyster spat on surface of the collector was observed. If we divide the concave surface of the roofing board into upper and lower parts according to the vertical position on the board, the intensity of spatfall on the upper part was always significantly higher than that on the lower part. About 86% of the setting was found on the upper part, whereas only 14% occurred on the lower part of the concave surface (Table 8).

Collector strings hanging vertically from the rack presented an opportunity for studying the intensity of setting in relation to depth. Each collector string was divided into five 1 m sections, and the number of spat in each section during the period October 31, 1979 till September 10, 1981 are listed in Table 9. The heaviest setting occurred most frequently at 1–2 m depth under the high-water mark, followed by the frequencies

TABLE 8
Mean number of oyster settlement on the upper and lower part of the concave surface of the roofing boards at station N2 during the period from December 21, 1980 to January 18, 1981

Number	Depth	Number of spat		Total
		Lower	Upper	
1	0	0	0	0
2	0.3	0	0	0
3	0.7	0	0	0
4	1.0	0	7	7
5	1.3	5	36	41
6	1.7	5	37	42
7	2.0	0	23	23
8	2.3	3	22	25
9	2.8	2	25	27
10	3.0	1	9	10
11	3.3	4	30	34
12	3.7	6	40	46
13	4.0	5	40	45
14	4.3	12	25	37
15	4.7	13	50	63
16	5.0	6	38	44
17	5.3	6	26	32
18	5.7	5	28	33
19	6.0	2	15	17
20	6.3	4	18	22
21	6.7	3	18	21
22	7.0	4	11	15
Total		86	508	594
Percentage		14.4	85.6	

TABLE 9
The average percentage of oyster setting at different depth from high water-mark to 5 m underwater at 1-m intervals

Date	Depth (m)				
	0-1	1-2	2-3	3-4	4-5
1979					
Oct. 31-Nov. 12	7	31	51	10	1
Nov. 12-Nov. 26	6	44	35	10	5
Nov. 26-Dec. 31	3	15	41	30	11
1980					
Jan. 13-Feb. 2	4	23	31	21	20
Feb. 2-Feb. 14	1	10	25	14	50
Feb. 14-Mar. 10	25	26	36	13	0
Mar. 10-Mar. 24	3	26	38	33	0
Mar. 24-Apr. 22	10	37	10	28	15
Apr. 22-May 12	5	21	32	32	10
May 12-Jun. 2	7	22	17	22	32
Aug. 14-Sep. 10	20	25	17	18	20
Sep. 10-Oct. 13	25	37	30	7	1
Oct. 13-Oct. 31	39	30	19	11	1
Oct. 31-Nov. 30	38	24	18	11	9
Nov. 30-Dec. 21	42	36	14	8	0
Dec. 21-Jan. 18	14	37	25	19	5
1981					
Jan. 18-Feb. 20	35	30	12	13	10
Feb. 20-Mar. 22	17	41	18	18	6
Mar. 22-Apr. 19	32	42	12	10	4
Apr. 19-May 21	27	39	18	11	5
May 21-Jun. 19	16	32	30	8	14
Jun. 19-Jul. 26	7	24	29	23	16
Jul. 26-Aug. 12	21	29	23	20	7
Aug. 12-Sep. 10	6	37	27	22	8

at depths 2-3 m, 0-1 m, 4-5 m, and 3-4 m, but no definite seasonal pattern in the vertical distribution of oyster setting was observed. Contrarily on one occasion, i. e. during August 14-September 10, 1980, oyster setting was more or less evenly distributed among different depths. Prior to that period, more than 85% of the spatfall occurred between depth 1-4 m under the high-water mark on most occasions. Sometimes the zone of intense setting would extend to the bottom section, but only occasionally (during February 14-March 10, 1980) was the setting more concentrated in the surface water (0-3 m). However, after September 10, 1980 a drastic change in the pattern of vertical distribution of oyster setting was observed. Heavy setting often occurred on the uppermost stratum (0-1 m). Consequently, the zone of intense setting was shifted to upper sections (0-3 m) of the collector string. On some occasions around 20% of setting were in the 3-4 m range, but the average percentage of setting at the bottom section was generally low and never exceeded 16%.

In addition to oyster spat, some fouling organisms including barnacles, bryozoans, ascidians, other bivalves, amphipods, and sea weeds also set on the collectors. Although the seasonal appearance and vertical distribution of these fouling organisms varied with the species, all of the setting periods overlapped with that of the oysters to some extent (Table 10). Except for the cold weather period of January and February, barnacle (*Balanus amphitrite albicostatus*) set was observed all the year round, being most abundant in August. They usually were more abundant from the high-water mark to 3 m in depth. The other major bivalve (*Anomia chinensis*) set occurred from March through October and distributed mainly in deeper water (below 3 m under the high-water level). Two kinds of bryozoans were found in Putai: erected bryozoan (*Bugula neritina*) and encrusted bryozoan. The latter have a large covering area and sometimes the entire surface of a collector was occupied by them. Although the covering area of the erected bryozoa was small when they first set on the collectors, they were able to divide by budding and form colonies within a short period. Ascidians (*Polycarpa* sp. and *Botrylloides* spp.) were found year-round except between June and August and amphipods were evident from September to December. The vertical distribution of ascidians and amphipods was similar, mainly in depths 2.5 m below the high-water mark. Sea weeds, which occurred year-round, were more abundant at stations near the shoreline. The vertical distribution of sea weeds was mainly limited to 1-3 m below the high-water mark.

TABLE 10
The sesonal appearance of the fouling organisms in Putai Bay during the period from August 1980 to August 1981

Organism	Period		Depth (m)
	1980	1981	
Barnacle	Aug.-Dec.	Mar.-Aug.	0.5-4
Erected bryozoan	Aug.-Dec.	Jan. -May	2.5-5
Encrusted bryozoan	Aug.-Dec.	Mar.-May	2.5-5
Conlonial Ascidians	Sep. -Dec.	Jan. -May	2.5-5
Bivalve	Aug.-Oct.	Mar.-Aug.	3.0-5
Amphipods	Sep. -Dec.	Jan. -Mar.	2.5-5
Sea weeds	Sep. -Dec.	Jan. -Aug.	1.0-3

DISCUSSION

Growth rates of oysters were affected by the daily immersion duration and the amount of food available in the environment. Longer submersion time resulted in better growth of the oysters: best growth was observed among oysters from the raft culture system, then followed in order by individuals from the rack of vertical type and rack of horizontal type. Comparison of growth rate of oysters from the upper, middle, and lower strata under vertical rack system also showed that oysters in the lower stratum which had longer daily immersion hours grew faster than those on the upper stratum. It was noted in that up until early March 1980, the growth rate of oysters among the three culture systems was similar, but variation in growth rate became more evident from March onward. Malouf and Breese[15] indicated that the growth rate for *C. gigas* was mainly influenced by abundance of phytoplankton. Our data also showed that the season of rapid growth coincided with the period of phytoplankton blooming in Putai Bay. Tseng[22] reported that the density of phytoplankton was low in the water of Putai Bay between November and the following March, but it increased rapidly during the period April-June.

In this study, oysters among the raft culture system reached a mean shell height of 4.8 cm in six months. This rate of growth was relatively slower than the mean shell height of

6 cm attained in six months by oysters under the long-line and the raft culture systems in Penghu[14]. Oysters in the vertical rack system measured 5.2 cm in mean shell height after being cultured for eight months, this figure was significantly smaller than the 6.5 cm observed by one of us from the same culture system in Putai some twelve years ago[12]. The retardation in growth rate of oysters was probably related to the much higher farming density in recent years than before. According to the Fisheries year Books published by Taiwan Fisheries Bureau, the total culture area was 1711 ha then, but has increased to 4876 ha in 1980.

Although oysters in the horizontal rack system were cultured for 18 months, the mean shell height remained relatively constant once it reached around 5.5 cm in September, 1980. This result was similar to earlier studies in Putai[12] and Penghu[14]. This is the typical growth pattern of oyster in Taiwan, which is probably related to the phenomenom of repeated cyclic accumulation of gonad material and spawning activity after the oyster attained maturity.

C. gigas larva would reach about 150 μm in shell height within 3-4 days after fertilization occurred, and it may reach the final setting size of about 300 μm in shell height in 20 days at 25°C[1,18]. During the period September-November, 1980 when larva distribution in Putai Bay was also monitored, the appearance of peak densities of small larvae in the sea water correlated quite well with the spawning activities of adult oysters as judged by the change in gonad conditions between two consecutive sampling dates. In addition, the time of intensive setting of oyster spat also agreed with the increase in density of large larvae in the water. Theoretically, the setting season of oyster could be predicted from the spawning activity of adult oysters and the abundance of the free-swimming larval stages. However, due to high mortality of small larvae, only the appearance of large amount of setting larvae would be a sure indication of intensive setting. For example, although mass amount of small larvae was observed in the water on October 25, 1980, the mortality of that brood was also very high. Hence very few large-sized larvae were found on later occasions and the setting during that period was also not so intensive. On the other hand, occurrence of large larvae in higher density during October, 1980 suggested that this month would be a good time for spat collection, and our data from spat collection also confirmed this assumption.

The relationship between intensity of setting and angle of surface had been studied on several species of oyster[3,4,16,19], and the common finding was that mature larvae set more readily on the under surface of shells or other submerged objects. Our setting results generally agree with the above finding and that of Soong *et al.*[21] done in northern oyster farming area (Shiangsan) in Taiwan.

Although the intensity of oyster setting on our experimental shell collectors during September-December were similar in both 1979 and 1980, oyster growers experience difficulty in collecting enough spat in 1980, but not in the previous year. One probable reason for this was the great increase in the amount of suspended silt in the water in 1980 due to excavation of the sea route. The large amount of silt particles floating in the water fouled up the surface of collector shells. In contrast, in that year oyster farmers did not have the problem in getting plentiful oyster spats from the oyster ground near the estuary of Peikang River (about 20 km north of Putai) where the sea water was not polluted by mud suspension. Kikuchi and Tanita[7] observed that if the oyster farmers lowered their spat collectors too early before there were plenty of setting larvae in the water, the collectors became progressively less attractive to the larvae because fouling organsms and mud accumulated on them. On the other hand, if oyster farmers delayed lowering spat collectors, they might miss the spatfall. The growers in Putai usually put their collector strings on the bamboo racks in September and leave the strings there until December. If the collectors were lowered when density of setting larvae was low, accumulation of mud or other fouling organisms would certainly affect the setting of oyster larvae in later occasions. On the other hand, our experimental shell strings were hung on racks that were close to the sea route where the speed of tidal current was fast, hence less mud settled on the surface of shell collectors. In addition, the experimental collector strings were renewed once per month, consequently, the shell collectors provided clean space for the setting of spat.

Because most of the oysters in the raft and rack of vertical type systems were harvested before June and September, respectively, the slow-growing oysters on the rack of horizontal type constituted the only source for spat production in Putai Bay. Koganezawa[8] found a close relationship between the quantity of larvae and that of mother oysters. Therefore, it is important to continue the horizontal rack culture even though it is less satisfactory as oyster meat producer than the raft and the vertical rack systems. Any man-made disturbance of the tidal flat environment should be considered carefully because of the possible impact on seed production. Unfortunately, the local government is planning to change 200 ha of the rack culture area in the tidal flat into saltern as well as land for housing project. In the future, the fish harbor will also be expanded and a new, large sea route excavated in the tidal flat. All these actions will cause drastic change of the marine environment, not to mention the great decrease in oyster culture area for the rack system of the horizontal type. To secure enough spat each year for the vast culture area of the raft and the vertical rack culture system with greatly diminished mother oysters on the horizontal rack culture system would be a difficult task in the future. Besides other remedies, a spatfall prediction scheme as practiced in Hiroshima, Japan[24] would be helpful to the oyster growers for more efficient spat collection.

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布袋沿岸養殖牡蠣之成長與着苗研究

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本研究的目的在於瞭解有關布袋地區養殖牡蠣之生物知識及蚵民在採苗上遭遇之困難。在牡蠣養殖期間自浮筏式、棚架垂下式及平掛式之養殖架上，每月逢機選取一串牡蠣，測定牡蠣之大小並檢視生殖巢之發育狀況。此外，在養殖區選取八個採樣站，調查牡蠣幼生之分布與幼苗附着之數量。

浮筏式養殖的牡蠣生長最快，棚架垂下式者次之，平掛式者最慢，此可能與不同養殖方式之牡蠣浸水時間之長短有關。浮筏式養殖之牡蠣在 6 個月後，殼長可達 4.8 cm。牡蠣生殖巢之發育隨個體、季節及養殖方式而異，牡蠣發育成熟後，便會經年不斷地進行排卵。1980 年 3 月至 1981 年 4 月中旬之間，平掛式養殖之牡蠣至少曾排卵 8 次。著苗之資料顯示布袋牡蠣養殖區內全年均可採到幼苗。

牡蠣幼生分布及著苗之研究顯示，牡蠣幼生之密度以近浮筏式養殖區的採樣站較高，著苗量則以鹽水溪口附近之採樣站最多。此外，並發現牡蠣幼苗多在高潮線下 1～3 m 間著苗，且較喜附着在採苗器凹面之上方。其他附着性生物與懸浮之泥沙對牡蠣之著苗有甚大之妨碍。本文亦討論到平掛式養殖牡蠣的重要性。