

GROWOUT OF BLACKLIP PEARL OYSTERS, *PINCTADA MARGARITIFERA* COLLECTED AS WILD SPAT IN THE SOLOMON ISLANDS

KIM J. FRIEDMAN¹ AND PAUL C. SOUTHGATE¹

¹Aquaculture Department,
James Cook University,
Townsville, Queensland 4811, Australia

²ICLARM Coastal Aquaculture Centre,
Honiara, Solomon Islands

ABSTRACT This study assessed growth and survival of juvenile blacklip pearl oysters (*Pinctada margaritifera*) in a number of intermediate culture systems: lantern nets, panel nets, perforated plastic trays, and attached to ropes enclosed by mesh. Juveniles with initial dorsoventral measurements of 8.3 to 51.5-mm increased in size by 20.4 to 24.8-mm in 3 months, and 30.7 to 36.5-mm in 5 months. Growth rates of juvenile *P. margaritifera* cultured in the open reef systems of the Solomon Islands compared favorably with those reported from the established pearl culture operations in French Polynesia and the Cook Islands. Initial experiments showed that survival of oysters in lantern nets in shallow reef areas was poor as a result of predation by fish and invertebrates. Siting of culture systems in deeper water decreased mortality by fish, although predation by invertebrates that recruited from plankton was still a potential problem. In general, there were no significant differences in growth or survival between juveniles held in lantern nets and panel nets; however, lantern nets were more difficult to clean and inspect for predators. Juvenile growth and survival did not differ significantly ($p > .05$) between panel nets and trays after 5 months, although the rigid trays were easier to clean of fouling organisms. Juveniles placed loosely into trays tended to aggregate, and rates of growth and survival of oysters glued separately into trays were significantly greater ($p < .05$) than those for oysters placed loosely into trays. There was no significant difference in growth between oysters glued into trays and those glued onto ropes and enclosed behind plastic mesh. Overall, this study shows that important criteria of the growout units needed for the intermediate culture of *P. margaritifera* in the Western Pacific include ease of cleaning and access for regular inspection and removal of predators.

KEY WORDS: Pearl oyster, spat, *Pinctada margaritifera*, intermediate culture, growth, survival, predation

INTRODUCTION

Protocols developed by the Japanese for collection and culture of the pearl oyster, *Pinctada fucata martensii*, have been adapted in French Polynesia for blacklip pearl oysters, *P. margaritifera* (Coeroli and Mizuno 1985). Since adapting and developing their own spat collection and growout techniques and stimulating market demand for cultured "black" pearls, there has been rapid growth in round pearl production in Polynesia. For example, annual value from the export of loose "black" pearls from French Polynesia presently stands in excess of US\$145m (Fassler 1995, Remoissenet 1996, Doubilet 1997, N. Sims pers comm. 1998).

Oysters used for the production of black pearls are collected as spat from substrates (spat collectors) deployed in the surface waters of "closed" and semiclosed atoll lagoons in Polynesia (Sims 1992, Sims 1993a). In French Polynesia, spat collectors are generally deployed for 6 months (Coeroli et al. 1984, Cabral et al. 1985, Lintilhac 1987); however, this period is extended in some French Polynesian lagoons (Preston 1990) and, in Manihiki atoll in the Cook Islands, collectors are immersed for up to 2 years (J. Lyons pers comm. 1997). *P. margaritifera* are generally harvested from collectors when they are large enough [65–90 mm dorsoventral measurement (DVM) Nicholls 1931], to be hung from dropper ropes or "chaplets" (AQUACOP 1982, Preston 1990, J. Lyons pers comm. 1997). Oysters are drilled through the hinge of their shell and attached to the chaplets with wire or monofilament fishing line. Chaplets are then connected to submerged longlines, and this is the predominant method of holding adult *P. margaritifera* in Polynesia.

The success of the Polynesian pearl culture industry has not

gone unnoticed by other small island nations in the Pacific (Lucas et al. 1998), which historically have relied on a more modest income from the sale of *P. margaritifera* shell for its nacre or mother-of-pearl (MOP) (Richards et al. 1994, Gervis and Sims 1992). However, not all nations with stocks of *P. margaritifera*, have access to "closed" atoll lagoons. For example, in the central-western Pacific, most reefs fringe high islands or occur in shallow, sublittoral areas (Wells 1988) with few "closed" atolls. Between 1994 and 1997, Friedman et al. (1998) conducted trials to adapt spat collection and culture protocols used in Polynesia for collection and growout of *P. margaritifera* in the "open" reefs of the Solomon Islands. Their study found that commercial quantities of *P. margaritifera* spat could be collected from open reefs at certain sites and at certain times (Friedman and Bell 1996, in review, Friedman et al. 1998). The study also showed that collectors harvested after 6 months held large numbers of dead spat and that greater numbers of live spat could be amassed if collectors were harvested after 3 to 4 months (Friedman and Bell in review b).

Because *P. margaritifera* were removed from collectors at a small size (10 to 30-mm DVM), and invertebrate and fish predators are widespread in Solomon Islands (Friedman et al. 1998, Friedman 1998), it is essential to nurse juveniles until they attain a "size refuge" (Coeroli et al. 1984). This process has been termed "intermediate culture" (Ventilla 1982), because it covers the culture stage between spat collection and transfer of oysters to chaplets. Because there is less emphasis on rearing juvenile pearl oysters in the "closed" atolls of Polynesia, there is a paucity of information relating to this stage in the culture process. Therefore, the aim of this study is to compare growth and survival of *P. margaritifera* in a number of intermediate culture systems. The information generated by this study will not only assist in developing appropriate culture protocols for pearl oysters in open reef sys-

tems, but will be valuable for those developing nursery culture systems for hatchery-reared *P. margaritifera* spat (Southgate and Beer 1997).

MATERIALS AND METHODS

There were two phases of this study. In Phase One (1994 and 1995), spat were harvested from collectors deployed at 21 sites spanning over 500 km of the Solomon Islands (Fig. 1). Oysters were grown out at nine of these sites (Fig. 1) on submerged longlines (Fig. 2). In Phase Two (1996 and 1997), spat were collected at 36 sites within the Western Province of the Solomon Islands, and grown out at one site in Gizo lagoon (Fig. 1).

When spat collectors were harvested, live oysters were placed in a number of intermediate culture units; lantern nets, panel nets, trays, and glued onto ropes (Fig. 3). Lantern nets consisted of a maximum of eight platforms surrounded with 6- or 12-mm netting. The platforms were positioned on a frame before being stocked with juveniles and enclosed with mesh. The size of the mesh used to contain the juveniles depended on the size of the oysters in the experiment. Panel nets were constructed from a galvanized wire frame covered with 6- or 12-mm netting. They had five horizontal rows that could be accessed to insert juveniles from holes cut into one side of the netting (Fig. 3). Trays were made from stiff perforated plastic (8.5-mm mesh) and had removable lids that allowed for inspection and removal of predators (Fig. 3). In a fourth culture unit, oysters were glued to 4-mm rope enclosed behind stiff plastic mesh (18-mm mesh size) (see Fig. 3).

Phase One

Growth of Juveniles in Lantern Nets at 3–4-m Depth

P. margaritifera juveniles (936 individuals) were cultured at nine sites throughout the Solomon Islands, in lantern nets suspended at 3 to 4-m depth, on longlines in shallow water reef areas (8 to 25-m depth). Lantern nets were checked every 3 months to remeasure juveniles, remove predators, clean or change the meshes, and record survival.

Growth of Juveniles of Different Sizes in Lantern Nets at 6-m Depth

In April 1995, an experiment was set up to assess the effects of two husbandry regimes on the growth and survival of two sizes of juveniles (10 to 25-mm DVM and 26 to 55-mm DVM). Lantern nets were suspended from a longline set at 6 m in Gizo lagoon, outside the reef flat in front of ICLARM's Nusa Tupe Research Station (NTRS) (Fig. 1). The longline was deployed in deeper water (25–30 m), running parallel to the reef edge (~15 m out from the reef edge). For each husbandry regime, eight (4 × 2 juvenile sizes) replicate lantern nets, each holding eight oysters (four juveniles per platform) were deployed. All oysters were marked individually with glued tags ($n = 128$). In the first husbandry regime, meshes alone were cleaned of predators, epibionts, and fouling. In the second regime, both oysters and meshes were cleaned. This process was carried out fortnightly for 6 months, after which the second cleaning regime was used for both sets of lantern nets. Growth (DVM) and survival of juveniles was recorded after 3, 6, and 12 months.

Phase Two

For this phase of the study, longlines for growout of juveniles were set at a depth of 9–12 m, in 35 to 45-m of water, just to the northeast of NTRS (Fig. 1). Longlines were sited >50 m from fringing reef, over sandy substrate. The area chosen for deployment of longlines was within a section of Gizo lagoon that was approximately 1 km², had a mean depth of ~40 m, and had numerous passages and submerged reefs linking the lagoon to the open ocean. In Phase Two, the timing of husbandry checks was increased to 2–3 times a month; SCUBA divers brushed off algal fouling and manually removed predators from growout units.

Comparison of Growth and Survival of Juvenile Oysters in Lantern Nets and Panel Nets

In Phase One, lantern nets had two deficiencies for the growout of juveniles: (1) larvae of invertebrate predators and particulate matter settled onto the platforms within the nets, and these plat-

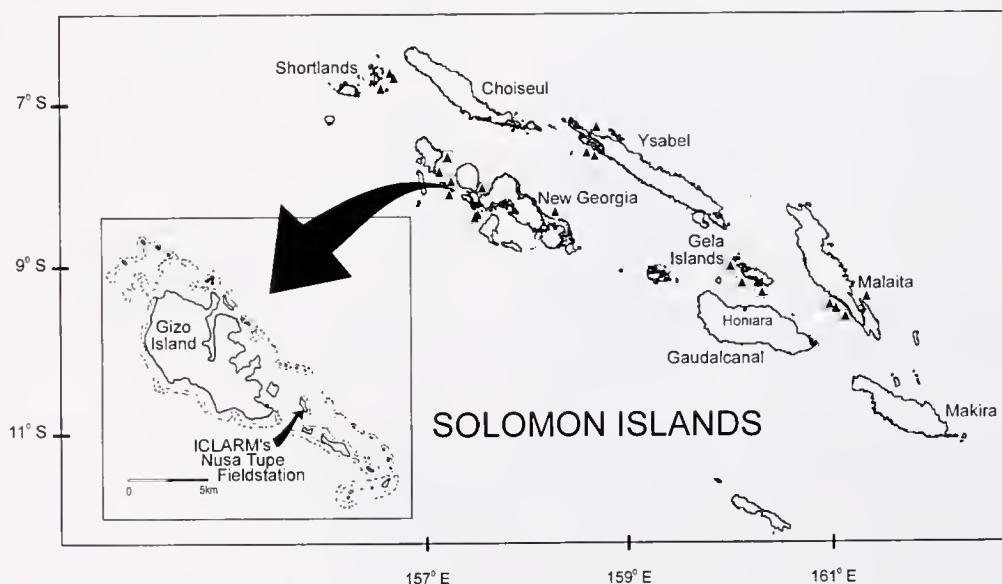


Figure 1. Twenty-one sites (triangles) where spat of *P. margaritifera* were collected and cultured (boxed triangles) in Phase One and, Gizo Lagoon (insert), where spat were held for growout trials in Phase Two of the study.

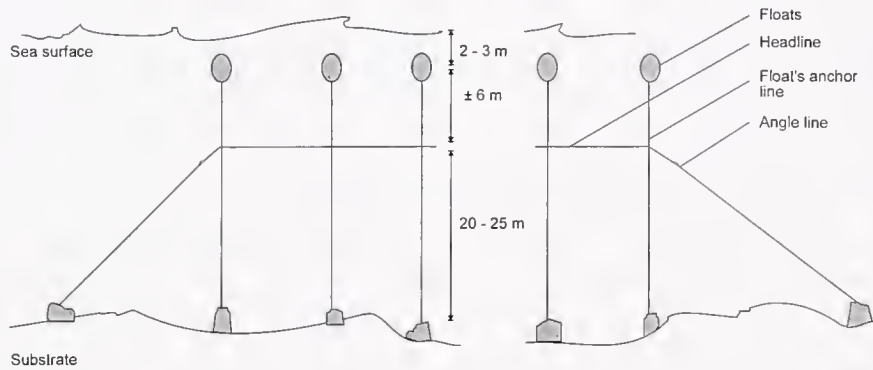


Figure 2. Longline system used to suspend growout units for juvenile *P. margaritifera*.

forms were difficult to access for cleaning; and (2) the flexible mesh on the sides of the nets made removal of algal fouling difficult.

Panel nets (Fig. 3) were trialed in an attempt to overcome some of these problems. Three experiments to compare growth and survival of juvenile *P. margaritifera* held in lantern nets and panel nets were conducted from 29 March to 29 September 1996 (Table 2). For the three experiments, juveniles of different mean sizes were used (DVM of 16- 24-, and 33-mm). To ensure that oysters were not lost through the meshes, juveniles of the smallest size class were enclosed behind 6-mm mesh; whereas, it was possible to use 12-mm mesh for the two experiments involving larger spat. Growth (DVM) and survival were recorded when units were removed from the water after 3 months.

Comparison of Growth and Survival of Juvenile Oysters in Panel Nets and Trays

Because panel nets also proved difficult to keep clean, an experiment was conducted using rigid perforated plastic trays that were easier to brush clean of algae. The first experiment compared growth and survival of juveniles of 24 mm in panel nets and trays and was run between 29 May 1996 and 29 August 1997 (Table 2). Growth (DVM) and survival were recorded when units were removed from the water after three months.

A second experiment was run from 29 January to 29 June 1997 (Table 2). In this experiment, we recorded growth (DVM), wet

weight, and survival of 11 mm juveniles when units were removed from the water after 5 months. Different colored threads were glued to 10 oysters per replicate at the start of the experiment, so that individual growth rates could be calculated.

Use of Cyano-Acrylate Glue in Intermediate Culture

Although management of plastic trays (Fig. 3) was faster and easier than panel nets, juveniles tended to form aggregations or "clumps" (Southgate and Beer 1997) in the trays. Juveniles "trapped" within these clumps had stunted development. Cyanoacrylate glue (Loctite 454 gel®) was assessed as a means of fixing juveniles to the sides and bottom of trays to prevent clumping and to determine whether spacing of oysters affected growth. Glue was also used to fix juveniles onto rope, which was then surrounded by stiff mesh of large size (Fig. 3). The mesh was too coarse to hold "loose" oysters but was stiff enough to be brushed clean of algal fouling.

Between 29 April and 29 September 1997, both growth (DVM and wet weight) and survival of juveniles were compared among four growout units: panel nets; trays with juveniles loosely added; trays with juveniles glued in place; and ropes with juveniles attached (glued) enclosed in large mesh. For each of the 10 replicates (25 juveniles per replicate), different colored threads were glued to 10 oysters at the start of the experiment so that individual growth rates could be calculated when growth units were removed from the water after 5 months.

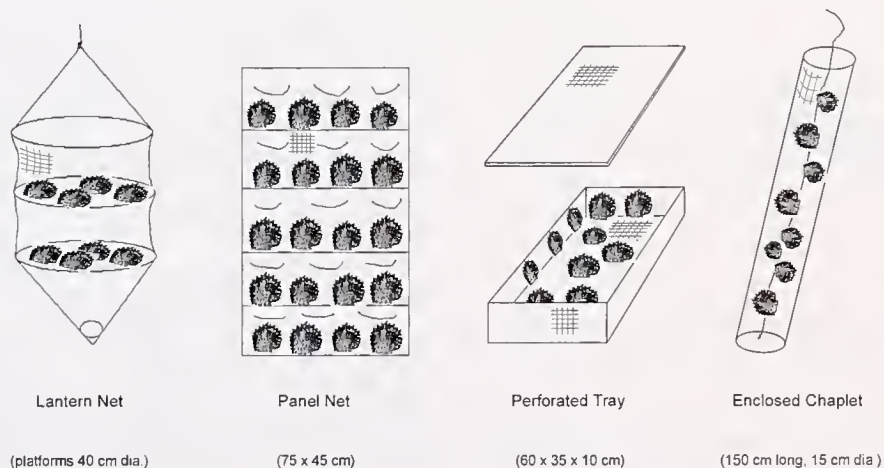


Figure 3. Units used for intermediate culture of *P. margaritifera* juveniles removed from spat collectors.

Growth (DVM and wet weight) and survival of juveniles attached to trays and ropes were also compared in a second experiment deployed between 2 May and 2 October 1997 (Table 2). Again, threads were used to mark juveniles individually.

General Growth Rates of Juveniles in Intermediate Culture

In 1996 and 1997, several different batches of oysters of different initial size, were reared in the intermediate culture systems described above. Growth (DVM) was measured after 3 and/or 5 months, and growth trajectories were plotted.

Analysis of Data

To examine differences in survival of juveniles reared in two types of culture units, *t*-tests were used in comparisons of live oyster number. In comparisons of survival among more than two types of culture units, a one-way analysis of variance (ANOVA) was used to analyze survival data.

To compare growth of juveniles marked individually, growth measurements from individual oysters were compared by *t*-test and, when appropriate, one-way ANOVA. To compare growth of juveniles in lantern nets, panel nets, and trays, the final size of juveniles were compared in each experiment using *t*-tests. In these tests, only subunits (e.g., platforms in lantern nets and rows in panel nets) and whole trays, which had 100% survival, were used.

Before *t*-tests or ANOVA, data were checked for homogeneity of variance using Levene's or Cochran's test, respectively, and transformed to $\log_{10}(x+1)$ to meet this assumption, where necessary. Significant differences between means were identified using Tukey's HSD test.

RESULTS

Phase One

Growth of Juveniles in Lantern Nets at 3 to 4-m Depth

Spat removed from collectors immersed for 6 months had a mean DVM of 20.4 mm \pm 0.4 SE ($n = 936$), and a range of 3–61 mm. Annual growth increments of juveniles of 10–100 mm DVM, grown in lantern nets suspended from shallow water longlines, are shown as a Ford-Walford plot in Fig 4. The "growth performance

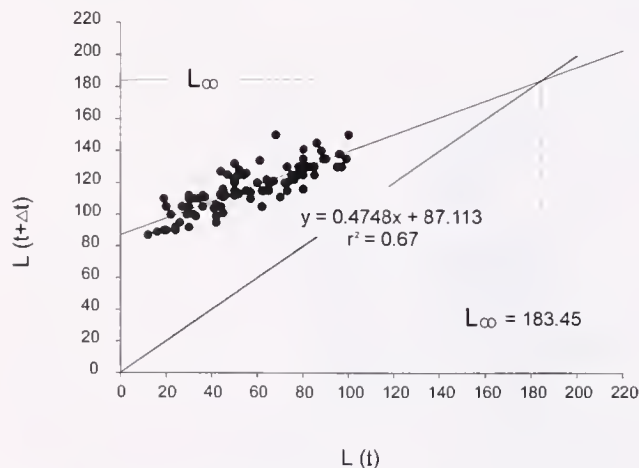


Figure 4. A Ford-Walford plot of annual growth of *P. margaritifera* juveniles ($n = 101$) held in lantern nets at eight sites spanning 500 km of Solomon Islands.

indicator" or ϕ' value, which can be calculated from the K and L_{∞} derived from this plot ($\phi' = \log K + 2 \log L_{\infty}$, Munro and Pauly 1984) was 4.39. Survival of spat grown in lantern nets in shallow reef areas was poor and averaged 36.2% \pm 8.4 SE, ($n = 9$ sites).

Growth and Survival of Juveniles of Different Sizes in Lantern Nets at 6-m Depth

Both sizes of juveniles held in lantern nets at 6 m grew at rates similar to those held at 3 to 4 meters ($y = 0.49x + 89.03$, $r^2 = 0.29$, $\phi' = 4.34$). Because of heavy mortality, it was impractical to analyze the differences in growth between husbandry regimes in this experiment. Only 49 (38.3%) of the 128 juveniles remained alive at the end of 6 months. Fish associated with a nearby reef caused the mortality, accessing the platforms by ripping the mesh of the lantern nets.

There were no significant differences in survival between the two husbandry treatments (Table 1). Mortality was, however, significantly greater than smaller-sized juveniles (Table 1). The decline in abundance of live juveniles over the course of this experiment was greatest in the first three months for the smaller size classes (Fig. 5).

Phase Two

Comparison of Growth and Survival of Juvenile Oysters in Lantern Nets and Panel Nets

Growth of oysters was significantly greater in lantern nets for the smallest size class of juveniles, but no significant difference in growth was detected between the two growout units for the two larger size groups (Table 2, Fig. 6). Survival for juveniles held in lantern nets and panel nets for 3 months was 59.5 and 96.0%, respectively (Fig. 7). Survival of oysters was significantly greater in panel nets for the smallest size class of juveniles, but no significant difference in survival was detected between the two growout units for the two larger size groups (Table 2, Fig. 7). Survival for the two larger size groups of juveniles was good (mean 86.9%), corresponding to a period when settlement of predators (e.g., *Cyrtium* spp) was low.

TABLE 1.

Survival (%) at 3, 6, and 12 months of small (10 to 25-mm DVM) and large (26 to 55-mm DVM) *P. margaritifera* juveniles deployed in lantern nets and subjected to two husbandry regimes.

	Husbandry Regime	
	Clean Mesh and Oysters	Clean Mesh Only
3 Months	36.0 ^a	54.8 ^a
6 Months	34.4 ^a	42.3 ^a
	Size of Oysters	
	Small (10–25 mm)	Large (26–55 mm)
3 Months	36.0 ^a	54.8 ^a
6 Months	25.0 ^a	51.6 ^b
1 Year	15.6 ^a	36.0 ^b

Means with the same superscript do not differ significantly by *t*-test ($p < .05$).

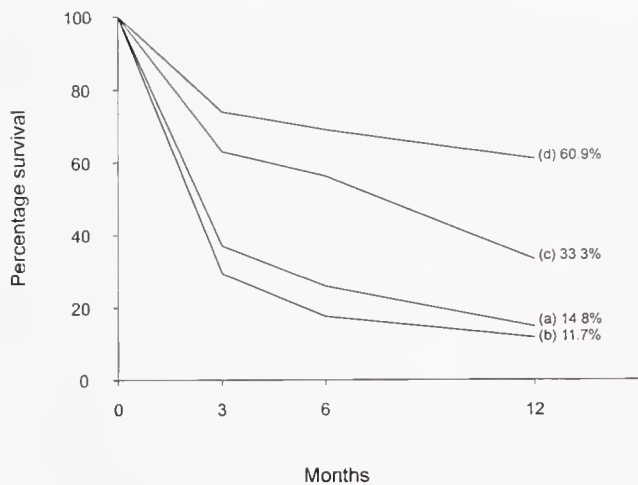


Figure 5. Percentage survival of *P. margaritifera* juveniles held in lantern nets after 3, 6, and 12 months. Oysters were divided into size classes: 10–19 mm (a), 20–29 mm (b), 30–39 mm (c), and 40 mm and above (d).

Comparison of Growth and Survival of Juvenile Oysters in Panel Nets and Trays

In the first experiment, juveniles in panel nets (46.97-mm \pm 1.1 SE DVM) were significantly larger than juveniles held in trays (43.59-mm \pm 0.7 SE DVM) after 3 months (Table 2). Survival in panel nets and trays averaged 94 and 96%, respectively, and did not differ significantly (Table 2).

In the second experiment, there was no significant difference in growth (DVM) of juveniles in panel nets (29.24-mm DVM, \pm 0.56 SE) and trays (31.47-mm \pm 1.3 SE DVM) after 5 months (Table 2). There was also no significant difference (df 16, t -value = -0.196, p = .847) in wet weight of juveniles between panel nets (11.68 g \pm 0.47 SE) and trays (11.93 g \pm 1.33 SE) after 5 months. Despite high mortality of oysters in two replicate trays because of predation by *Cymatium* spp. gastropods, there was no significant difference in survival between panel nets (70.0% \pm 4.0 SE, n = 10) and trays (60.5% \pm 10.7 SE, n = 10) (Table 2).

Use of Cyano-Acrylate Glue in Intermediate Culture

Growth (DVM) of glued oysters was significantly greater than that of oysters placed loosely into trays or in panel nets (Table 3, Fig. 8). There was no significant difference in growth increment between juveniles glued to ropes and juveniles glued to trays after 5 months (Table 3, Fig. 8). Survival was greatest for juveniles attached to rope enclosed behind mesh (88.4% \pm 2.6 SE). Survival of oysters glued to trays (86.4% \pm 2.4 SE) and in panel nets (82.4% \pm 3.0 SE) was also high. Oysters not glued into trays had the lowest survival (74.8% \pm 4.9 SE). Analysis of survival at 5 months was significantly different among the four culture units tested (df 3,36, F = 3.20, p = .035), however *post hoc* analysis (Tukey's HSD) only distinguished significant differences between oysters attached to rope and oysters "loose" in trays.

In the second experiment, average growth (DVM) of juveniles glued into trays (31.29 mm \pm 1.71 SE) and onto rope (31.68 mm \pm 0.64 SE) did not differ significantly (df 17, t value = 0.201, p = .843) after 5 months. Difference in survival of juveniles glued onto trays (71.2% \pm 6.10 SE) and glued onto rope (86.7% \pm 3.26 SE) was significant (df 17, t value = 2.16, p < .05); however,

because the two datasets were heterogeneous by Levene's test (p = .01), this result should be viewed with caution.

Growth Rates of Juveniles in Intermediate Culture

The growth trajectory of 10 batches of oysters that entered intermediate culture at different sizes is shown in Figure 9.

DISCUSSION

In the Solomon Islands, "intermediate" culture is required to nurse juvenile pearl oysters collected from the wild before they can be hung on chaplets. Juvenile *P. margaritifera* grew well in the culture units tested in this study; batches of juveniles with initial DVM of 8.3 to 51.5 mm increased in size by 20.4 to 24.8 mm in 3 months and 30.7 to 36.5 mm in 5 months. These growth rates compare favorably with growth of *P. margaritifera* reported from "closed" and semiclosed atolls in the Pacific. For example, in Takapoto atoll, French Polynesia, juveniles of 40 to 50-mm DVM grew 30 mm in 6 months (Coeroli et al. 1984, Lintilhac 1987); whereas, in the Cook Islands, Braley (1997) reported that hatchery produced *P. margaritifera* juveniles with a mean DVM of 10 mm grew approximately 16.4 mm DVM in 3 months. On the other hand, Sims (1993b) presented size-at-age data for 9-month-old *P. margaritifera* from Manihiki atoll as approximately 81 mm DVM, which indicate fast growth of juveniles in a "closed" atoll environment. However, the age of spat used in Sims's study may initially have been underestimated, because "median date" or "heaviest fall" was used to estimate the age of spat removed from collectors prior to the beginning of the growth study.

In the open reef systems of Dongonab Bay in Sudan, *P. margaritifera* juveniles collected as spat between 18 to 37-mm DVM grew by 13 to 24 mm and by 24 to 32 mm in 3 and 5 months of culture, respectively (Nasr 1984). However, in Sudan, there is little or no growth during winter (Nasr 1984). In Australia, hatchery-produced juveniles of *P. margaritifera* with a mean DVM of 13.9 mm, grew by 21.8 to 26.6 mm when held loosely in perforated plastic trays for 19 weeks (4.3 months) (Southgate and Beer 1997).

Our study demonstrates that growth is also dependant on the method used to hold juvenile oysters; that is, juveniles held under different intermediate culture conditions grew at different rates. A major difference between the systems used in this study was the ability to separate oysters. For example, oysters held in panel nets or glued into trays and on ropes were prevented from clumping; whereas, juveniles that were able to move around freely tended to form aggregations, such as those reported by Crossland (1957), Southgate and Beer (1997), and Sims and Sarver (1998). Oysters in the units where clumping occurred exhibited highly variable growth rates as a result of increased competition for food and space. In another study on *P. maxima*, Taylor et al. (1997b) reported that this behavior promoted an increase in the prevalence of growth deformities in juveniles.

Separation of juveniles in intermediate culture had the added advantage that units were easier to check for predators, because *Cymatium* spp. and crabs could not hide within clumps of oysters. The results of the trials where juveniles were stuck directly onto ropes highlighted the potential for holding juveniles behind meshes that were too large to contain oysters, but small enough to afford the growing juveniles some protection from fish. Although the use of cyano-acrylate glue gave some of the best growth rates in this study, adhesives are not a panacea for the problems en-

TABLE 2.

Results of experiments to assess growth and survival of *P. margaritifera* juveniles in various culture units in Phase 2 of the study (between March 1996 and October 1997).

Experiment	Replicates	Oysters per Replicate	Mean Starting Size (DVM)	Survival			Growth (DVM)		
				df	t-value	p	df	t-value	p
a) Lantern vs. panel nets									
29/3/96 to 29/6/96	12	20	16 mm	22	-3.77	0.001	250	3.81	<0.000
29/5/96 to 29/8/96	12	25	24 mm	22	-1.91	0.069	510	0.16	0.870
29/6/96 to 29/9/96	8	20	33 mm	14	-1.45	0.168	184	-0.66	0.507
b) Panel nets vs. trays									
29/5/96 to 29/8/96	12	25	24 mm	22	0.52	0.607	460	-2.79	0.006
29/1/97 to 29/6/97	10	20	11 mm	18	0.82	0.418	16	-1.66	0.116
c) Trays (glued) vs. ropes (glued)									
2/5/97 to 2/10/97	10	25	34 mm	17 ^a	2.16	0.045	133	0.64	0.521

^aOne rope was lost in this experiment.

countered in growout; cyano-acrylate is both expensive and difficult to apply.

Because the central south-western Pacific [e.g., Fiji, Vanuatu, Papua-New Guinea (PNG)] has few "closed," deep-water lagoons, pearl oyster growout under these conditions contrasts with growout in the atoll lagoons of the eastern Pacific. Whereas atoll lagoons are surrounded by low-lying carbonate islands, the reef systems in the Solomon Islands are subject to relatively large inputs of nutrients and particulate matter from high islands (Littler et al. 1991). The higher nutrient load in the lagoons of Solomon Islands may have been a factor in the good growth rates recorded in this study (Yukihira 1998). However, the negative side of this is the increased algal fouling when compared to the relatively nutrient-poor atoll lagoons of Polynesia. In the Solomon Islands, meshes of culture units required regular cleaning; thereby, increasing labor needs. Although meshes required cleaning, there was relatively little fouling by such "cementing" organisms as bivalves and polychetes ("hard" fouling). Algal fouling is easier to remove than "hard" fouling, and regular brushing for this purpose may have inhibited recruitment and survival of hard-fouling organisms and other byssally attached bivalves, which have been shown to be

a problem during growout of other pearl oyster species (Taylor et al. 1997a). In addition to being simpler to remove, algal fouling does not directly compete with juveniles for food resources and space. We also found that control of algal fouling was easier when culture units were made of stiff plastic meshes. This material was more practical and cost effective than flexible mesh, which could not be easily cleaned and had limited potential for reuse.

Coeroli et al. (1984) reported that 30% of 6 to 12-month-old *P. margaritifera* juveniles were lost in culture in French Polynesia and stated that fishes from the family Balistidae and Tetraodontidae were the chief predators of pearl oysters. In initial trials in the Solomon Islands, fish devastated juveniles in intermediate culture when longlines were deployed too close to reefs (Friedman et al. 1996). Although there was no direct comparison between growout culture in shallow and deeper water in this study, the lack of broken shells in culture units on longlines placed farther from reefs, and evidence presented in other studies (Sims and Sarver 1995), supports the inference that juvenile pearl oyster culture conducted at a distance from reefs and in deeper water reduces predation by fish. For example, in the Marshall Islands 5.5% of juveniles were lost to fish predation on longlines set in deeper

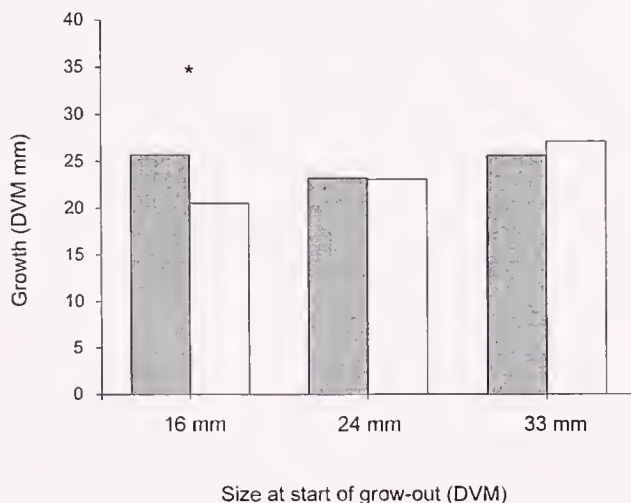


Figure 6. Growth (final DVM—mean DVM at start of experiment) in shell size (DVM mm) of *P. margaritifera* juveniles held for 3 months in lantern nets (shaded) and panel nets (open).

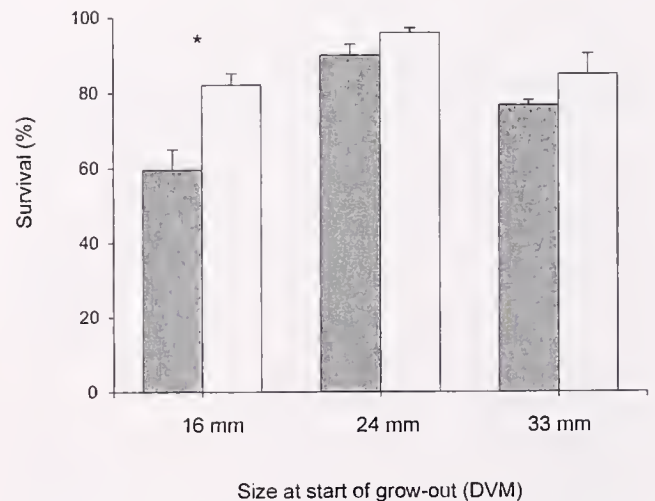


Figure 7. Percentage survival (\pm SE) of *P. margaritifera* juveniles held in lantern nets (shaded) and panel nets (open) for 3 months. Columns marked with an asterisk differed significantly in *t*-tests.

TABLE 3.

Results of one-way ANOVA for effects of culture unit on a) increase in mean shell height (DVM), b) increase in mean wet weight, and c) survival of juvenile *P. margaritifera*, grown for 5 months.

	df	MS	F	p
a) Growth (DVM, mm)				
Culture unit	3	231.771	29.299	.0000
Residual	36	7.911		
b) Change in wet weight (g)				
Culture unit	3	423.122	21.346	.0000
Residual	36	19.822		
c) Survival				
Culture unit	3	22.567	3.201	.0350
Residual	36	7.050		

The four culture units in this study were: panel nets; trays with juveniles loosely added; trays with juveniles glued in place; and ropes with juveniles attached (glued), enclosed in large mesh.

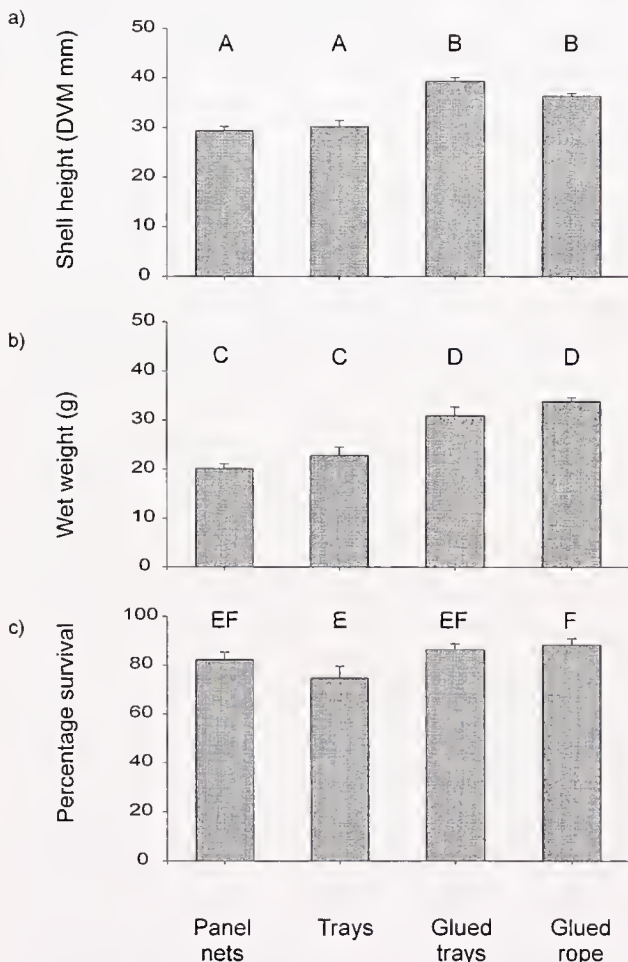


Figure 8. Changes in mean (\pm SE) a) mean shell height, b) wet weight, and c) survival of juvenile *P. margaritifera* held in growout units after 5 months. Columns with the same letter do not differ significantly ($p < .05$) in *post hoc* tests (Tukey's HSD).

water, as compared to 25.5% losses on shallow water longlines (Sims and Sarver 1995). In French Polynesia, pearl farmers hold young oysters behind galvanized wire mesh to isolate oysters from attacks by balistid fish (Lintilhac 1987). Smaller fish also had an effect on growth. In this and other studies (Sims 1993a; Southgate and Beer 1997), small balistids and tetraodontids "grazed" on the non-nacreous shell margins of juvenile oysters in culture. In the Solomon Islands, this was only found to be significant at embayed inshore sites, and relocation of growout longlines to less turbid areas with greater water movement reduced or eliminated this problem.

Once longlines were located in areas free from predation by reef fish, survival of juveniles was influenced primarily by invertebrate predation. Invertebrate predators, such as *Cymatium* spp. (Govan 1995), crabs, and flatworms (Newman et al. 1993, Taylor et al. 1997b) recruited into growout units from the plankton (Dayton et al. 1989, Newman et al. 1993, Friedman and Bell 1996, Friedman 1998). The effect on the hydrodynamics of water flow has been presented as a major determinant of the success of culture unit design (Claereboudt et al. 1994). In the Solomon Islands, invertebrate predators were found in all growout units, but were more common in lantern nets and trays than in units that had smaller holding spaces (e.g., panel nets) or less scope for reducing water flow (e.g., glued ropes). This may have been caused by differences in water flow characteristics that could have influenced settlement of suspended particulate matter and the larvae of potential predators.

Predators that settle within nondivided culture units (e.g., trays) had access to all the juveniles within that unit. On two occasions

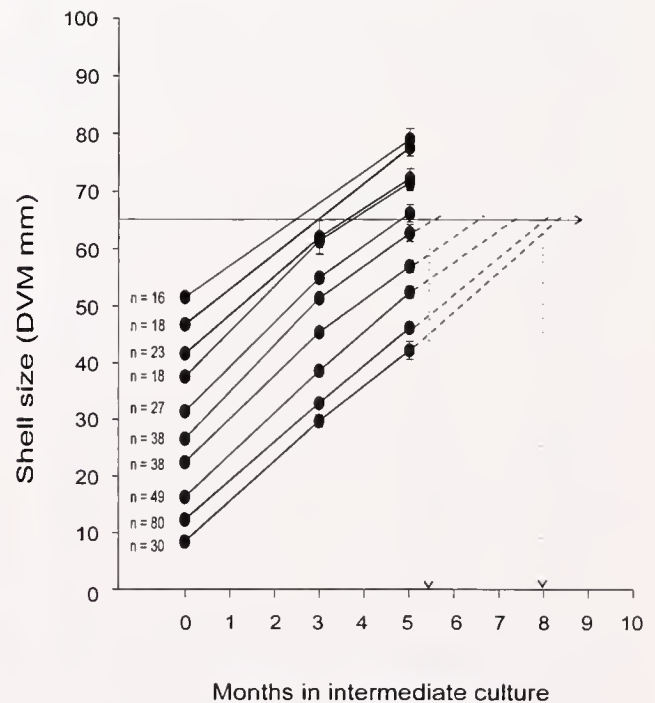


Figure 9. Growth trajectories for *P. margaritifera* juveniles of different sizes (\pm SE) grown in intermediate culture. Once oysters reach a size of approximately 65-mm DVM (marked on graph), they can be drilled for ear hanging. Trajectories that have been extended past the 5-month period (dashed lines), were added using real data from growth experiments involving larger juveniles.

in this study, 20 juveniles (≈ 11 mm DVM) were killed by a *Cymatium* spp. within a single tray. To combat the problem of sequential juvenile predation in intermediate culture, one of two strategies can be adopted: (1) juveniles could be separated into small groups by mesh barriers; or (2) units could be designed to make them easier to inspect for predators. The first strategy relies on the predator outgrowing the mesh size of a single compartment in the growout unit and being prevented from entering other compartments of the culture unit. One such system has been successfully trialed in the Marshall Islands, where settlement of *Cymatium* spp. had previously devastated hatchery-produced *P. margaritifera* juveniles in nursery culture (Sarver et al. 1998, Sims and Sarver 1998). In the Solomon Islands, the second strategy was adopted for three reasons: (1) because in intermediate culture of spat taken from collectors, there is no need to deal with very small spat (< 6 -mm DVM), which are difficult to handle and check for predators; (2) multispaced culture units are difficult to set up and keep free of fouling; and (3) because staff in the Solomon Islands could quickly recognize settlement periods of such predators as *Cymatium* spp. and respond accordingly. Although no reliable seasonal trends in settlement of the main predator groups have been recognized in the Solomon Islands, divers increased the intensity of inspections when large numbers of newly settled predators were found. In this way, predators were removed from growout units when they were small—before they caused significant juvenile mortality.

This study showed that there was a positive relationship be-

tween the size of juveniles placed into intermediate culture and their survival. Also, Coeroli et al. (1984) suggested that oysters over 50-mm DVM were "resistant to attacks from predators." In the Solomon Islands, oysters that had reached ≈ 65 -mm DVM could be removed from intermediate culture and grown on chaplets without a protective mesh covering.

In summary, this study has shown that within the open-reef systems typical of the western Pacific: (1) the rate of growth of juveniles compared favorably to that reported for the closed-atoll lagoons of Polynesia. In the Solomon Islands, juveniles of 10-mm DVM placed in intermediate culture generally attained a size suitable for transfer to chaplets (≈ 65 mm DVM) in 8 months. Those entering intermediate culture at a size of 25- to 30-mm DVM were ready for moving to chaplets after 5–6 months; (2) the siting of longlines in deepwater decreased mortality attributed to fish associated with reef; (3) important characteristics of pearl oyster growout units include ease of cleaning and access for regular inspection and removal for invertebrate predators; and (4) separating oysters in intermediate culture resulted in more uniform growth.

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