RESEARCH ON PRACTICES IN THE WESTERN AUSTRALIAN CULTURED PEARL INDUSTRY

FISHING INDUSTRY RESEARCH AND DEVELOPMENT COUNCIL

PROJECT BP 12

JULY 1987 TO JUNE 1990

FINAL REPORT

BY RICHARD J S SCOONES

(M G KAILIS GROUP OF COMPANIES)

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BROOME PEARLS PTY LTD
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ABSTRACT

The Western Australian Cultured Pearl Industry is based on the silver-lip or gold-lip pearl oyster Pinctada maxima *(Jameson). This study examined the scientific basis for a number of culture practices and oyster management techniques. Some commonly-held opinions relating to the influence of various management techniques on the value of the pearls were not supported by the study.*

Nuclei made from mother-of-pearl had similar physical properties and performed as well as the more expensive imported nuclei. The production techniques were established.

Pearl oyster spat collection was shown to be technically and practically feasible, but its commercial viability has yet to be proved.

1. INTRODUCTION

The cultured pearl industry is the second-most valuable fishery-based industry in Western Australia after the rock lobster fishery, with an estimated value of $80 million in 1990. The pearl oyster quota for the industry is set by the Government in response to the perceived availability of oyster stocks in the wild fishery. The quota is also used as an instrument to control the output of pearls. As a consequence of quota impositions, the only ways to increase profits are to improve product quality, to decrease the costs of production and to increase the efficiency of oyster usage.

The industry, centred around Broome in the Kimberley Region of Western Australia (Figure 1), is based on the older Japanese cultured pearl industry, having directly adopted many methods and techniques (Scoones, 1988 and Taylor, 1985). It is highly labour-intensive with relatively little mechanisation apart from the use of modern vessels and diving equipment.

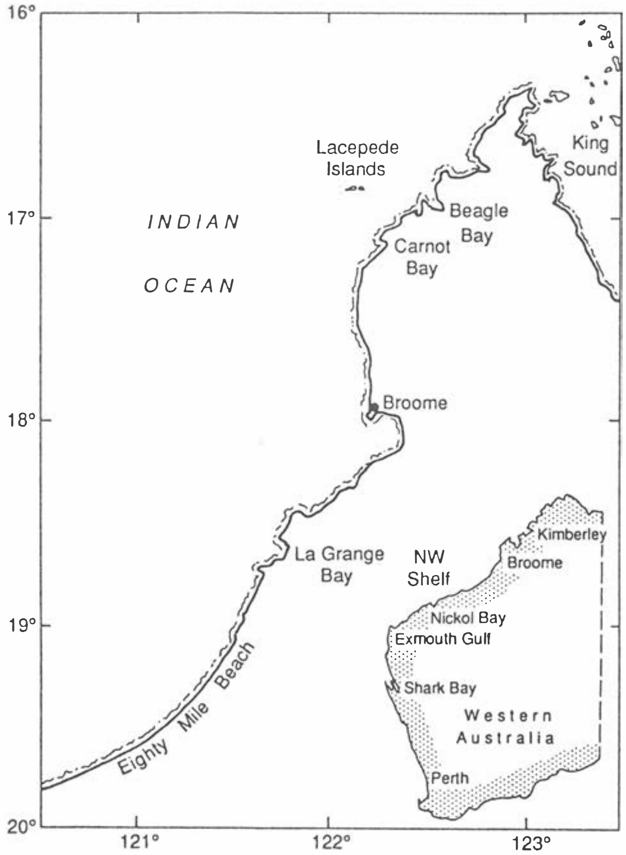


FIGURE 1 LOCATION MAP

Little research has been done on the Western Australian industry and most of the Japanese research is published only in Japanese, making access to the results difficult and expensive. This meant that little information was available on which to design a research programme.

This study began in 1986 with a company-funded research programme aimed at identifying areas in the industry which could benefit most from applied research. That programme identified six current culture practices and associated theories which seemed to lack a scientific basis. The practices included shell cleaning and culture, shell turning and shell opening. The potential for tissue-type dissimilarities to cause the failure of pearl operations, for pearl oyster spat collection as an alternative to the collection of mature wild oysters by divers, and for the production of nuclei (beads) from Australian mother-of-pearl as an alternative to imported nuclei were also considered worth examining. Subsequently, investigation of these six topics was the subject of a successful application by Broome Pearls Pty Ltd to the then Fishing Industry Research Council administering the FIRTA Grants.

The field work was done by the Research and Development Division of the M G Kailis Group of Companies on the Broome Pearls Pty Ltd farm in Roebuck Bay in the Kimberley region of Western Australia.

2. LITERATURE AND BACKGROUND

2.1 Description of Modern Australian Pearl Culture

The pearl culture process begins with collection by divers of appropriately-sized pearl oysters from the sea in the area around Broome. Divers are towed behind special catching vessels, picking up the oysters from the sea-bed. The majority of shells are caught near the Eighty Mile Beach area of the Kimberley Region of Western Australia. After cleaning and grading, the oysters are stored in net panels (Plate 1) on special sea-bed storage areas (dumps) adjacent to the catching grounds. They are left there until operating time, between June and September each year, when the shells are recovered and delivered by boat to the operating vessel.

The shells must be opened before the operation; some relax open by themselves, but the majority are opened by inserting the tips of a pair of shell openers (a tool like circlip pliers with flattened ends) between the lips of the shell and forcing the valves of the shell apart. A small wooden wedge is placed between the valves to keep the shell open (Plate 2).

The shells are delivered to the operating room on the vessel where a pearl technician, or operator (Plate 3), inserts a bead or nucleus (Plate 4) into the soft body tissue of the oyster. The technician also inserts a piece of tissue from the mantle of a donor oyster which is killed to provide the implants for approximately twenty-five operations. The mantle tissue implant provides the basis for the development of a pearl sac which secretes the nacre onto the nucleus to form a pearl. Shortly after the operation, the oyster is placed back into a net panel and returned to the sea-bed of the operating lease for post-operative handling practices which are said to enhance the development of the pearl.

Following a rest period of between 7 and 10 days after the operation, a turning programme is commenced. The panels of oysters are turned over by divers every few days. The frequency and timing of the turning varies between companies. The period of turning may extend to two months or more after operating. The oysters are then left on the sea floor until late October or early November, when they are recovered and transported to the farm sites for the remainder of the culture period.

The culture equipment used to support the oysters varies according to location, with those farms in exposed waters using bottom culture methods to avoid excessive exposure to rough seas which may cause failure of the culture equipment. Broome Pearls Pty Ltd's farm in Roebuck Bay is exposed to the open sea; this influenced the decision to culture the pearls on the bottom instead of using the "traditional" Japanese surface culture methods. The methods used in the past include bottom longlines (panels of oysters flat on the sea floor clipped to a rope), fences (panels of shells clipped to ropes which are slung between star pickets driven into the sea bed at 3.5-metre spacings), poles (star pickets covered by PVC tubes with rows of small holes drilled in them to accept stainless steel hooks through the heels of the oysters), and A-frame racks (steel frames covered with plastic mesh, shaped like a small tent on which the oysters are hung using a stainless steel hook through the heel of the shell). The farms in the Northern Territory and north of Cape Leveque are in more protected waters and prefer to grow the oysters in net panels hanging from surface longlines slung between buoys and anchored at each end to the sea floor. This avoids diver problems with crocodiles as well as allowing the employment of less skilled workers for routine farm work.

The oysters are X-rayed 4 to 6 months after operating to determine whether they have retained the nucleus. Those where the nucleus has been lost are normally operated on again during the following operating season and go through treatment similar to that described above. The oysters with a developing pearl are cared for with regular cleaning to remove marine fouling organisms. After two years, the oysters are recovered from the sea and taken to the operating vessel for harvesting. They are opened in the same manner as that used during the first operation and the technicians remove the pearls using a technique similar to that used to implant the nucleus. If a pearl is considered to be of adequate value, a new nucleus, similar in size to the pearl recently removed, is placed in the empty pearl sac. There is no need for a new piece of mantle tissue since the pearl sac survives the harvest operation. The oyster is then returned to the sea for a further two years.

2.2 Development of a Cultured Pearl

The operation to produce a cultured pearl involves the insertion of a spherical bead or nucleus, made from the shell of a freshwater mussel, into a pearl oyster along with a small section of mantle tissue from a donor oyster. In a successful operation, the implant grafts into the host oyster and proliferates to form a pearl sac which secretes nacre around the nucleus (Dix, 1973, Scoones, 1988). The development of the pearl sac may take from a few days in warm water to 65 days in cold water (George, 1967). Achari (1982) wrote that pearl sac development in tropical waters takes 25 to 30 days, although Wada (1970, 1973) said that it develops in approximately one week after the implant of the nucleus. He also said that the physiological condition of the oyster affects the secreting activity of the pearl sac by affecting the size, shape and orientation of the crystals comprising the nacre. This, in turn, affects the optical properties of the nacre. He concludes that a regular laminar structure produces a pearl of good lustre and iridescence, while an irregular laminar structure produces a dull pearl of poor transparency. Wada (1970) described the nacre of a cultured pearl as "concentric laminated structure consisting of alternate accumulation of mineral crystals of aragonite and membranous organic matrix of protein with large amounts of aspartic acid, serine, glycine and alanine residues".

Wada (1973) and Alagarswami (1975) noted that seawater temperature has a considerable effect on the secreting activity of the pearl sac. Wada (1973) also wrote that the quality of a pearl depended on factors such as growth rate, lustre and colour; the last two factors alter following seasonal changes of temperature. Pearls are harvested during autumn and winter when the lustre of the pearls is greatest. He also claimed that the quality of a pearl depended almost entirely on the quality of the nucleus, but he did not cite any evidence.

3. HANDLING PRACTICES

3.1 SHELL TURNING

3.1.1 Background

After a short post-operation rest period (7-10 days) on the bottom, the pearl oysters are turned over on a regular basis (every 1 to 3 days) for a period of up to two months. The frequency and period of turning varies between companies. It is claimed that regular turning during the early stages of a pearl's development, particularly when the pearl sac is developing, helps to produce pearls which are rounder than would be the case without turning. This practice may be a direct import from the Japanese pearl industry but there is no published information relating to it. George (1969) did not mention shell turning in his description of Australian pearl culture practices .

In view of the significant costs of turning and the lack of data on its effects, an experiment was designed to determine the effects of turning on the value of pearls produced.

3.1.2 Materials and Methods

Six hundred and forty oysters were implanted under normal commercial conditions in June 1987 by one experienced company technician. On their return to the bottom the oysters were separated into the four groups of 160 for different treatments. Seven days after operating, the turning treatment (Table 1) commenced. The oysters in Groups B, C, and D were stored on the sea-bed in net panels of six oysters each for the duration of the turning programme, while the oysters in Group A were hung up in net panels on a fence immediately after operating. Groups B, C, and D were turned over according to the turning regime and then hung up on fences after all turning was completed on day 25. Subsequently, all four groups of oysters were treated identically in terms of cleaning regime, physical location and other maintenance.

TABLE 1 SHELL TURNING TREATMENTS

TREATMENT	TURNING REGIME
A	Not turned, oysters hung up immediately
B	Not turned, oysters left on sea floor, and then hung up on day 25
C	Oysters rested for 7 days after operating, then turned every 3 days for 18 days, then hung up on day 25
D	Oysters rested for 7 days after operating, then turned every 2 days for 18 days, then hung up on day 25

The oysters were X-rayed in February 1988, in accordance with usual commercial practice, to determine the nucleus retention and mortality rates. The pearls were removed during the normal commercial farm harvest in August 1989 and valued. All valuations were carried out by the pearl marketing consultant to Broome Pearls Pty Ltd.

For the purposes of the analysis, it was assumed that the size of nuclei used was normally distributed across the four treatments and was therefore not a variable to be considered in the analysis of pearl values. The oysters used in the experiment were randomly selected from those available at the time of operation with a resultant expected random distribution of oyster sizes. Shell size is a major determinant in nucleus size selection by the pearl technician. The analysis focussed on the effects of turning on the value of marketable pearls. It was not considered appropriate to analyse for the total value of pearls within each treatment due to the small numbers of pearls produced and the high variability of pearl values. However, it was possible to analyse for the effects of turning on nucleus retention, oyster mortality and total pearl production (marketable and non-marketable).

3.1.3 Results

The data from this experiment are given in Appendix 1. As the pearl values were not normally distributed it was necessary to transform them (log *e* value) before doing an analysis of variance. Figure 2 is a histogram of the mean log *e* values of the marketable pearls from the 4 treatments.

Although treatment "C" appeared to produce more valuable pearls (Figure 2), the analysis of variance showed no significant difference between the two relevant sets of three treatments; treatments "A, C, and D" ($P=0.166$) and treatments "B, C, and D" ($P=0.640$).

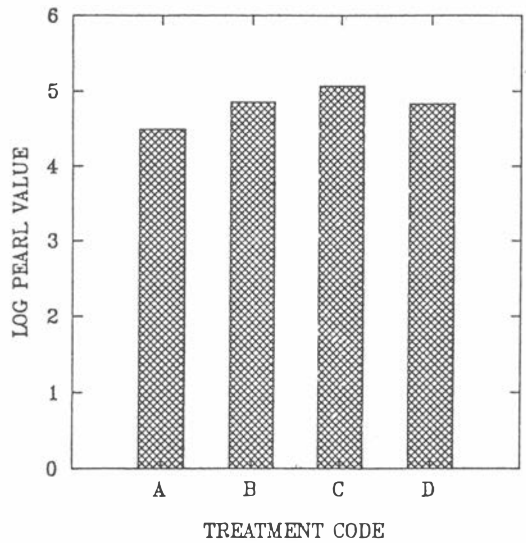


FIGURE 2 LOG PEARL VALUES FROM TURNING TREATMENTS

A Chi Square test on survival of shells to X-ray time, approximately five months, showed no significant differences between the control (treatment "D") and treatments "A" or "C". However, treatment "B" (left on the bottom without turning) suffered higher mortality than the control ($P < .001$).

A Chi Square test on the production of marketable pearls, non-marketable pearls and barren shells (no pearl) showed a better result for treatment "C" than treatment "D", the control ($P< .05$).

3.1.4 Discussion

Due to the unexpectedly high variance, the sample sizes used in this experiment were inadequate to show differences between treatments, if such differences exist. Nevertheless, there was no confirmation of the value of the turning practices employed by the industry. Further experimentation using considerably larger samples is required to provide definitive results.

3.2 SHELL CLEANING AND CULTURE METHODS

3.2.1 Background

3.2.1.1 Cleaning

During the two years taken for a pearl to develop, large amounts of marine organisms settle and grow on the pearl oysters and the culture equipment. Sponges, colonial ascidians, barnacles and corals are the most prominent and grow rapidly in the warm, nutrient-rich waters.

Fouling growth increases friction between the culture equipment and the water currents (which may exceed three knots) occasionally causing structural failure in the culture equipment.

Alagarswami and Chellam (1976) reported that barnacles were the most significant problem in terms of fouling organisms on pearl oysters, often restricting the opening and closing of the valves. They also found a correlation between the intensity and composition of the fouling assemblages and the rate of mortality of *Pinctada martensii* on a pearl farm at Veppalodai.

There is a common belief in the Australian pearl industry that cleaning increases the growth-rate of pearl oysters by eliminating competition for food and by physical stimulation. Wada (1973) claimed that the oysters in Japanese pearl farms were cleaned between four and six times between April and November because animals and seaweed settling on the shells and cages inhibit the growth of shells and of the pearls in those oysters. Arakawa (1980) reported the potential for reduction in oyster quality and growth and for increase in mortality from excessive fouling growth. Mohammad (1975) reported an inverse correlation between the diversity of biofouling assemblages and the growth-rate of *Pinctada fucata* in the Arabian Gulf. He found that the percentages of both infestation by *Polydora vulgaris* (a polychaete) and mortality were higher among fouled (uncleaned) oysters than those cleaned regularly.

Kuriyan (1951) found that cleaning the cages on a regular basis resulted in more rapid growth of the oysters and claimed that the fouling organisms on the outside of oyster cages competed with the oysters for food.

In the Western Australian pearl culture industry oysters grown on surface longlines or rafts are cleaned as often as every two or three weeks because of the rapid development of fouling biomass. Bottom-farmed oysters, as in the case of Broome Pearls Pty Ltd, are cleaned about every six weeks.

These frequent cleaning operations use considerable resources and are expensive. For this reason, it was considered appropriate to investigate shell cleaning to provide information which could allow an evaluation of the economics of this practice.

3.2.1.2 Culture Methods

The original culture method in the Japanese pearl industry was to scatter the oysters on the seabed. This resulted in high mortalities through predation, parasitism and disease (Wada, 1973). These problems led to the modern Japanese method of surface raft culture to protect the oysters and to increase the convenience of handling them. This also allowed the utilisation of areas previously considered unsuitable for pearl farming. There is no reference in the literature to bottom farming methods similar to those used by Broome Pearls Pty Ltd, however, Denis George (pers. comm.) states that bottom farming had been practised as early as the late 1950's in various parts of the world.

Several different culture methods have been used in bottom farming; it was considered appropriate to compare these methods to determine the most efficient system in terms of value of pearls produced. The methods tested, described in detail in Section 2.1, include: A-frame racks, bottom longlines, and fences. An older method which used PVC pipes to support oysters with stainless steel hooks in them was not tested due to the technique being superseded. Two locations with different water depths (8 metres and 15 metres below chart datum) were used in this experiment to test for differences in the effects on fouling development and shell growth. Although the experiment was concerned mainly with bottom farming, a surface longline was included but it broke before the completion of the experiment.

3.2.2 Materials and Methods

Fifteen groups of 60 oysters were operated on in normal commercial conditions using two experienced company technicians. All shells were then drilled through the base of the shell near the hinge with a 2.5 mm drill and individually identified with a small sheep tag using a plastic cable tie. The Hinge Depth (HD) and Dorso-Ventral Measurement (DVM) (Figure 3) were recorded for each shell and the oysters placed on the bottom in accordance with normal practice, ie. they were rested for seven days, then turned every second day for 18 days, and then hung up on their culture equipment on day 25.

The oysters were not X-rayed as per normal practice due to the problem of possible stimulus inconsistent with the treatments being tested. Cleaning was done by divers bringing the oysters to the surface, removing the marine growth with meat cleavers, and then replacing them on their respective structures. At harvest time, the shells were measured and the pearls from the individual oysters were measured and valued separately.

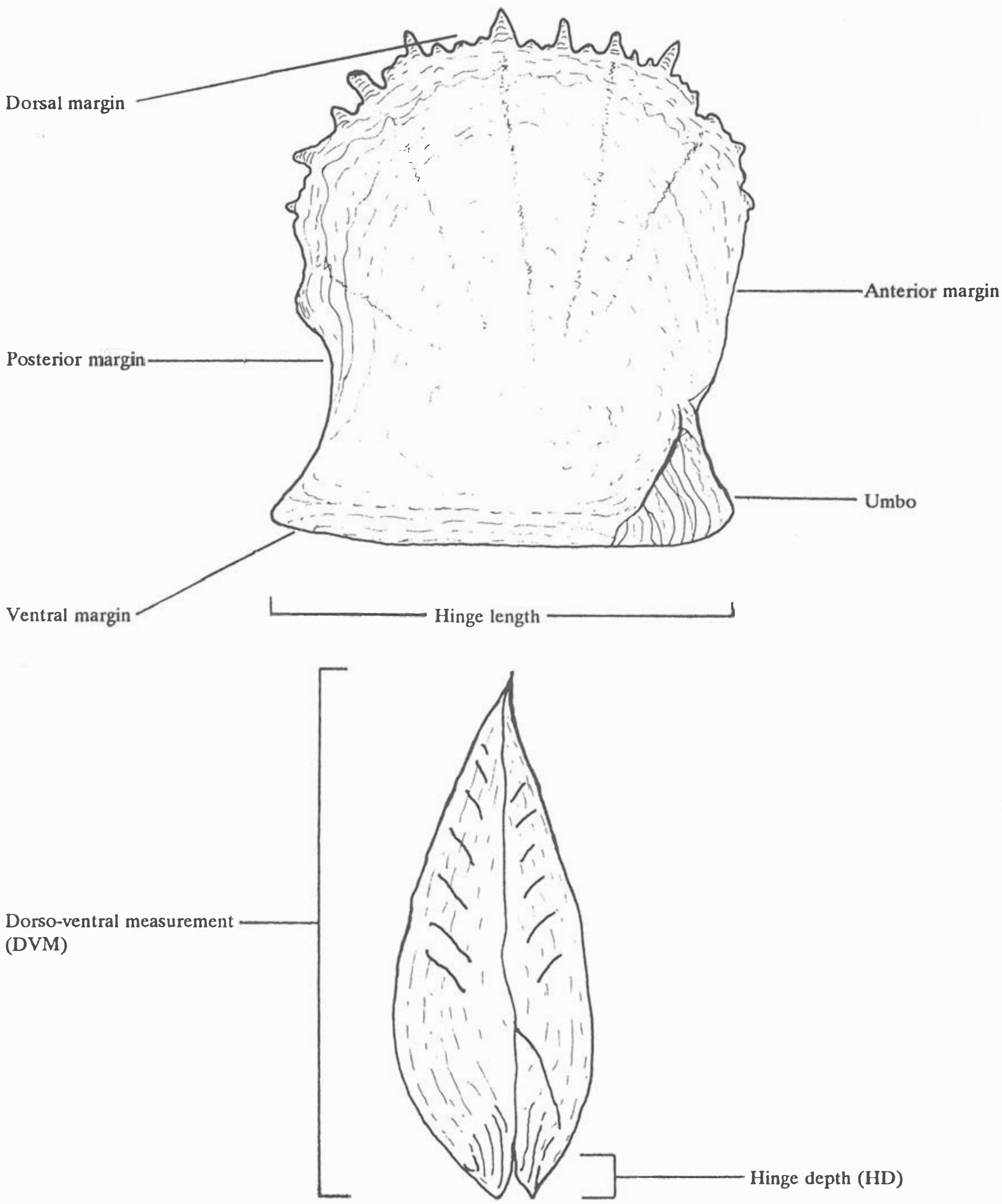


FIGURE 3 EXTERNAL SHELL ANATOMY

After Alagarswami and Chellam (1977)

Five cleaning regimes and three methods of supporting the oysters were tested (Table 2). Treatment "O" was not cleaned but was shocked at regular two month intervals to simulate the physical disruption of cleaning without removing the fouling growth.

TABLE 2 CLEANING AND CULTURE TREATMENTS

TREATMENT	CLEANS/2 YEARS	DEPTH METRES	CULTURE METHOD
A	0	8	BOTTOM
B	0	8	A-FRAME
C	0	8	FENCE
D	4	8	BOTTOM
E	0	15	BOTTOM
F	0	15	A-FRAME
G	0	15	FENCE
H	4	15	BOTTOM
I	2	8	A-FRAME
J	6	8	A-FRAME
K	4	8	FENCE
L	4	8	A-FRAME
M	4	15	FENCE
N	4	15	A-FRAME
O	0	15	A-FRAME

3.2.3 Results

This experiment was to assess the contribution of three factors to the value of cultured pearls. All marketable pearls containing a nucleus were included in the analysis. Because of the nature of the data (Appendix 2) it was necessary to use a log *e* transformation. A three-way analysis of variance was done on data from the twelve treatments which had the necessary complement of alternatives (ie alternative culture depth, culture methods or cleaning regime, Table 3).

TABLE 3 ANALYSIS OF VARIANCE OF MARKETABLE PEARL LOG VALUES

SOURCE OF VARIATION	MEAN SQUARE	d.f.	F	P
DEPTH	0.383	1	0.346	0.558
CULTURE METHOD	2.761	2	2.495	0.090
CLEANING REGIME	0.429	1	0.387	0.536
DEPTH*CULTURE	1.233	2	1.114	0.334
DEPTH*CLEANING	5.043	1	4.558	0.036
CULTURE*CLEANING	7.336	2	6.630	0.002
DEPTH*CULTURE*CLEANING	4.659	2	4.211	0.019
ERROR	1.106	72		

3.2.3.1 Cleaning

There was no significant difference in terms of pearl value between the cleaning regimes (Table 3). The combined effects of cleaning regime and culture depth, cleaning regime and culture method, and the combination of all three factors were significant.

3.2.3.2 Culture Methods

The low P value for culture method in the analysis of variance (Table 3) indicates a likelihood of some culture method(s) differing in their effect on the value of the pearls. Significant differences (at the 5% level) were not demonstrated in these trials, but may be borne out using larger samples.

The average log pearl values from different culture methods are shown in Figure 4. A series of "t"-Tests between pairs of culture methods was used to assess the differences. The average values of pearls from bottom longline and A-Frame culture were not significantly different ($t = 0.332$, $P = 0.741$, (90 df)), but the pearl values from fence culture were significantly higher than those from bottom longline culture ($t = 4.062$, $P < .001$, (55 df)), and A-Frame culture ($t = 3.772$, $P < .001$, (73 df)).

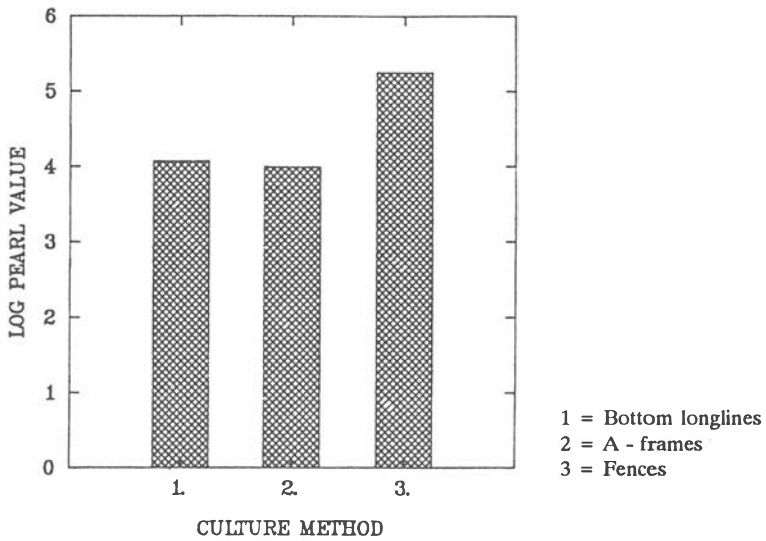


FIGURE 4 EFFECTS OF CULTURE METHOD ON PEARL VALUE

3.2.3.3 Culture Depth

There was no significant difference between the values of pearls grown in the two different culture depths tested (8 metres and 15 metres).

3.2.4 Discussion

There is no evidence that the practice of cleaning shells increases the value of pearls. However, other economic and management justifications for cleaning shells are not considered here.

The fence culture method showed a clear advantage in terms of pearl value over other techniques which hold the oysters nearer the sea-bed. The reasons for this are not certain, but there appears to be less choking by water-borne sediments as shown by the more profuse growth of fouling on the fences compared with the other two methods tested. Owing to equipment failure, it was not possible to include the results from a surface longline.

3.3 SHELL OPENING

3.3.1 Background

Prior to the nucleus inserting operation, the shell is forced open with a pair of shell openers (a tool like a pair of circlip pliers with flattened points) and a small wooden wedge is placed between the valves to keep them apart for the technician (Plates 2 and 3). The amount of force needed to open shells varies from almost nothing (for very relaxed oysters) to considerable force using two pairs of openers. In the latter case there is a significant risk of tearing or straining the adductor muscle, either of which results in the death of the oyster. Up to 12 percent of oysters may die within 2 months of operating, possibly as a result of excessive force used during opening.

Tranter (1957) recorded the use in Australia of menthol dissolved in seawater to relax the shells prior to opening for operation. Alagarswami (1974) wrote that menthol crystals were spread over the surface of the water in a tank containing pearl oysters to prepare them for the operation. Taylor (1985) claimed that the Japanese practice of narcotising shells in menthol and seawater was not used in the Australian industry. This was probably correct by the time of this publication. Kunz and Stevenson (1908) wrote that chloral hydrate or chlorosone was used for the relaxation of freshwater molluscs and that magnesium sulphate crystals added to seawater were used for marine molluscs. The author had used magnesium chloride to narcotise marine invertebrates prior to preservation.

Hollyer (1984) recorded the practice of overcrowding the oysters in small containers to weaken them prior to operating; he also wrote of induced spawning as a means of reducing the effort required to open the oysters prior to operating.

The potential to reduce post-operative mortalities was considered large enough to justify the investigation of chemically-induced relaxation.

3.3.2 Materials and Methods

Difficult-to-open oysters were selected for testing the effects of solutions, of various concentrations of both magnesium chloride and menthol in seawater, injected into their shell cavities. Seawater was used as one control and comparisons were also made with oysters not injected at all. Five millilitres of the relevant test solution were injected using a hypodermic syringe into the body cavity either between the outer lips of the shells or through the umbo region. The time was taken from the injection until a gap appeared between the valves. After opening, the oysters were operated on by an experienced technician and returned to the farm for normal commercial procedures. Special care was taken during the immediate post-operative period to look for mortalities or signs of ill health which could be attributed to the chemicals used.

3.3.3 Results

Tables 4 and 5 show the rate of opening of groups of oysters with various strengths of two chemicals. After 60 minutes, there were no significant differences between the effects of the chemicals or concentrations. Between 60 and 90 minutes after injection, concentrations of 18 and 21 grams of menthol per litre of seawater caused more shells to open than lower or higher concentrations. At the concentrations used, no negative effect of the chemicals or mortalities were observed.

TABLE 4 CUMULATIVE TOTALS OF OYSTERS OPENING USING MAGNESIUM CHLORIDE

	MAGNESIUM CHLORIDE ($g\ l^{-1}$)					
TIME (MINS)	CONT.	0	8	16	24	32
15	1					
30	3	3	2		3	
45	5	3	5	2	6	
60	7	8	7	3	6	2
UNOPENED	5	4	5	7	6	10

TABLE 5 CUMULATIVE TOTALS OF OYSTERS OPENING USING MENTHOL

	MENTHOL CONCENTRATION ($g\ l^{-1}$)					
TIME (MINS)	CONT	0	16	18	21	24
15	1	1		1		1
30	3			3	3	4
45	5		3	7	6	5
60	7			8	7	6
75			4	9	10	
90			5	10	12	
105				11		
120		2				
135		5				
150		6				
165		7				
180		8				
UNOPENED	5	4	7	1	0	6

3.3.4 Discussion

These results show that an injection of menthol dissolved in seawater can be used to promote the opening of stubborn oysters. It takes more time than conventional methods but, by eliminating muscle strain or other physical damage which may cause death of the oyster or rejection of the nucleus, it could increase pearl production by at least 3 or 4 percent. The practice should be viable in any situation where the extra time waiting for the stubborn shells to open is not a constraint.

Dosages should be established with care since they probably vary with conditions such as temperature and oyster health and reproductive conditions.

4. PEARL SAC AND NUCLEUS

4.1 MANTLE TISSUE COMPATIBILITY

4.1.1 Background

During the operation a small (3-4 mm square) piece of tissue from the mantle of another oyster is inserted into the receiver (host) oyster to lie alongside the nucleus. Each oyster killed for the supply of these implants provides enough for approximately twenty-five operations. The tissue contains a layer of nacre-secreting cells which normally secrete the smooth silver-white coating on the inside of the shell. In a successful operation the tissue implant grafts onto the host and becomes a living part of that animal. Through successive division, the nacre-secreting cells form a pearl sac completely enveloping the nucleus. Subsequent secretion of nacre by these cells produces a pearl.

The 4 percent of oysters killed for implants could be saved and used for producing pearls, if implants could be taken from the oyster being operated on. The technique of using tissue from the same oyster was used in a modified form at Kuri Bay by Pearls Pty Ltd. The first oyster of a batch of three provided the mantle tissue for itself and the following two operations (Hancock, 1973). This technique appears to have been discontinued. However, at a time when greater efficiency of the usage of oysters is desirable, the technique was considered deserving of re-examination.

4.1.2 Materials and Methods

To test for tissue incompatibility, the performance of oysters with implants taken from their own mantle tissue was compared with that of oysters with foreign implants. The self tissue implant, about 4 mm square and 1 mm thick, was taken from the outer mantle using a tissue punch as used for biopsy samples by E N T surgeons. The operation and subsequent culture then proceeded as normal.

4.1.3 Results

The data from this experiment are contained in Appendix 3. The results (Table 6) show no difference between the use of implants from the same or different oysters and, therefore, that there is no immunological effect. They did show that it is possible to produce pearls successfully using the "same oyster donor" technique, thus avoiding the sacrifice of 4 percent of oysters.

TABLE 6 MANTLE TISSUE COMPATIBILITY TESTS

	SOURCE OF IMPLANT			
	SAME OYSTER		DIFFERENT OYSTER	
NO. OF OPERATIONS	60		60	
TIME PER OPERATION (MINS)	2.25		1.71	
POST-OP MORTALITIES	9		7	
X-RAY RESULTS YES NO	28	23	28	25
SALEABLE PEARLS	15		15	
NON-SALEABLE PEARLS	2		4	
KESHIS	8		6	
BARREN SHELLS	3		3	
MEAN VALUE MARKETABLE (SD)	230.33	(279.76)	201.66	(211.46)
MEAN VALUE ALL PEARLS (SD)	203.24	(273.07)	159.21	(201.53)

The mean values of marketable pearls from the two groups did not differ significantly ($P=.934$). No significant differences ($P<0.05$) were found using Chi Square tests on the proportion of saleable pearls, non-saleable pearls, keshis (seedless pearls) and oysters with no pearls.

4.1.4 Discussion

At the time the experiment was designed, the general rate of loss or rejection of the nucleus within six months was between 55 and 65 percent and it was thought that tissue-type differences may be contributing to this failure rate. Tissue-type differences and basic immune response reactions have been detected in the Mollusca and in lower animal groups (Dr P Hodgkin, pers. comm.) strengthening the belief that tissue incompatibility may be a contributing factor. However, as more experienced operators now suffer only 35 percent loss of nuclei, the likelihood that tissue incompatibility may be a major problem is considerably reduced. Therefore, the main value in changing to this operating technique lies in the potential to increase productivity by eliminating the need to kill oysters for implants. Normal pearl production levels and quality can be achieved using mantle tissue from the same oyster, as opposed to using tissue from a different oyster killed for that purpose. The slightly higher mortality rate of "same oyster" implant may reflect the additional trauma suffered in the removal of the tissue for the implant, a factor not allowed for in the experiment design. Larger samples would be required to test whether this apparently higher rate is a real phenomenon. If so, the loss from this higher mortality versus the loss for the supply of tissue from other oysters would need evaluation.

The technique needs some development to ensure that the tissue is taken from the correct location with minimum trauma for the animal and in as short a time as possible to allow the operations to proceed at the desired rate. The technician took about 30 percent longer for operations using self-implants than in the normal procedure but it is likely this time would reduce with practice.

4.2 MOTHER-OF-PEARL NUCLEI

4.2.1 Background

The beads, or nuclei, currently used for Australian cultured pearls are made in Japan and other Asian countries and imported by Australian pearling companies. The cost of these imports represents a major cost component of pearl production and a loss to Australia of foreign exchange. In the early years of pearl culture, nuclei were made from mother-of-pearl (Taburiaux, 1985), but in later years a preference for Japanese nuclei developed, possibly due to their white colour (Plate 4). It is not clear whether the "mother-of-pearl" referred to in some of the early texts means the shell of a pearl oyster or whether the term is used loosely to include the shell of other bivalves. It was reasoned that nuclei should be made from the same crystalline morph of calcium carbonate as that coating them (aragonite) in order to be physically compatible (Roberts and Rose, 1989).

When this study was planned, the largest nuclei (approximately 14 mm) cost $A4.00 each but by 1990 they cost approximately $A25.00 each and were in short supply due to a shell production problem in USA, with further supply problems and price increases anticipated for future years. The development of substitute materials and Australian production technology could considerably reduce the approximately $A12 million spent annually on nuclei by the industry.

The nuclei used in the cultured pearl process are produced in Japan from shell belonging to the Family Unionidae, which includes some of the freshwater mussels and clams. The genera include *Amblema, Quadrula, Pleurobema* and *Megalonais* (Wada 1973). The common names used for these freshwater mussels include pig-toe, dove, three-ridge and butterfly shells (Velu et al., 1973). Alagarswami (1970) also recorded *Tritigonia* (Family Unionidae) as a source of material for nucleus manufacture. Ward (1985) wrote that the pig-toe mussel, at one time the most commonly-used shell in nucleus manufacture, is no longer available in large quantities due to reduction in the populations by agricultural pesticides. This has been replaced by the washboard mussel comprising approximately 50 percent of the current shell production from the Mississippi River in Tennessee, USA.

Velu et al. (1973) made nuclei from the sacred chank, a conch of India, using a machine made from a modified drill press and silicon carbide grinding wheels. The nuclei were polished using a weak hydrochloric acid solution. Hardness or roundness of these nuclei were not stated although the authors claim that they "compare favourably with those used for pearl culture elsewhere in the world". Roberts and Rose (1989) tested the shells of giant clams (Tridacnidae) and Australian pearl oysters for their physical suitability as nuclei with the specific objective of finding a material similar to that composing a natural pearl. They argued that the prime concern in producing a nucleus should be that the thermal expansivity, thermal conductivity and hardness of the material be similar to those of the currently-used, Japanese-made, nuclei. Subsequently, Rose (pers. comm.) stated that overseas operators had found that nuclei made from giant clam shell were satisfactory for pearl formation but that they cracked when drilled, making them unsuitable for necklaces. Roberts and Rose (1989) measured thermal expansion at temperatures between -20°C and 50°C and found an almost linear rate of expansion over that range. The usefulness of this result for nucleus materials is questionable in light of the high temperatures reached when a nucleus is drilled (high enough to boil a drop of water, pers. obs.).

4.2.2 Materials and Methods

The first machine used in this study for making beads was copied from Velu et al. (1973) but it failed to perform to the level claimed. A second machine was based on an electric motor driving a grinding disc. Cubes of mother-of-pearl were cut from pearl shell using an angle grinder. These were put into the grinding machine for approximately 12 hours to obtain beads of the same roundness qualities as those from the first machine. These were then smoothed by immersion in concentrated hydrochloric or nitric acid for approximately 5 minutes. Further smoothing was achieved through slow tumbling in a lapidary tumbler. These nuclei were implanted into a sample of pearl oysters which were cultured normally.

Later, a bead-making machine was imported from Taiwan. This machine was designed for working with hard materials such as stone and although beads produced with it were better than those made with the first machine, they still did not meet the tolerances required by the pearl industry. Satisfactory nuclei were made after modifying the machine to make it closer to the design of Taburiaux (1985), (Plates 5 and 6).

Roundness was assessed by measuring the largest and smallest diameters of the nuclei with a dial micrometer.

Hardness was measured using the Vickers Hardness Test. It was measured in both the light and dark bands of the nuclei (Plate 4). Three tests were made on both light and dark bands and the readings averaged to calculate the overall hardness values and their variances. Brittleness or plasticity was assessed by microscopic examination for the presence or absence of cracks around the edge of the impression left by hardness tests.

The rate of, and total, expansion are important when pearls are drilled for making strands (necklaces). Excessive heat from the friction of the drill can cause differential expansion and fracture the pearl. The thermal expansion characteristics were determined for each nucleus type using a Theta Dilatometer with a sintered alumina specimen holder.

The effect of drilling was assessed by drilling up to 3 holes in different directions in a number of nuclei of both materials. A selection of pearls containing the different nuclei was drilled to test the possibility of nacre loss due to expansion while drilling.

The mother-of-pearl nuclei are a dull grey-to-brown colour with considerable variation across each individual, compared with a vivid white with little variation across each individual for the imported nuclei (Plate 4). Concern that the colour of the nucleus may adversely affect the colour of the pearls was expressed by some industry members.

The specific gravities of the two nucleus types were compared by measuring the volume of water displaced by a known mass of each material.

The pearls containing the MOP nuclei were assessed by the professional pearl grader without prior knowledge of their origin or treatment.

4.2.3 Results

4.2.3.1 Roundness

The techniques developed during and after this experiment have achieved the goal of producing "adequately round" (almost spherical) nuclei from MOP. Roundness data (Table 7) from randomly-selected nuclei of each type over the range of sizes most commonly used show greater variation in diameters in the MOP nuclei than in the Japanese nuclei. Further refinements are expected to improve these results.

TABLE 7 NUCLEUS ROUNDNESS TESTS

MOTHER-OF-PEARL NUCLEI			JAPANESE NUCLEI		
MEAN DIAMETER (MM)	+/- MM	%	MEAN DIAMETER (MM)	+/- MM	%
8.55	0.08	0.94	8.81	.03	0.34
9.00	0.18	2.00	9.01	.05	0.55
9.28	0.08	0.86	9.12	.04	0.44
9.61	0.16	1.66	9.22	.04	0.43
10.04	0.12	1.20	10.14	.04	0.39
10.55	0.11	1.04	10.30	.05	0.49
10.91	0.05	0.46	11.07	.03	0.27
11.65	0.14	1.20	11.45	.05	0.44
11.74	0.08	0.68	11.47	.03	0.26

The mean diameter is the average of the largest and smallest diameters.

4.2.3.2 Hardness and Brittleness

The data from the hardness tests are given in Appendix 4. A "t"-test showed that the light and dark bands of the MOP nuclei (Table 8) were not significantly different (P= .210) and that the MOP nuclei are approximately nine percent harder than the Japanese nuclei (P=.001).

TABLE 8 NUCLEUS MATERIALS VICKERS HARDNESS TEST SUMMARY

	MOTHER-OF-PEARL NUCLEI		IMPORTED NUCLEI	
	DARK BAND	LIGHT BAND	DARK BAND	LIGHT BAND
MEAN	223.47	189.67	188.50	188.53
ST. DEV.	19.37	27.17	29.20	27.58
NO. OF NUCLEI	10	10	10	10
NO. OF TESTS	30	30	30	30
MEAN VHN (STD)	206.57 (29.02)		188.52 (28.40)	

Microscopic examination showed that both MOP and Unionidae materials are plastic rather than brittle.

4.2.3.3 Thermal Expansion

The rate of thermal expansion (Figure 5) in MOP nuclei is slightly higher than that of Japanese nuclei below 140°C. However, above 140°C the rate of expansion in the Japanese nuclei is higher than that in the MOP nuclei.

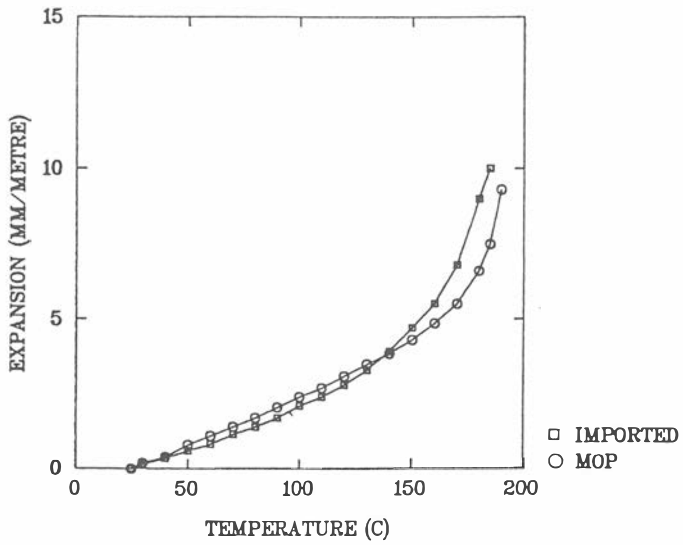


FIGURE 5 THERMAL EXPANSION OF NUCLEUS MATERIALS

4.2.3.4 Drilling Tests

The results (Table 9) of tests show that the MOP nuclei are more tolerant of drilling than the Japanese nuclei. The MOP nuclei failed to crack after as many as three holes were completed, with one possible exception, while the Japanese nuclei varied with some accepting three holes without cracking and some cracking after one or two holes. If drilled parallel to the laminations, the Japanese nuclei cracked, but did not necessarily split, in more than 80 percent of tests. None of the pearls with either MOP or imported nuclei cracked or flaked with drilling.

TABLE 9 SUMMARY OF NUCLEUS DRILLING TESTS

NUCLEUS TYPE	NUMBER OF HOLES DRILLED 1	2	3
IMPORTED % CRACKED (n)	80 (10)	66 (3)	0 (7)
MOP % CRACKED (n)	11* (9)	0 (4)	0 (6)

* one possible crack

4.2.3.5 Specific Gravity

The specific gravity measurements showed that the density of mother-of-pearl (2.71) is almost identical to that of the Unionidae shell (2.81).

4.2.3.6 Colour Influence from Underlying Material

The pearls containing the MOP nuclei were described by the professional pearl grader, unprompted and without knowledge of their origin, as being high quality in terms of colour and skin characteristics. There was no indication of the colour of the nucleus showing through the nacre of the pearls. Although the sample was only twenty-five pearls this is good evidence that the MOP nuclei do not adversely affect the appearance of the cultured pearls formed around them.

4.2.3.7 Technical Aspects of Bead Making

The technique used to make the nuclei in this study were adapted from Taburiaux (1985) and other commercially-available bead-making technology. The MOP is susceptible to cracking during the early stages of rounding the blocks of material requiring care when starting the grinding process. The fine roundness tolerances and final polishing of the nuclei have yet to be achieved.

4.2.4 Discussion

It is necessary to be fully confident that any substitute materials in pearl nuclei will not cause any diminution in the reputation of the Australian South Sea Pearl. The physical tests show that the MOP and imported nuclei are very similar in most of the characteristics measured. However, MOP nuclei did not crack as frequently as the Japanese nuclei which were particularly prone to cracking when drilled parallel to the laminations in the shell materials. In most cases the cracking did not split the nuclei but a weakened zone adjacent to the drill hole developed at the time of drilling, manifested as a sharp line of a colour different from the surrounding material, sometimes accompanied by a faint cracking sound. The fact that the MOP nuclei did not crack under similar treatment, and that there was no adverse effect from the colour of the underlying nucleus provided confidence in MOP as a substitute material.

5. SPAT COLLECTION

5.1 Background

The oysters used to produce cultured pearls are caught as mature animals off the Western Australian coast. The costs of catching oysters, the variability of catches experienced in the two years immediately prior to this study, and the uncertainty surrounding the recruitment of juvenile oysters to the fishery provided the justification for this research. Supply of oysters from a successful spat collecting programme would permit better planning through early knowledge of operable oyster stocks and would reduce pressure on the wild fishery.

The growth rate of spat is an important factor in the economic feasibility of obtaining oysters by spat collection. If they cannot be grown to operating size in 18 months they need to be kept for another 12 months before operation, incurring extra culture costs and delaying return on investment.

Rose et al. (1990) noted that a female oyster may produce up to 12 million ova per spawning and that seasonal spawnings appeared to have two peaks, with the main spawning at the beginning of the season and a secondary spawning at the end.

Normal fertilised eggs develop into larvae which are planktonic for a period of up to four weeks. As metamorphosis approaches, with consequent decrease in buoyancy, the larvae fall towards the bottom and begin to seek suitable substrate on which to settle. If a satisfactory surface is found, the spat attach by means of their byssus threads secreted by the byssus gland. If the substrate is unsatisfactory, complete metamorphosis can be delayed for up to several days to allow the animal a chance to find a better location.

Wada (1973) wrote that the material used in Japan for collection of *Pinctada fucata* spat consisted of branches of the Japanese cedar suspended from rafts at depths between 0.5 and 4.0 metres. Kafuku and Ikenoue (1983) wrote that pearl oyster spat in Japan are collected in devices deployed from the surface (normally from a raft) containing old nets and branches from the Japanese cedar as settlement materials. Frames covered with mesh are used as the main collecting device. Nayar et al. (1978) tested various spat settlement materials in a range of spat collector designs. The most productive materials were artificial twines and pearl oyster shells, with coir rope failing to catch any spat. The best spat collector design was found to be a circular or square fame covered with nylon mesh. Lintilhac (1985) described a number of different settlement media for spat of the black lip pearl oyster including a native scrub plant called miki miki (*Pemphis acidula*), coconut fibre, awning material, foam rubber and offcuts from the production of rubber thong sandals in bags or nets, slung from surface longlines.

This experiment was planned to assess spat settlement substrates, collection devices and growout methods.

5.2 Materials and Methods

A variety of spat collector designs was tested in the first year of this experiment including Japanese-designed lantern nets, Canadian and French scallop spat collectors, New Zealand mussel spat ropes and several new designs. Factors considered were the catching power of the collectors, the labour content of their construction, deployment and recovery and the costs of the construction materials. Features which excluded, as far as possible, predators such as fish and crabs, were incorporated in the designs. The collectors tested, and their deployment, included steel-framed cylinders (Plate 7) covered with plastic mesh hung from surface and sub-surface longlines and star pickets on the bottom, pyramid-shaped devices covered with mesh (Plate 8) on the bottom, onion bags filled with collecting material hung from star pickets and longlines, car tyres on the bottom, and extruded plastic netting envelopes filled with a variety of collecting materials.

The collecting materials tested included pearl shell, scallop shell, concrete, plastic materials of various forms including extruded garden mesh and similar forms, twigs from local plants, coconut husk, rope (both artificial and natural fibre), fishing nets, Hardiflex board and beer cans. Subsequent research has attempted to identify the best configuration of the preferred materials for ease of sorting and survival of the spat.

After establishing the materials preferred by the oyster spat, groups of approximately ten collectors were deployed at intervals between October 1988 and May 1989 to establish the time of greatest settlement. Water temperatures were measured during this period.

After collection, the spat were kept in small plastic mesh bags placed in trays 3 m x 1 m, supported approximately 1 m above the bottom by star pickets. When they reached 70 mm DVM, they were transfered to grow-out panels hung on fences.

Experienced pearl technicians decided to operate on the spat if they had reached 90 mm DVM. Those spat which had reached operable size were operated on in early September, 1990.

5.3 Results

5.3.1 Collector Design and Collecting Material

The collector design which caught the most spat was a cylinder constructed from reinforcing steel covered with either prawn mesh or extruded plastic mesh. The data from other collectors were only adequate for providing indications of spat preferences for settlement substrates and are therefore not used for statistical analysis. The final collector dimensions used were 500 mm diameter and 1500 mm high; they were hung up between two star pickets driven into the sea floor. Grow-out trays filled with collecting material and supported by 4 star pickets driven into the sea floor performed adequately, as did onion bags suspended from star pickets or sub-surface longlines. Square-based pyramids (Plate 8), designed to be deployed like lobster pots, also performed adequately but were less efficient in terms of catch per unit cost of construction. The design tested also required securing with a star picket by divers due to the force of water currents and so were no more cost effective than the cylinders in terms of operation costs; this requirement could change with the use of a different design. Other collector designs, including various lightly built lantern nets, were unsuited to Broome conditions tending to collapse under the force of the strong currents after fouling developed on them. The open and unprotected spat collectors (French Discs) used in the NSW edible oyster industry (Holliday, 1985) are totally unsuited to the Broome situation due to the excessive development of fouling, high currents and lack of protection from crabs and fish. The preferred cylindrical design performed adequately when suspended from star pickets near the bottom. However, the requirement for divers to deploy and recover them is expensive.

The best settlement media were old fishing nets, particularly prawn and shark nets, but some other materials including frayed polypropylene and polyethylene rope (Plate 9), extruded plastic meshes and woven meshes of various artificial polymers were also adequate.

5.3.2 Timing of Spawning and Spat-fall

Spat yields from collectors deployed at various times are shown in Table 10 and Appendix 5. Those deployed on 8 February 1989 had the highest yield but those deployed on 28 March 1989 also collected well.

TABLE 10 SPAT SETTLEMENT TIME SERIES

DEPLOYMENT DATE	NO. OF COLLECTORS	AVERAGE SPAT	SD	SPAT PER LITRE
20/10/88	20	6.65	3.73	0.0229
25/11/88	18	7.94	3.63	0.0274
8/2/89	9	54.44	19.57	0.1396
28/2/89	3	26.67	18.45	0.0684
28/3/89	20	36.05	15.83	0.0924

Comparison of the settlement data with local water temperatures (Figure 6) indicates that spawning activity of the adult oysters, and therefore yield of the collectors, is possibly related to temperature and corresponds to the two peaks in spawning referred to by Rose et al. (1990).

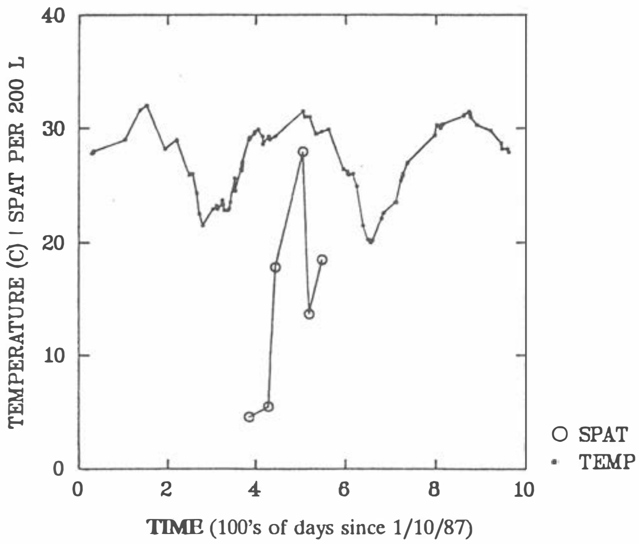
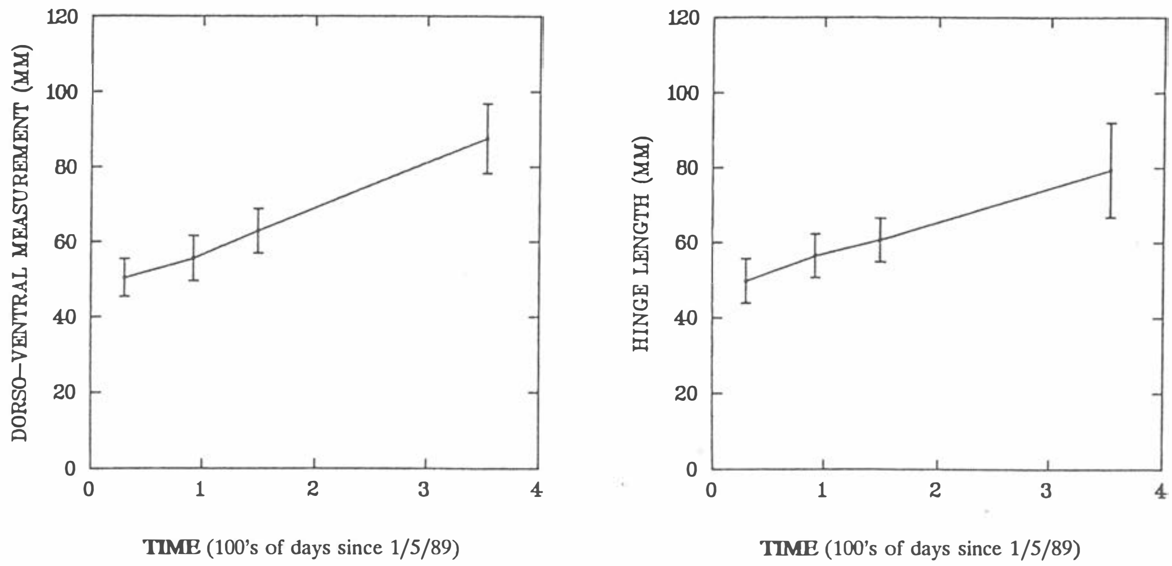


FIGURE 6 TEMPERATURE AND SPAT SETTLEMENT

5.3.3 Spat Growth Rates

Growth rates of spat (Figure 7 and Appendix 6) during the first culture trials show that growth in dorso-ventral and hinge length dimensions is almost identical between ages 6 months and 18 months. Growth rates vary greatly between individual spat with the range increasing with time. Only about 25 percent of the spat grew to operable size by 18 months from settlement.



Bars are standard deviations

FIGURE 7 SPAT GROWTH RATES

Predation was a problem while the spat were in the trays. Crabs killed approximately 20 percent of the spat in trays left un-inspected for long periods. Overcrowding seemed to cause high mortalities in some trays; over 90 percent of the spat in one tray died when left for a long period without attention. There was no evidence of crab predation in that tray and the spat had reached at least 65 mm, by which size they are almost immune to crab attack.

Excessive delay in harvesting the spat from the collectors led to deformations in the shells due to the lack of space for free growth (Plate 10).

The technicians found that oysters less than 105 mm DVM were difficult to operate on because their tissues are soft raising the likelihood of nucleus rejection. Also, only small nuclei can be inserted into them resulting in pearls of low value.

5.4 Discussion

The use of artificial settlement devices and media for collecting juvenile pearl oysters has been shown possible. The economics depend on costs of collecting them, catch-rate and costs of growing them to operable size. In order to compete with wild shell capture, it would be necessary to build, deploy and recover spat collectors, and on-grow the spat to operating size for less than the current cost per shell. For this purpose, it is desirable to establish the precise timing of pearl oyster spawning or, at least, the environmental conditions for high spat settlements.

To be able to accept the smallest industry-acceptable nucleus at first operation (6.5 - 7.0 mm) the grow-out conditions need to be conducive to producing oysters no less than 105 mm DVM within 18 months or the first operations will need to be delayed until the oysters are two and a half years old.

Spat collection is not considered likely to affect the wild population levels on the basis that it enhances the survival of juvenile oysters through the provision of extra habitat which provides security from predation (observations by Broome Pearls research staff were that "only occasional" wild pearl oysters were found on the Broome Pearls farm in the vicinity of the spat collectors which produced over 1500 spat in the space of a few months).

6. GENERAL DISCUSSION AND FURTHER STUDIES

The research topics in this study were chosen at a time when there was little published information from the Western Australian pearl industry and, at the same time, a perceived need for research on a wide range of subjects. It was therefore decided to address a wide range of issues simultaneously rather than to try to guess which was the most important. Subsequent changes to some of the farming practices have lessened the importance of some of the chosen subjects, while others have become more important. The results of this programme have highlighted some topics which are in need of further research, and at the same time identified those which are not likely to yield useful results.

The practice of turning the oysters after the operation to insert a nucleus did not increase the value of pearls. The unexpectedly high variances in the values of pearls from this experiment meant that the numbers of pearls produced could not allow adequate confidence in determining whether a difference existed between the treatments tested. It was decided therefore to repeat the experiment comparing a number of turning regimes using larger sample sizes. An experiment using five groups of approximately 800 oysters was established in 1990 and will conclude in 1992. The results will be published and copies sent to all industry members.

Shell cleaning did not increase the value of pearls but, for reasons of culture equipment integrity and maintenance, it is necessary to maintain the oysters and associated equipment in a clean state. In terms of pearls produced, fence culture was better than bottom longline or A-frame culture; Broome Pearls Pty Ltd uses fences exclusively as the oyster culture method.

An injection of menthol dissolved in seawater has the potential to reduce post-operative mortalities in difficult-to-open pearl oysters; dosage rates need to be established for the prevailing environmental and physiological conditions.

It is possible to produce good quality pearls using a mantle tissue implant taken from the oyster being operated on, thereby eliminating the need to kill 4 percent of the quota. This technique would mean, however, that the technicians could not select the sacrificial oysters for their nacre colour, a parameter widely believed to influence the colour of pearls. Higher mortality rates amongst the self implant oysters may also reduce the benefits of this practice.

The production of nuclei from mother-of-pearl has been proved possible. The technique is based on existing methods. The physical parameters of the nucleus material considered important to the quality of pearls do not appear to vary significantly from the "normal" nuclei. Of concern, however, is the possibility that other shell types, eg. giant clams, may be used as nucleus materials despite reported fears that they may crack when drilled. The recent appearance in Australia of shell beads from a number of different sources increases that concern. Further work assessing the suitability of the various shell types as nucleus materials is considered to be of a high priority in light of the ramifications of the potential failure by some pearls during drilling. Broome Pearls Pty Ltd has initiated a research programme which will investigate the suitability of giant clam shell nuclei, mother-of-pearl shell nuclei, Korean nuclei (which may be clam shell), and New Zealand nuclei (which are claimed to be made from Unionidae shell). All parameters considered important will be assessed including hardness, brittleness, thermal expansion, colour influence and physical performance. The results will be published and sent to all industry members. It is considered to be of great importance that the customers are aware of the nucleus types used in the Australian south sea pearls and that those nuclei have been proved to perform at least to the levels achieved by the imported nuclei.

Pearl oyster spat collection is technically possible. The feasibility of spat collection as a substitute for wild shell supply will depend on catch rates and spat growth rates. Further research is required to establish the timing of maximum spat-fall in order to maximise catch-rates. The growth-rates achieved in this study were not adequate to allow operation of the majority of the spat inside 18 months. It is generally felt that failure by the spat to achieve operable size within the second year of culture will make them unattractive as a substitute for the quota-controlled wild oysters which currently provide the stock for pearl culture. The costs of a further year's culturing would not, however, be likely to affect significantly the feasibility of utilising special spat quotas recently discussed by the industry controlling body. Further research is required in an attempt to achieve the minimum operable size during the second year of growth.

During the research programme it became apparent that there is an incomplete understanding of the factors which contribute to the development, and particularly the quality, of a cultured pearl. Operation techniques, shell health, mantle tissue quality and many other subtle factors are likely to contribute significantly to the final quality of a pearl. The observed repeatability of pearl characteristics between first and second pearls from the same pearl sac indicate that there is likely to be a significant contribution made by the tissue component of the pearl sac. It is therefore the intention of Broome Pearls Pty Ltd to carry out research into the histological characteristics of the pearl sac and their relationships to blemishes on the skins of cultured pearls. The study will be done in association with the University of Western Australia Zoology Department.

The study reported on in this document and those referred to in this section will contribute to the development of a better understanding of pearl culture. There are many other areas of research which could also help the pearl companies to understand their industry better, with consequent improvement in their performance. This type of research should be considered not only desirable but fundamental to the continued success of Australia's south sea pearl industry.

ACKNOWLEDGMENTS

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The work was also supported by the M G Kailis Group of Companies of which Broome Pearls Pty Ltd is a wholly-owned subsidiary. Company funds, infrastructure, financial services and other assistance helped in the successful completion of the research programme. The ongoing encouragement and guidance provided by Dr Patricia Kailis, Chairman of the Research and Development Committee, is gratefully acknowledged. Special thanks must go to the technicians who had to endure the sometimes difficult requests from the research staff, and to members of the field staff of Broome Pearls Pty Ltd who assisted throughout the study. Chris Richards, Broome Pearls Pty Ltd's Research Officer, contributed significantly in all aspects of the studies.

Professor Terry Pyle from the Materials Engineering Department of Curtin University of Technology provided valuable assistance and advice in the testing and assessment of pearl nucleus materials. Members of the Western Australian Department of Fisheries research staff assisted at various stages; these include Mr Rand Dybdahl who provided reference material and equipment for spat grow-out trials, Dr Lindsay Joll who provided a critique of the final manuscript, and Mr Nick Caputi who provided valuable advice on statistical analysis of results. Mr Ray Perry, a former Division chief of CSIRO, and Dr Trevor White, consultants to the M G Kailis Group, assisted during the preparation and editing of the report.

PLATES

PLATE 1 The net panel is almost universally used in Australia as a means of carrying pearl oysters

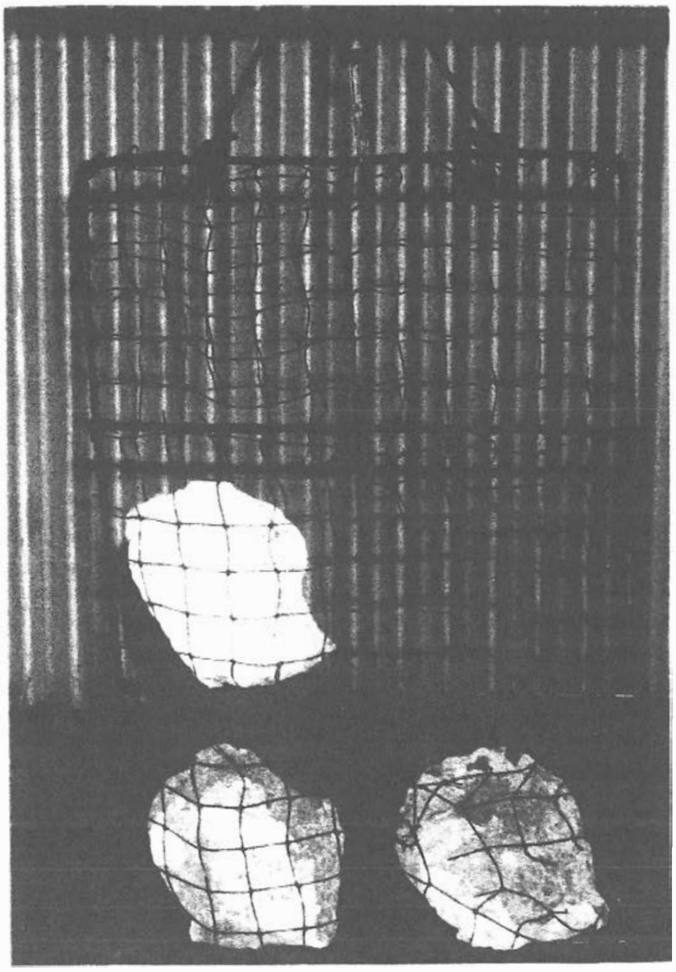

PLATE 2 A basket of pegged shells ready for the pearl technician.

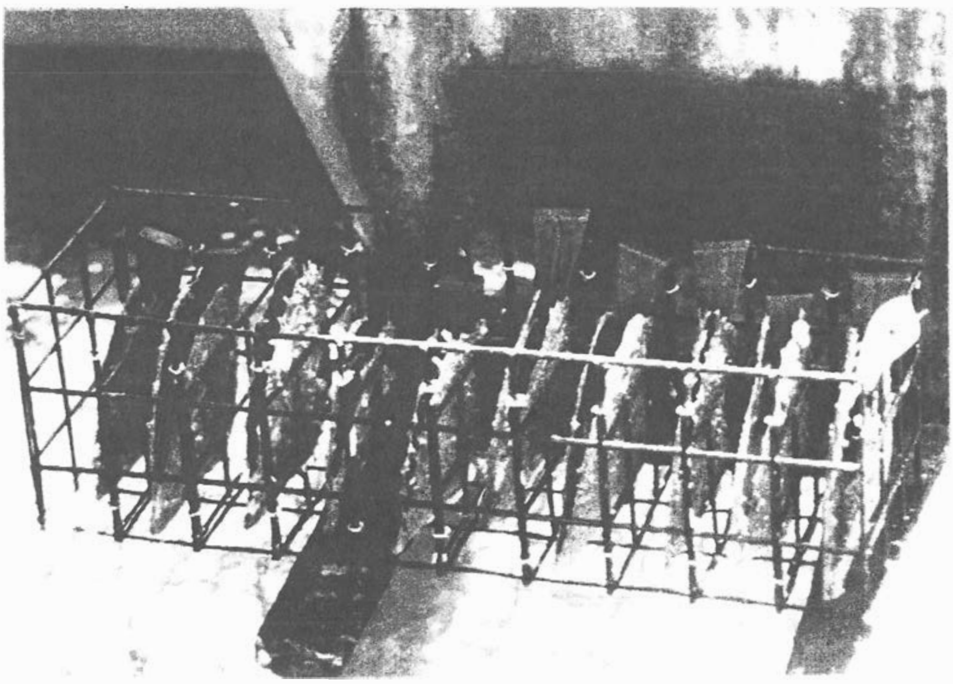

PLATE 3 A pearl technician performs an operation on a pearl oyster.

PLATE 4 The grey/brown nuclei are Mother-of-Pearl, the white nuclei are imported from Japan.

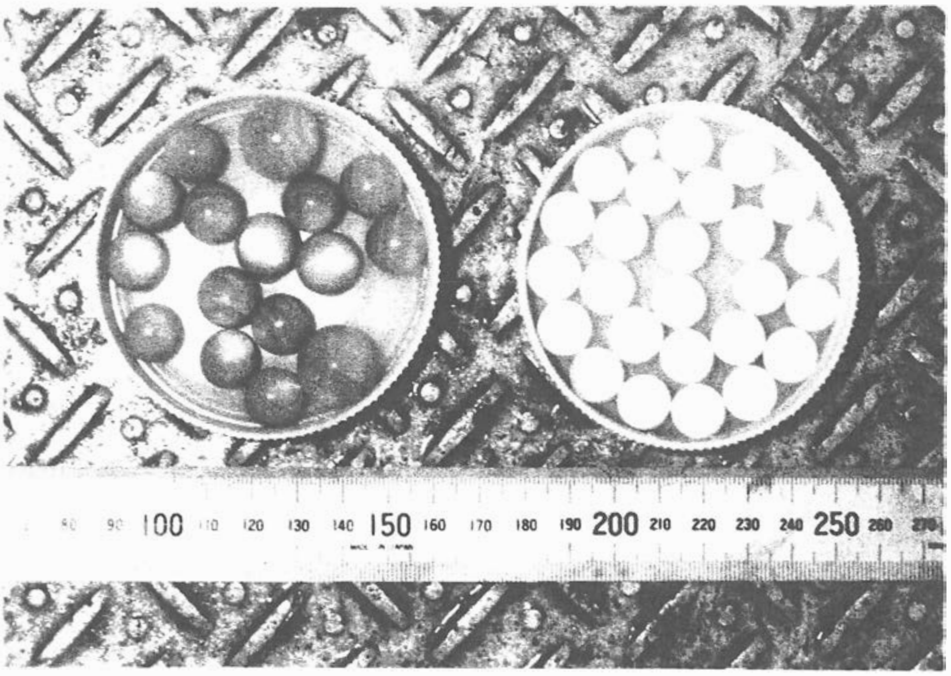

PLATE 5 The modified bead-grinding machine made the nuclei in this study.

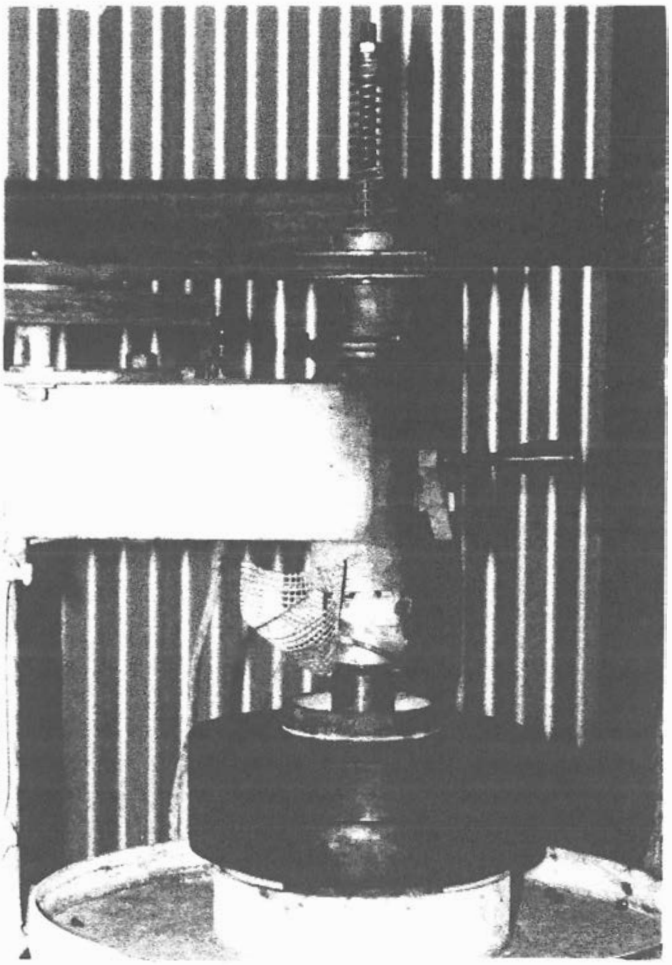

PLATE 6 The grooved plate which was adapted from Taburiaux (1985) to produce nuclei.

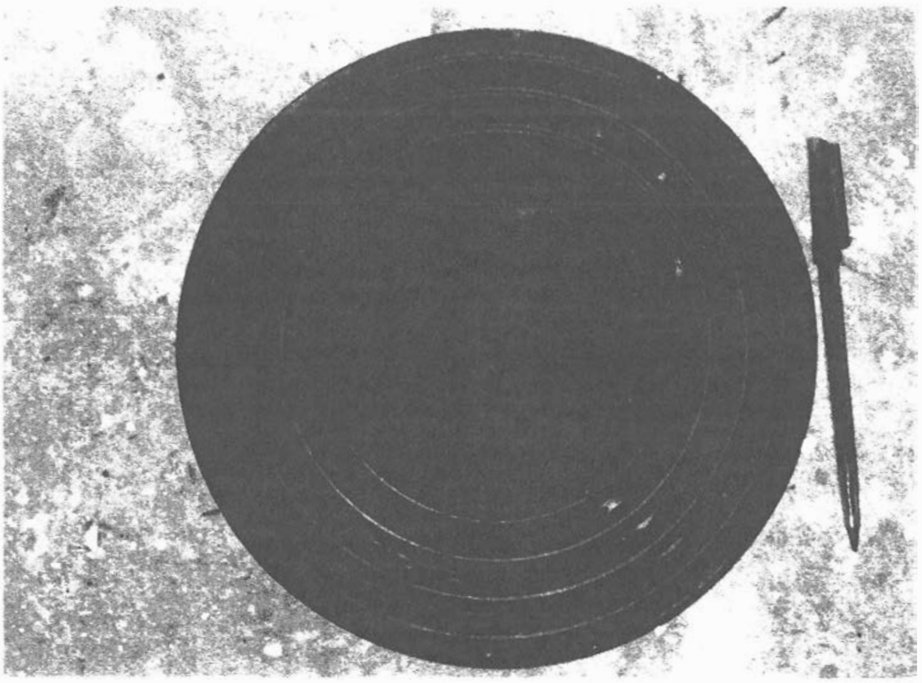

PLATE 7 The cylindrical spat collector was the most effective design tested.

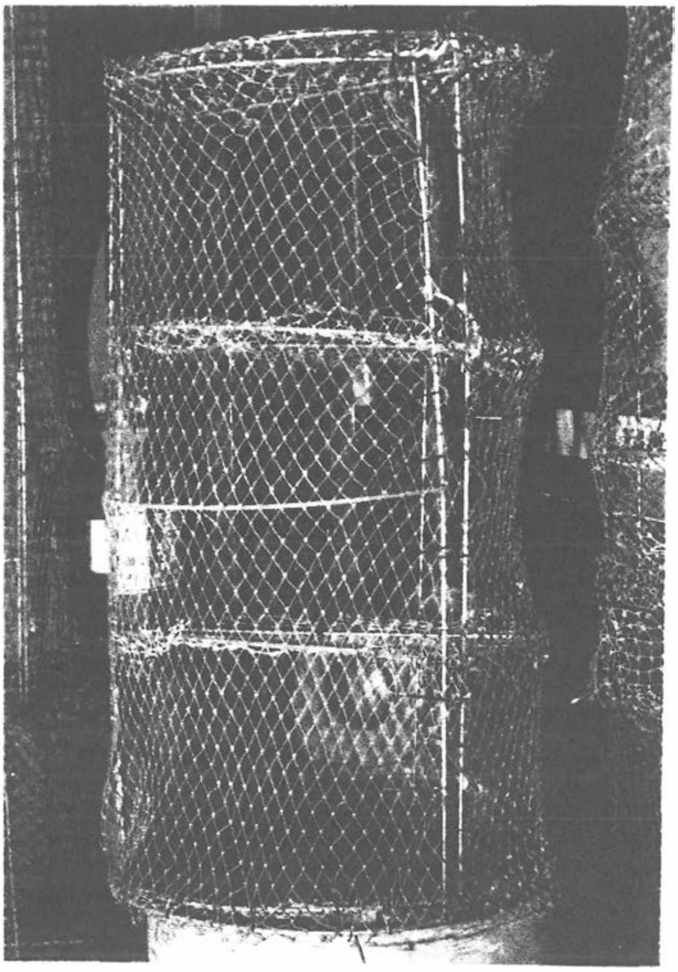

PLATE 8 The square-based pyramid was the easiest spat collector to use but had limitations due to its small volume and relatively high costs.

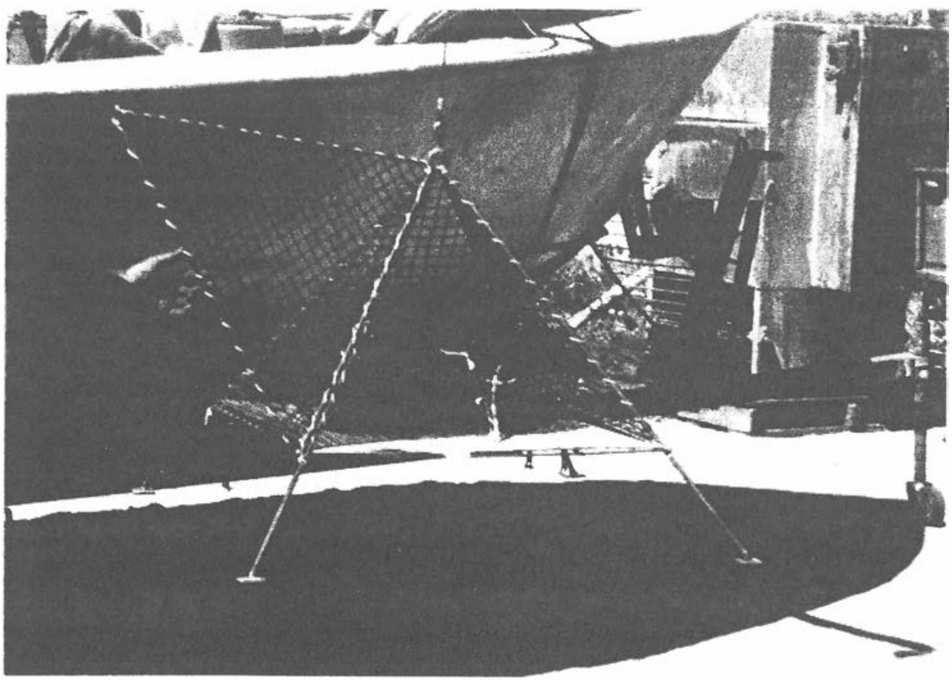

PLATE 9 A healthy 6 month old spat settled on a piece of frayed rope.

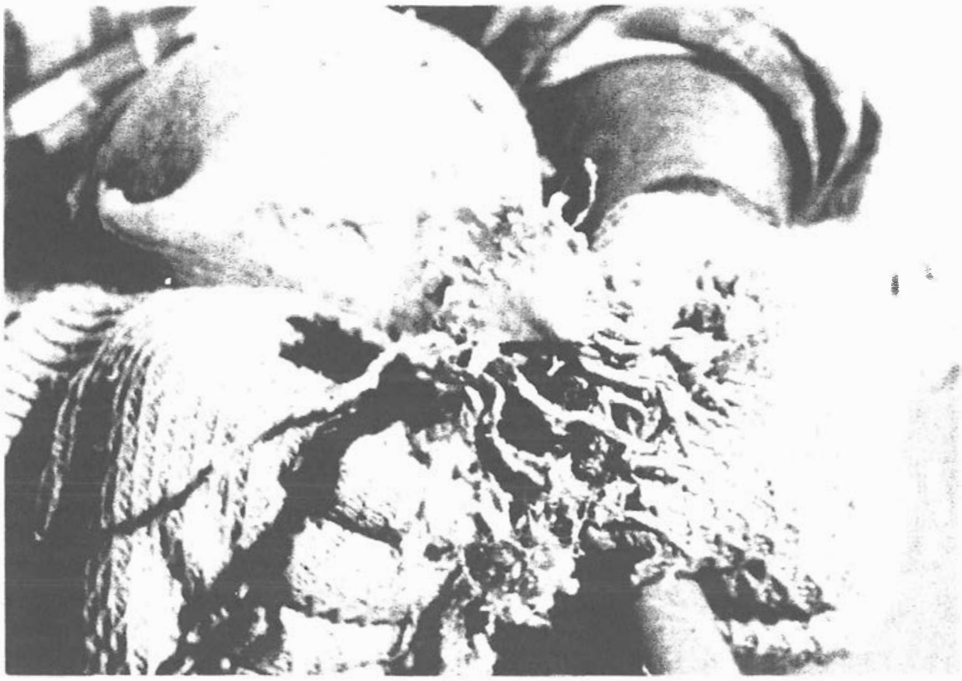

PLATE 10 Overgrown spat develop malformations at the growing edge of the shell.

REFERENCES

Achari, G.P.K. (1982). Project Profile for Pearl Culture. *Seafood Export J.* 16 (1), 9-11.

Alagarswami, K. (1970). Pearl Culture In Japan And Its Lessons For India. *Proc. Symp. Mollusca,* 3, 975-993. Mar. Biol. Ass. India.

Alagarswami, K. (1974). Development of Cultured Pearls in India. *Curr. Sci.* 43 (7), 205-207.

Alagarswami, K. (1975). Preliminary Study on the Growth of Cultured Pearls. *Ind. J. Fish.*, 22 (1-2), 300-303.

Alagarswami, K., and Chellam, A. (1976). On Fouling and Boring Organisms and Mortality of Pearl Oysters in the Farm at Veppalodai, Gulf of Mannar. *Ind. J. Fish.* 23 (1 & 2), 11-22.

Alagarswami, K., and Chellam, A. (1977). Change of Form and Dimensional Relationship in Pearl Oyster *Pinctada fucata* from Gulf of Mannar. *Ind. J. Fish.* 24 (1-2), 1-14.

Arakawa, K. Y. (1980). Prevention and Removal of Fouling on Cultured Oysters - A Handbook for Growers. *Maine Sea Grant Tech. Rep.* 56. (Sea Grant Pubs. Univ. Maine) 38 pp.

Dix, T. G. (1973). Histology Of The Mantle And Pearl Sac Of The Pearl Oyster Pinctada Maxima (Lamellibranchia). *J. Malacol. Soc. Aust.* 2, (4), 365-375.

George, C. D. (1967). The Cultured Pearl - Its History and Development to the Present Day. *Lap. J. Amer.* Jul-Sep., 1-16.

George, C. D. (1969). Techniques of Pearl Cultivation. *South Pac. Bull.* Fourth Quarter, 13-19.

Hancock, D. A. (1973). Kuri Bay Pearls Some of Finest in the World. *Aust. Fish.* 32 (4), 11-12.

Holliday, J. E. (1985). Current Oyster Spat Research in NSW. *Aust. Fish.* 44 (3), 24-26.

Hollyer, J. (1984). Pearls - Jewels of the Sea. *Infofish Mark. Dig.* 5, 32-34.

Kafuku, T., and Ikenoue, H. (1983). Modern Methods of Aquaculture in Japan. *Devs. Aquaculture Fish. Sci.* 11, 161-171.

Kunz, G. F., and Stevenson, C. H. (1908). The Book of the Pearl; The History, Art, Science And Industry Of The Queen Of Gems. (The Century Co. N.Y.) 548 pp.

Kuriyan, G.K. (1951). The Fouling Organisms of Pearl Oyster Cages. *J. Bombay Nat. Hist. Soc.* 49, 90-92.

Lintilhac, J-P. (1985). Black Pearls Of Tahiti. (Royal Tahitian Pearl Book). Papeete, Tahiti) 109 pp.

Mohammad, M-B. M. (1975). Relationship Between Biofouling and Growth of the Pearl Oyster *Pinctada Fucata* (Gould) in Kuwait, Arabian Gulf. *Hydrobiologia* 51 (2), 129-138.

Nayar, K. N., Mahadevan, S., Ramadoss, K., Sundaram, N., and Rajan, C. T. (1978). Experimental Study of the Settlement and Collection of Pearl Oyster Spat From Tuticorin Area. *Ind. J. Fish*. 25 (1 & 2), 246-252.

Roberts, R. B., and Rose, R. B. (1989). Evaluation of Some Shells for Use as Nuclei for Round Pearl Culture. *J. Shellfish Res*. 8 (2), 387-389.

Rose, R.A., Dybdahl, R.E., and Harders, S. (1990). Reproductive Cycle of the Western Australian Silverlip Pearl Oyster *Pinctada maxima* Jameson (Mollusca: Pteriidae). *J. Shellfish Res.* 9 (2), 261-272.

Scoones, R. J. S. (1988). An Overview of Pearl Oyster Culture in Western Australia. *Proc. First Aust. Shellfish Aquaculture Conf.*, 266-282, (Curtin Univ. Tech. Perth).

Taburiaux, J. (1985). Pearls - Their Origin, Treatment and Identification. (Chilton Book Company, PA, USA) 247 pp.

Taylor, M. L. (1985). The Pearling Industry of Western Australia 1850-1985. *Fish. Education Pub*. 3, 30 pp.

Tranter, D. J. (1957). Pearl Culture in Australia. *Aust. J. Sci.* 19 (6), 230-232.

Velu, M., Alagarswami, K., and Qasim, S. Z. (1973). Technique of Producing Spherical Shell Beads as Nuclei for Cultured Pearls. *Ind. J. Fish.* 20 (2), 672-676.

Wada, K., (1970). Cultured Pearl and its Structure. *Proc. Symp. Mollusca, Cochin, Jan 12-16, 1968 Part 3*, 972-975. (Mar. Biol. Soc. India).

Wada, K., (1973). Modern and Traditional Methods of Pearl Culture. *Underwater J.*, February, 28-33.

Ward, F. (1985). The Pearl. *Nat. Geog.* August, 1985, 193-222.

APPENDIX 1

SHELL TURNING

LIST OF ABBREVIATIONS AND EXPLANATIONS

TREAT	Turning treatment code: A = Not turned, oysters hung on culture equipment immediately after operating B = Not turned, left on the sea floor, and then hung up on day 25 C = Oysters rested for 7 days after operating, then turned every 3 days for 18 days, then hung up on day 25 D = Oysters rested for 7 days after operating, then turned every 2 days for 18 days, then hung up on day 25
PLSZ	Pearl size in millimetres, 0.5 mm size classes
GD	Pearl grade 1=top, 5=unmarketable; A partly subjective assessment of the quality of the pearl skin.
SHP	Pearl shape: R=round; SR=semi-round (a "slightly eccentric" pearl, but not eccentric enough to be a semi-baroque); SB=semi-baroque (ie only one axis of symmetry); BA=baroque (no axis of symmetry); K=keshi (seedless pearl ie. without a nucleus). NB. Some of the shape classifications are subjective and it is not possible to put succinct limits on the qualifying criteria for each shape.
VAL	Export value in $Aus.

TREAT	PLSZ	GD	SHP	VAL
A	10.0	5	BA	0
A	14.5	5	BA	0
A	11.5	5	SB	0
A	9.5	5	SR	0
A	11.5	2	R	770
A	12.5	3	SR	700
A	11.5	3	SR	440
A	12.5	2	SR	1300
A	11.0	4	SR	125
A	10.0	4	SR	30
A	10.5	2	SR	250
A	10.5	1	SR	330
A	10.5	2	SR	250
A	10.5	3	SR	135
A	10.0	2	SB	125
A	9.5	4	SR	30
A	14.5	2	SB	1750
A	12.5	1	SB	1350
A	12.5	4	SB	600
A	11.0	3	SB	425
A	10.5	3	SB	125
A	10.0	2	SB	100
A	10.5	2	SB	235
A	11.0	1	SB	700
A	11.0	4	SB	290
A	11.0	3	SB	425
A	10.0	1	SB	130
A	10.0	1	SB	260
A	12.0	1	BA	355
A	10.5	2	BA	55
A	10.0	1	BA	75
A	11.5	4	BA	20
A	11.5	3	BA	35
A	11.0	3	BA	75
A	9.0	4	BA	10
A	10.0	4	BA	12
A	10.0	3	BA	12
A	10.0	3	BA	12
A	10.0	3	BA	12
A	10.5	4	BA	12
A	9.5	3	BA	10
A	9.5	3	BA	10
A	10.0	3	BA	12
A	10.0	3	BA	12
A	9.5	2	BA	10
A	8.5	4	BA	5
B	10.5	2	BA	55
B	9.0	3	BA	10
B	11.5	1	BA	330
B	12.0	2	BA	240
B	11.5	2	BA	175
B	10.0	2	BA	40
B	10.5	3	BA	12
B	10.0	3	BA	40
B	11.5	5	BA	0
B	9.5	5	BA	0
B	10.5	1	BA	110
B	10.0	1	BA	75
B	10.0	1	BA	75
B	10.5	1	BA	110
B	10.5	3	BA	12
B	10.5	2	BA	55
B	9.5	2	SB	10
B	12.0	1	SB	1100

SHELL CLEANING AND CULTURE METHOD

LIST OF ABBREVIATIONS AND EXPLANATIONS

EXP	Experiment code
SN	Shell number
DVM1	Original dorso-ventral measurement (mm)
HD1	Original hinge depth measurement (mm)
DVM4	Final dorso-ventral measurement (mm)
HD4	Final hinge depth measurement (mm)
PLSZ	Pearl size (mm); seedless pearls were given a nominal size of 2 mm
GD	Pearl grade 1 = top, 5 = unmarketable
SHP	Pearl shape: R = round; SR = semi-round; SB = semi-baroque; BA = baroque; K = keshi (seedless pearl)
VAL	Pearl export value in $Aus.
WGHT	Pearl weight in grams
DS	Deep or shallow water (8m or 15m) for the culture period
CM	Culture method: 0 = fence culture; 1 = bottom longline; 2 = A-frame
CR	Cleaning regime: 0 = no cleaning; 1 = once per year; 2 = twice per year; 3 = three time per year; 4 = no cleaning, regular shocking to simulate cleaning without removal of fouling organisms.

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
A	812	155	8.0	178	12.5	10.5	2	BA	55	1.92	S	1	0
A	813	165	10.5	181	14.1	0.0	0		0	0.00	S	1	0
A	814	154	6.7	175	11.0	2.0	6	K	1	0.46	S	1	0
A	815	177	9.4	195	12.6	9.0	5	BA	0	1.32	S	1	0
A	818	176	7.0	181	17.9	10.0	4	BA	40	1.81	S	1	0
A	819	171	9.5	190	13.3	10.0	5	BA	0	1.57	S	1	0
A	821	163	7.2	182	13.8	10.0	5	BA	0	1.87	S	1	0
A	823	168	6.3	180	12.4	0.0	0		0	0.00	S	1	0
A	825	173	11.3	182	11.5	2.0	6	K	1	0.59	S	1	0
A	827	169	6.2	179	13.3	0.0	0		0	0.00	S	1	0
A	830	162	5.4	180	11.5	0.0	0		0	0.00	S	1	0
A	832	168	8.8	179	13.0	9.0	5	BA	0	1.22	S	1	0
A	833	176	10.1	196	11.4	2.0	6	K	1	0.18	S	1	0
A	834	159	7.3	179	12.4	0.0	0		0	0.00	S	1	0
A	835	170	10.3	172	13.2	0.0	0		0	0.00	S	1	0
A	838	129	6.8	155	12.4	0.0	0		0	0.00	S	1	0
A	839	172	8.2	201	9.3	10.5	4	SB	75	1.85	S	1	0
A	841	170	9.6	175	9.8	0.0	0		0	0.00	S	1	0
A	842	180	7.8	187	12.4	0.0	0		0	0.00	S	1	0
A	843	149	3.2	180	8.0	0.0	0		0	0.00	S	1	0
A	845	182	7.2	196	12.1	2.0	6	K	1	0.16	S	1	0
A	847	170	7.2	180	13.1	9.0	5	SB	0	1.21	S	1	0
A	849	150	8.6	171	13.8	2.0	6	K	1	0.53	S	1	0
A	850	162	8.3	186	13.7	10.5	3	BA	135	1.90	S	1	0
A	851	140	5.2	171	9.3	0.0	0		0	0.00	S	1	0
A	854	192	11.5	200	16.4	0.0	0		0	0.00	S	1	0
A	856	160	9.5	170	13.6	0.0	0		0	0.00	S	1	0
A	860	148	3.6	160	10.4	0.0	0		0	0.00	S	1	0
A	862	144	5.1	175	8.1	0.0	0		0	0.00	S	1	0
A	863	163	5.6	189	9.3	10.0	5	R	0	0.00	S	1	0
A	864	134	4.6	173	10.0	0.0	0		0	0.00	S	1	0
A	867	143	5.9	164	12.0	9.0	5	R	0	0.96	S	1	0
A	950	0	0.0	0	0.0	10.0	5	BA	0	1.88	S	1	0
A	951	0	0.0	0	0.0	9.5	4	SR	30	1.34	S	1	0
A	952	0	0.0	0	0.0	11.5	3	BA	75	2.77	S	1	0
A	953	0	0.0	0	0.0	10.0	5	BA	0	1.78	S	1	0
A	954	0	0.0	0	0.0	10.0	2	BA	40	1.53	S	1	0
A	955	0	0.0	0	0.0	10.0	5	BA	0	1.62	S	1	0
A	956	0	0.0	0	0.0	2.0	6	K	1	0.11	S	1	0
A	957	0	0.0	0	0.0	2.0	6	K	1	0.41	S	1	0
B	163	164	11.5	183	15.5	0.0	0		0	0.00	S	2	0
B	164	164	5.2	187	13.5	0.0	0		0	0.00	S	2	0
B	165	169	8.8	181	14.9	0.0	0		0	0.00	S	2	0
B	166	176	10.3	181	15.2	0.0	0		0	0.00	S	2	0
B	168	165	11.8	188	16.5	11.5	3	BA	75	2.43	S	2	0
B	169	159	7.5	184	10.5	0.0	0		0	0.00	S	2	0
B	170	170	8.9	185	12.2	11.0	3	BA	75	2.15	S	2	0
B	172	168	9.0	172	13.6	2.0	6	K	1	0.19	S	2	0
B	173	169	8.1	178	14.3	0.0	0		0	0.00	S	2	0
B	174	160	10.7	160	14.2	2.0	6	K	1	0.20	S	2	0
B	175	161	7.5	189	10.1	0.0	0		0	0.00	S	2	0
B	177	183	13.0	201	19.0	0.0	0		0	0.00	S	2	0
B	178	159	8.6	183	14.3	0.0	0		0	0.00	S	2	0
B	179	167	11.2	180	12.4	9.5	5	BA	0	1.56	S	2	0
B	180	160	8.6	178	11.1	13.0	5	BA	0	2.70	S	2	0
B	182	170	6.7	178	11.2	0.0	0		0	0.00	S	2	0
B	184	169	12.1	194	13.8	0.0	0		0	0.00	S	2	0
B	185	172	8.9	189	15.9	0.0	0		0	0.00	S	2	0
B	187	174	6.0	179	13.2	0.0	0		0	0.00	S	2	0
B	190	152	7.0	172	9.7	0.0	0		0	0.00	S	2	0
B	191	170	7.3	183	15.0	2.0	6	K	1	0.97	S	2	0
B	192	148	6.8	163	10.0	0.0	0		0	0.00	S	2	0
B	194	154	9.7	190	13.2	2.0	6	K	1	0.22	S	2	0
B	195	165	10.9	178	18.3	11.0	2	BA	165	2.03	S	2	0
B	196	158	10.0	173	11.7	0.0	0		0	0.00	S	2	0

TREAT	PLSZ	GD	SHP	VAL
B	11.5	1	SB	880
B	10.5	1	SB	260
B	11.5	2	SB	660
B	12.0	2	SB	950
B	11.0	1	SB	700
B	10.5	1	SB	260
B	10.5	2	SB	235
B	10.5	3	SB	125
B	10.5	3	SB	125
B	10.5	1	SB	260
B	9.5	3	SB	40
B	10.0	1	BA	75
B	10.5	3	SB	60
B	12.0	5	SB	0
B	11.0	2	SB	650
B	11.0	4	SB	290
B	9.5	3	SB	40
B	9.0	3	SB	25
B	10.0	1	SB	130
B	11.5	2	SR	600
B	12.0	2	SB	950
B	11.0	4	SB	290
B	10.0	2	SR	140
B	10.0	2	SB	100
B	10.5	3	SB	125
C	11.5	1	SR	800
C	10.5	1	SR	330
C	10.5	2	SR	250
C	10.0	1	SR	195
C	10.0	3	SR	95
C	10.0	3	SR	95
C	12.0	2	BA	240
C	12.0	3	BA	80
C	12.0	4	BA	30
C	12.5	4	BA	30
C	12.0	3	BA	75
C	12.0	3	BA	75
C	10.5	2	BA	55
C	9.5	2	BA	10
C	10.0	2	BA	55
C	10.5	1	BA	110
C	9.5	3	BA	10
C	9.0	2	BA	10
C	10.5	2	BA	55
C	10.5	2	BA	55
C	13.0	1	SB	1425
C	13.5	3	SB	825
C	13.0	3	SB	880
C	12.0	3	SB	660
C	13.0	2	SB	1200
C	12.5	2	SB	1250
C	13.0	3	SB	880
C	12.5	3	SB	990
C	11.0	4	SB	290
C	11.0	3	SB	425
C	12.0	4	SB	350
C	11.5	3	SB	425
C	12.0	4	SB	350
C	11.0	2	SB	650
C	11.0	3	SB	425
C	11.0	2	SB	650
C	11.5	1	SB	880
C	10.5	3	SB	125
C	9.5	2	SB	40
C	11.5	4	SB	40

TREAT	PLSZ	GD	SHP	VAL
C	11.0	4	SB	135
C	10.5	3	SB	125
C	11.5	3	SB	440
C	11.5	2	SB	660
C	11.0	3	SB	425
C	10.5	3	SB	125
C	10.5	3	SB	125
C	9.5	3	SB	40
C	10.5	4	SB	75
C	9.5	3	SB	40
C	10.0	3	SB	60
C	9.5	3	SB	40
C	9.0	1	SB	25
D	8.5	5	SB	0
D	8.5	5	BA	0
D	9.0	5	BA	0
D	9.0	5	BA	0
D	9.0	5	BA	0
D	8.5	5	BA	0
D	11.0	2	SR	330
D	10.5	3	SR	135
D	10.0	4	SR	40
D	10.0	2	SR	140
D	10.0	3	SR	95
D	13.5	3	SB	825
D	11.0	1	SB	700
D	11.0	1	SB	700
D	11.0	2	SB	650
D	10.0	2	SB	100
D	11.0	4	SB	135
D	11.5	2	SB	660
D	12.5	2	SB	1250
D	10.0	1	SB	260
D	11.0	3	SB	425
D	10.5	2	SB	235
D	10.0	2	SB	100
D	11.5	3	SB	425
D	10.5	3	SB	125
D	10.5	3	SB	125
D	9.5	3	SB	40
D	9.5	3	SB	40
D	9.5	2	SB	40
D	9.0	1	SB	40
D	10.5	2	SB	235
D	11.5	4	BA	235
D	10.5	2	BA	55
D	8.5	4	BA	5
D	12.5	1	BA	400
D	11.0	3	BA	75
D	11.0	5	BA	0
D	13.0	4	BA	40
D	9.5	4	BA	35
D	9.5	4	BA	35
D	10.0	2	BA	40
D	9.5	2	BA	10

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
F	624	155	6.6	169	10.0	0.0	0		0	0.00	D	2	0
F	627	174	8.5	190	14.6	0.0	0		0	0.00	D	2	0
F	628	160	8.4	192	12.3	0.0	0		0	0.00	D	2	0
F	629	142	5.9	180	12.8	2.0	6	K	1	0.61	D	2	0
F	634	138	6.0	170	8.4	0.0	0		0	0.00	D	2	0
F	636	160	8.3	169	10.3	10.0	5	SB	0	1.25	D	2	0
F	637	167	7.2	176	11.0	0.0	0		0	0.00	D	2	0
F	638	165	12.2	192	15.9	0.0	0		0	0.00	D	2	0
F	639	187	10.1	204	15.8	0.0	0		0	0.00	D	2	0
F	641	173	4.7	201	12.9	0.0	0		0	0.00	D	2	0
F	643	164	7.7	175	12.5	2.0	6	K	1	0.31	D	2	0
F	645	175	7.5	181	14.9	0.0	0		0	0.00	D	2	0
F	646	148	6.7	149	12.1	0.0	0		0	0.00	D	2	0
F	647	189	11.0	209	15.4	0.0	0		0	0.00	D	2	0
F	949	0	0.0	0	0.0	10.5	3	BA	25	2.03	D	2	0
G	705	163	5.7	199	9.5	0.0	0		0	0.00	D	0	0
G	706	168	9.3	190	13.0	9.5	5	N	0	0.80	D	0	0
G	709	152	5.2	160	8.4	0.0	0		0	0.00	D	0	0
G	710	140	9.2	165	10.8	0.0	0		0	0.00	D	0	0
G	714	140	6.0	150	9.2	2.0	6	K	1	0.19	D	0	0
G	718	140	4.1	174	8.2	0.0	0		0	0.00	D	0	0
G	720	141	7.3	173	11.9	11.5	3	SR	440	1.63	D	0	0
G	724	148	7.9	179	12.0	0.0	0		0	0.00	D	0	0
G	725	140	4.3	172	10.0	0.0	0		0	0.00	D	0	0
G	729	150	8.5	180	11.2	11.5	4	SB	135	2.06	D	0	0
G	730	158	5.3	178	9.7	0.0	0		0	0.00	D	0	0
G	731	148	7.3	174	13.6	11.5	3	SB	440	2.24	D	0	0
G	733	136	4.7	161	7.8	0.0	0		0	0.00	D	0	0
G	738	174	8.0	210	11.4	0.0	0		0	0.00	D	0	0
G	739	169	8.6	187	12.3	0.0	0		0	0.00	D	0	0
G	740	164	9.1	179	12.9	0.0	0		0	0.00	D	0	0
G	741	166	5.4	195	9.4	13.5	1	BA	450	4.01	D	0	0
G	747	141	7.3	154	10.2	0.0	0		0	0.00	D	0	0
G	749	165	10.3	193	11.5	9.0	5	BA	0	1.18	D	0	0
G	753	150	6.5	185	11.8	0.0	0		0	0.00	D	0	0
G	754	164	8.3	182	11.4	0.0	0		0	0.00	D	0	0
G	755	115	4.5	169	10.7	2.0	6	K	1	0.82	D	0	0
G	758	146	5.1	179	11.1	11.5	3	SB	440	2.84	D	0	0
G	759	136	4.7	172	9.2	0.0	0		0	0.00	D	0	0
G	760	139	4.9	164	10.0	9.5	1	SR	75	1.94	D	0	0
G	762	147	7.8	186	13.0	0.0	0		0	0.00	D	0	0
G	763	155	6.6	179	11.4	0.0	0		0	0.00	D	0	0
G	764	168	9.0	175	10.2	0.0	0		0	0.00	D	0	0
G	768	175	13.1	188	14.5	0.0	0		0	0.00	D	0	0
G	769	164	6.9	174	10.3	10.5	2	BA	55	1.85	D	0	0
G	771	140	4.2	160	8.6	0.0	0		0	0.00	D	0	0
G	772	155	7.6	174	8.7	0.0	0		0	0.00	D	0	0
G	967	0	0.0	0	0.0	8.5	3	BA	10	1.37	D	0	0
G	968	0	0.0	0	0.0	10.5	2	SR	250	1.82	D	0	0
G	969	0	0.0	0	0.0	10.0	1	SB	130	1.63	D	0	0
G	970	0	0.0	0	0.0	2.0	6	K	1	1.01	D	0	0
G	971	0	0.0	0	0.0	10.5	5	BA	0	2.26	D	0	0
H	361	162	11.0	179	14.6	10.5	4	SB	75	1.85	D	1	2
H	363	183	10.8	196	13.9	0.0	0		0	0.00	D	1	2
H	366	169	9.4	181	12.4	10.0	5	R	0	1.50	D	1	2
H	367	160	7.2	183	11.4	0.0	0		0	0.00	D	1	2
H	368	163	7.5	179	11.7	0.0	0		0	0.00	D	1	2
H	369	182	10.4	185	15.7	11.0	3	SB	250	2.31	D	1	2
H	372	138	6.8	179	11.3	2.0	6	K	1	0.43	D	1	2
H	375	142	5.7	160	11.4	0.0	0		0	0.00	D	1	2
H	376	156	10.7	165	11.7	9.5	1	BA	35	1.51	D	1	2
H	380	155	5.3	188	11.9	0.0	0		0	0.00	D	1	2
H	381	153	7.5	181	13.3	0.0	0		0	0.00	D	1	2
H	383	168	5.8	179	12.7	0.0	0		0	0.00	D	1	2
H	384	160	6.4	185	12.0	0.0	0		0	0.00	D	1	2

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
H	385	125	4.5	169	12.1	9.5	1	BA	35	1.65	D	1	2
H	387	163	7.3	170	13.2	9.5	5	BA	0	1.51	D	1	2
H	389	150	4.5	169	12.7	0.0	0		0	0.00	D	1	2
H	391	152	7.4	167	15.1	9.5	3	SR	30	1.30	D	1	2
H	394	150	5.2	165	10.8	0.0	0		0	0.00	D	1	2
H	395	168	10.7	189	16.1	0.0	0		0	0.00	D	1	2
H	399	167	5.1	187	12.2	0.0	0		0	0.00	D	1	2
H	401	162	11.1	189	15.3	9.0	5	SR	0	1.13	D	1	2
H	402	159	9.2	194	16.0	0.0	0		0	0.00	D	1	2
H	403	159	8.1	189	13.1	0.0	0		0	0.00	D	1	2
H	404	140	5.6	175	10.9	0.0	0		0	0.00	D	1	2
H	406	145	5.2	166	10.5	10.5	4	SB	35	2.00	D	1	2
H	407	161	5.5	183	9.3	0.0	0		0	0.00	D	1	2
H	408	165	7.8	187	11.4	9.5	5	BA	0	1.41	D	1	2
H	410	160	7.6	178	11.8	0.0	0		0	0.00	D	1	2
H	411	152	6.3	175	12.3	9.0	2	SB	40	1.27	D	1	2
H	415	157	8.3	181	11.5	2.0	6	K	1	0.00	D	1	2
H	416	165	8.6	189	14.2	0.0	0		0	0.00	D	1	2
H	418	155	7.0	168	12.8	11.0	4	SR	75	1.98	D	1	2
H	419	163	7.1	188	11.3	10.0	2	SB	100	1.77	D	1	2
H	420	141	8.5	164	13.4	8.5	5	SB	0	1.13	D	1	2
H	972	0	0.0	0	0.0	9.5	1	BA	35	1.52	D	1	2
I	651	148	4.5	179	11.2	0.0	0		0	0.00	S	2	1
I	652	170	9.0	176	11.2	2.0	6	K	1	0.28	S	2	1
I	653	166	9.5	187	10.3	0.0	0		0	0.00	S	2	1
I	654	171	7.6	196	8.8	10.0	5	BA	0	0.00	S	2	1
I	655	135	5.3	155	10.3	0.0	0		0	0.00	S	2	1
I	660	170	9.9	201	13.9	9.0	4	SB	12	1.49	S	2	1
I	664	165	6.5	193	9.7	0.0	0		0	0.00	S	2	1
I	665	130	5.0	168	15.1	9.5	2	BA	35	1.44	S	2	1
I	667	169	6.9	190	10.0	0.0	0		0	0.00	S	2	1
I	670	145	4.2	184	10.3	0.0	0		0	0.00	S	2	1
I	672	159	7.1	176	10.7	0.0	0		0	0.00	S	2	1
I	673	155	7.2	174	11.3	0.0	0		0	0.00	S	2	1
I	675	154	7.4	168	12.3	0.0	0		0	0.00	S	2	1
I	676	147	6.2	179	10.4	10.0	4	SB	40	1.53	S	2	1
I	677	146	5.9	174	8.9	0.0	0		0	0.00	S	2	1
I	679	166	7.6	180	12.1	0.0	0		0	0.00	S	2	1
I	680	128	4.0	171	12.2	2.0	6	K	1	0.00	S	2	1
I	681	145	6.3	172	8.7	0.0	0		0	0.00	S	2	1
I	682	174	9.8	189	11.2	0.0	0		0	0.00	S	2	1
I	683	149	6.3	167	12.7	11.5	2	BA	175	1.94	S	2	1
I	685	150	8.3	162	13.9	0.0	0		0	0.00	S	2	1
I	686	152	5.2	195	9.3	0.0	0		0	0.00	S	2	1
I	687	147	6.9	178	12.8	2.0	6	K	1	0.00	S	2	1
I	688	141	7.2	170	10.9	0.0	0		0	0.00	S	2	1
I	689	138	6.5	169	11.1	0.0	0		0	0.00	S	2	1
I	691	162	10.1	175	14.3	0.0	0		0	0.00	S	2	1
I	693	168	8.8	191	13.0	0.0	0		0	0.00	S	2	1
I	694	161	5.8	190	11.0	0.0	0		0	0.00	S	2	1
I	696	138	6.5	153	9.2	2.0	6	K	1	0.25	S	2	1
I	697	184	5.8	194	10.2	0.0	0		0	0.00	S	2	1
I	698	151	9.5	172	13.2	0.0	0		0	0.00	S	2	1
I	702	157	7.8	178	9.0	0.0	0		0	0.00	S	2	1
I	704	155	6.8	184	9.5	9.5	3	BA	25	1.55	S	2	1
I	973	0	0.0	0	0.0	10.0	3	BA	12	1.86	S	2	1
I	974	0	0.0	0	0.0	10.0	3	BA	12	1.81	S	2	1
I	975	0	0.0	0	0.0	9.0	5	SB	0	1.15	S	2	1
I	976	0	0.0	0	0.0	9.5	2	SB	40	1.40	S	2	1
J	302	168	10.4	195	14.3	10.5	4	BA	12	1.55	S	2	3
J	304	174	6.7	183	11.8	0.0	0		0	0.00	S	2	3
J	305	172	10.3	196	16.3	0.0	0		0	0.00	S	2	3
J	306	146	5.4	175	8.5	2.0	6	K	1	0.19	S	2	3
J	307	160	7.6	181	9.4	0.0	0		0	0.00	S	2	3
J	308	152	7.1	185	12.6	0.0	0		0	0.00	S	2	3

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
J	310	135	7.0	174	10.9	0.0	0		0	0.00	S	2	3
J	312	130	4.5	182	10.7	0.0	0		0	0.00	S	2	3
J	313	151	6.7	172	13.7	0.0	0		0	0.00	S	2	3
J	314	138	8.5	171	14.1	0.0	0		0	0.00	S	2	3
J	315	165	9.6	176	14.4	2.0	6	K	1	0.28	S	2	3
J	316	135	8.5	165	13.6	0.0	0		0	0.00	S	2	3
J	320	156	7.6	182	13.0	0.0	0		0	0.00	S	2	3
J	322	138	7.4	148	11.8	0.0	0		0	0.00	S	2	3
J	324	146	4.7	177	10.7	9.5	2	SB	40	1.50	S	2	3
J	325	168	9.6	180	11.6	0.0	0		0	0.00	S	2	3
J	326	139	6.0	178	10.9	9.5	5	BA	0	1.09	S	2	3
J	329	148	6.0	168	9.2	0.0	0		0	0.00	S	2	3
J	330	175	9.1	199	11.4	0.0	0		0	0.00	S	2	3
J	332	178	7.8	200	14.4	0.0	0		0	0.00	S	2	3
J	336	170	7.7	192	13.0	9.0	4	BA	10	1.48	S	2	3
J	337	157	8.5	162	11.5	0.0	0		0	0.00	S	2	3
J	338	159	8.0	170	12.0	10.5	2	SB	55	1.97	S	2	3
J	339	149	7.0	180	12.6	0.0	0		0	0.00	S	2	3
J	342	178	12.5	194	13.5	10.0	2	BA	40	1.57	S	2	3
J	346	152	4.5	187	9.6	0.0	0		0	0.00	S	2	3
J	349	147	3.8	161	8.2	0.0	0		0	0.00	S	2	3
J	350	127	6.1	146	12.0	0.0	0		0	0.00	S	2	3
J	351	117	6.8	145	14.5	0.0	0		0	0.00	S	2	3
J	352	169	10.1	198	17.3	0.0	0		0	0.00	S	2	3
J	354	169	8.0	180	13.4	9.5	3	BA	25	1.71	S	2	3
J	355	145	5.8	189	10.0	0.0	0		0	0.00	S	2	3
J	356	128	7.1	164	13.4	9.0	4	BA	10	0.97	S	2	3
J	359	145	3.6	184	10.8	9.0	4	BA	10	1.48	S	2	3
J	360	152	8.3	175	13.7	2.0	6	K	1	0.13	S	2	3
J	977	0	0.0	0	0.0	11.0	1	SB	700	2.28	S	2	3
J	978	0	0.0	0	0.0	9.0	5	SB	0	1.06	S	2	3
J	979	0	0.0	0	0.0	10.5	2	BA	55	1.92	S	2	3
J	980	0	0.0	0	0.0	9.5	3	SB	40	1.80	S	2	3
J	981	0	0.0	0	0.0	10.5	1	SB	260	1.73	S	2	3
J	982	0	0.0	0	0.0	10.5	3	SB	235	2.15	S	2	3
J	983	0	0.0	0	0.0	11.5	5	BA	0	2.67	S	2	3
K	479	149	4.0	167	8.1	0.0	0		0	0.00	S	0	2
K	482	161	8.5	181	13.0	0.0	0		0	0.00	S	0	2
K	500	128	5.5	165	11.0	2.0	6	K	1	0.25	S	0	2
K	509	153	6.3	180	9.0	9.5	4	BA	12	1.76	S	0	2
L	421	150	5.2	176	9.2	0.0	0		0	0.00	S	2	2
L	423	153	5.4	181	10.8	11.0	2	BA	165	1.79	S	2	2
L	424	145	6.0	175	15.4	0.0	0		0	0.00	S	2	2
L	425	169	8.2	188	13.3	2.0	6	K	1	0.15	S	2	2
L	426	140	6.6	159	11.3	0.0	0		0	0.00	S	2	2
L	427	160	8.0	182	9.3	9.5	5	BA	0	1.32	S	2	2
L	429	134	2.8	169	9.2	0.0	0		0	0.00	S	2	2
L	431	141	5.7	180	12.8	0.0	0		0	0.00	S	2	2
L	432	141	5.1	145	8.5	0.0	0		0	0.00	S	2	2
L	434	157	6.6	190	12.2	0.0	0		0	0.00	S	2	2
L	437	150	9.5	150	12.0	10.0	5	BA	0	1.51	S	2	2
L	440	149	4.7	163	11.0	0.0	0		0	0.00	S	2	2
L	441	151	8.3	170	9.0	0.0	0		0	0.00	S	2	2
L	442	141	5.7	173	10.8	0.0	0		0	0.00	S	2	2
L	443	136	5.3	168	11.7	0.0	0		0	0.00	S	2	2
L	449	154	8.4	178	9.6	0.0	0		0	0.00	S	2	2
L	451	163	6.9	190	15.1	0.0	0		0	0.00	S	2	2
L	453	156	5.4	175	15.0	0.0	0		0	0.00	S	2	2
L	455	170	8.3	182	13.7	0.0	0		0	0.00	S	2	2
L	459	151	6.7	171	15.8	10.5	2	BA	55	1.84	S	2	2
L	460	160	8.1	187	13.2	0.0	0		0	0.00	S	2	2
L	462	153	7.5	183	10.8	10.5	5	BA	0	1.45	S	2	2
L	463	143	5.7	178	11.8	0.0	0		0	0.00	S	2	2
L	464	142	4.2	180	9.7	11.0	2	BA	165	2.08	S	2	2
L	468	149	4.2	175	10.4	0.0	0		0	0.00	S	2	2

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
L	469	145	6.9	164	12.5	0.0	0		0	0.00	S	2	2
L	471	169	6.5	185	10.3	0.0	0		0	0.00	S	2	2
L	472	153	5.6	194	8.9	0.0	0		0	0.00	S	2	2
L	984	0	0.0	0	0.0	10.5	3	SB	125	1.69	S	2	2
L	985	0	0.0	0	0.0	9.5	5	SB	0	1.37	S	2	2
L	986	0	0.0	0	0.0	10.0	5	BA	0	1.45	S	2	2
M	716	142	5.8	175	10.0	11.5	3	BA	75	2.80	D	0	2
M	746	169	8.3	184	15.3	0.0	0		0	0.00	D	0	2
M	772	135	5.2	173	9.2	0.0	0		0	0.00	D	0	2
M	773	154	8.7	175	11.3	0.0	0		0	0.00	D	0	2
M	774	183	8.8	210	12.1	0.0	0		0	0.00	D	0	2
M	775	150	7.2	169	12.7	0.0	0		0	0.00	D	0	2
M	776	170	12.5	188	17.4	0.0	0		0	0.00	D	0	2
M	777	145	8.5	179	10.7	0.0	0		0	0.00	D	0	2
M	780	150	7.8	175	12.9	12.5	1	SB	1350	3.04	D	0	2
M	782	164	11.1	195	15.7	0.0	0		0	0.00	D	0	2
M	783	149	8.1	180	10.9	0.0	0		0	0.00	D	0	2
M	785	145	4.8	152	11.2	0.0	0		0	0.00	D	0	2
M	788	151	7.4	180	10.1	0.0	0		0	0.00	D	0	2
M	789	150	6.2	182	12.0	0.0	0		0	0.00	D	0	2
M	790	170	8.5	204	12.6	11.0	1	BA	210	2.24	D	0	2
M	791	159	9.6	189	14.2	0.0	0		0	0.00	D	0	2
M	796	140	5.4	164	8.1	2.0	6	K	1	0.32	D	0	2
M	797	166	8.6	179	10.3	0.0	0		0	0.00	D	0	2
M	798	145	4.1	174	11.0	0.0	0		0	0.00	D	0	2
M	799	140	4.3	173	8.4	0.0	0		0	0.00	D	0	2
M	802	154	7.5	174	10.3	0.0	0		0	0.00	D	0	2
M	803	140	8.6	150	11.5	0.0	0		0	0.00	D	0	2
M	805	140	6.5	169	7.9	11.5	4	SB	290	2.57	D	0	2
M	806	137	4.4	190	9.5	0.0	0		0	0.00	D	0	2
M	807	165	9.4	184	11.9	0.0	0		0	0.00	D	0	2
M	809	150	6.3	170	11.3	0.0	0		0	0.00	D	0	2
M	811	154	6.4	159	10.9	0.0	0		0	0.00	D	0	2
M	947	0	0.0	0	0.0	9.0	5	R	0	0.93	D	0	2
M	987	0	0.0	0	0.0	8.5	5	R	0	1.01	D	0	2
M	988	0	0.0	0	0.0	12.5	3	BA	80	3.96	D	0	2
M	989	0	0.0	0	0.0	8.5	5	R	0	0.88	D	0	2
M	990	0	0.0	0	0.0	2.0	6	K	1	0.68	D	0	2
N	561	137	4.7	174	12.4	0.0	0		0	0.00	D	2	2
N	564	148	5.4	158	9.3	9.0	3	SB	25	1.37	D	2	2
N	568	148	3.7	186	8.8	2.0	6	K	1	0.38	D	2	2
N	570	138	4.1	175	8.8	12.0	2	BA	950	3.18	D	2	2
N	571	150	6.4	191	11.0	0.0	0		0	0.00	D	2	2
N	574	148	4.1	175	10.3	0.0	0		0	0.00	D	2	2
N	575	149	5.0	171	9.8	0.0	0		0	0.00	D	2	2
N	577	136	3.2	153	13.1	0.0	0		0	0.00	D	2	2
N	578	157	9.3	189	13.8	2.0	6	K	1	0.19	D	2	2
N	579	150	7.4	195	11.6	0.0	0		0	0.00	D	2	2
N	581	146	9.9	178	13.4	0.0	0		0	0.00	D	2	2
N	586	143	4.5	183	9.9	0.0	0		0	0.00	D	2	2
N	587	163	7.6	203	12.4	10.0	3	SB	60	1.83	D	2	2
N	588	158	11.5	165	12.2	0.0	0		0	0.00	D	2	2
N	589	159	8.1	188	8.9	0.0	0		0	0.00	D	2	2
N	590	163	8.3	180	14.9	0.0	0		0	0.00	D	2	2
N	592	130	3.8	179	10.1	9.0	2	BA	10	1.50	D	2	2
N	593	168	8.9	189	13.3	0.0	0		0	0.00	D	2	2
N	594	157	6.8	188	12.7	2.0	6	K	1	0.43	D	2	2
N	595	163	8.6	184	12.0	0.0	0		0	0.00	D	2	2
N	596	166	7.9	189	12.4	0.0	0		0	0.00	D	2	2
N	598	140	7.2	194	10.8	0.0	0		0	0.00	D	2	2
N	599	159	5.0	190	10.7	10.0	3	BA	12	1.94	D	2	2
N	991	0	0.0	0	0.0	11.0	4	BA	20	2.30	D	2	2
N	992	0	0.0	0	0.0	12.0	3	SB	440	3.08	D	2	2
N	993	0	0.0	0	0.0	11.5	2	BA	175	3.89	D	2	2
N	994	0	0.0	0	0.0	10.5	2	SB	235	1.81	D	2	2

EXP	SN	DVM1	HD1	DVM4	HD4	PLSZ	GD	SHP	VAL	WGHT	DS	CM	CR
O	515	146	5.4	173	12.4	12.5	3	SB	990	2.87	D	2	4
O	517	169	11.9	183	15.1	11.0	4	SB	135	2.37	D	2	4
O	518	166	4.0	178	8.0	0.0	0		0	0.00	D	2	4
O	519	154	5.7	182	11.2	11.5	4	SB	290	2.43	D	2	4
O	520	153	6.7	173	10.3	0.0	0		0	0.00	D	2	4
O	521	140	4.5	173	9.1	0.0	0		0	0.00	D	2	4
O	523	158	5.5	162	13.5	0.0	0		0	0.00	D	2	4
O	524	135	5.3	137	9.5	0.0	0		0	0.00	D	2	4
O	525	164	7.2	184	10.8	0.0	0		0	0.00	D	2	4
O	526	150	5.0	183	10.0	12.0	4	SB	350	2.21	D	2	4
O	527	167	6.4	175	8.8	0.0	0		0	0.00	D	2	4
O	528	130	3.6	146	9.9	0.0	0		0	0.00	D	2	4
O	533	176	7.7	188	12.1	11.0	4	SB	135	2.37	D	2	4
O	534	141	5.5	175	11.6	0.0	0		0	0.00	D	2	4
O	536	173	7.7	179	12.1	10.5	4	SR	30	1.68	D	2	4
O	537	180	8.7	192	12.8	0.0	0		0	0.00	D	2	4
O	539	175	7.6	183	14.5	0.0	0		0	0.00	D	2	4
O	542	139	5.3	158	10.9	0.0	0		0	0.00	D	2	4
O	543	160	7.2	183	11.0	9.0	5	BA	0	1.29	D	2	4
O	546	152	9.0	168	11.0	0.0	0		0	0.00	D	2	4
O	547	152	6.4	189	11.3	0.0	0		0	0.00	D	2	4
O	548	155	6.3	177	13.8	2.0	6	K	1	0.53	D	2	4
O	549	149	5.5	174	11.1	9.0	5	SB	0	1.36	D	2	4
O	552	172	6.1	188	10.3	8.5	5	N	0	0.58	D	2	4
O	995	0	0.0	0	0.0	10.0	1	SB	130	1.75	D	2	4

APPENDIX 3

MANTLE TISSUE COMPATIBILITY

LIST OF ABBREVIATIONS AND EXPLANATIONS

EXP	Source of mantle implant : "D" = different oyster, "S" = same oyster
PLSZ	Pearl size (mm), 0.5 mm classes
GD	Pearl grade 1 = top, 5 = unmarketable
SHP	Pearl shape: R = round; SR = semi-round; SB = semi-baroque; BA = baroque; K = keshi (seedless pearl)
VAL	Pearl Export Value in $Aus.

EXP	PLSZ	GD	SHP	VAL
D	10.5	1	BA	110
D	11.0	2	BA	125
D	11.5	2	BA	110
D	12.0	3	SR	440
D	11.5	3	R	440
D	10.5	2	BA	55
D	9.5	4	BA	10
D	14.0	3	SB	750
D	12.0	1	BA	440
D	11.5	3	BA	75
D	10.0	4	SB	75
D	10.5	2	BA	55
D	11.0	1	BA	210
D	10.5	2	BA	55
D	12.0	3	BA	75
D	10.0	5	BA	0
D	10.0	5	BA	0
D	9.5	5	BA	0
D	12.0	5	BA	0
D	2.0	6	K	1
D	2.0	6	K	1
D	2.0	6	K	1

EXP	PLSZ	GD	SHP	VAL
S	11.0	3	SR	440
S	10.5	4	SB	75
S	14.0	3	SB	750
S	12.0	2	SB	950
S	13.0	4	SB	475
S	8.0	1	SB	50
S	10.0	3	SB	60
S	10.0	3	SB	55
S	11.5	3	BA	75
S	11.0	1	BA	210
S	12.0	3	BA	75
S	11.5	3	BA	75
S	9.0	1	BA	35
S	10.5	2	BA	55
S	10.0	1	BA	75
S	12.0	5	SB	0
S	9.5	5	BA	0
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1
S	2.0	6	K	1

APPENDIX 4

NUCLEUS HARDNESS TESTS

LIST OF ABBREVIATIONS AND EXPLANATIONS

AUS 1	Dark band in the mother-of-pearl nucleus
AUS 2	Light band in the mother-of-pearl nucleus
IMP 1	Dark band in the imported nucleus
IMP 2	Light band in the imported nucleus

All figures are Vickers Hardness Numbers (VHN)

Each reading is a single hardness test. Each nucleus was tested three times in each band.

AUS 1	AUS 2	IMP 1	IMP 2
235	171	183	158
226	198	195	180
213	195	198	204
224	179	199	185
211	196	204	192
234	178	187	208
194	238	144	156
206	214	153	150
203	222	142	148
165	247	214	198
173	252	223	213
168	242	218	222
248	154	260	227
214	139	197	217
202	176	208	211
209	142	164	199
207	167	176	182
229	162	177	191
205	188	220	237
195	203	228	223
197	214	217	232
263	235	185	193
253	243	169	187
248	228	193	202
165	191	148	158
174	198	145	163
198	206	137	147
224	234	176	143
236	218	187	172
221	224	208	158

APPENDIX 5

SPAT COLLECTION RAW DATA

LIST OF ABBREVIATIONS AND EXPLANATIONS

COL # Serial number of collector

DAYIN Date of deployment

SPAT Number of spat found in collector

COL #	DAYIN	SPAT
21	20/10/88	4
18	20/10/88	8
2	20/10/88	7
14	20/10/88	1
10	20/10/88	3
17	20/10/88	9
7	20/10/88	12
16	20/10/88	16
13	20/10/88	4
19	20/10/88	7
4	20/10/88	10
5	20/10/88	7
8	20/10/88	7
20	20/10/88	3
1	20/10/88	4
3	20/10/88	5
15	20/10/88	3
12	20/10/88	4
9	20/10/88	6
6	20/10/88	13
24	15/12/88	7
40	15/12/88	3
36	15/12/88	2
37	15/12/88	11
27	15/12/88	6
39	15/12/88	10
30	15/12/88	6
25	15/12/88	10
32	15/12/88	5
41	15/12/88	17
34	15/12/88	9
43	15/12/88	8
28	15/12/88	12
44	15/12/88	4
33	15/12/88	4
31	15/12/88	9

COL #	DAYIN	SPAT
26	15/12/88	9
23	15/12/88	11
50	08/02/89	78
53	08/02/89	90
54	08/02/89	36
51	08/02/89	54
61	08/02/89	26
57	08/02/89	37
59	08/02/89	66
56	08/02/89	48
52	08/02/89	55
61	28/02/89	48
62	28/02/89	29
9	28/02/89	3
73	28/03/89	34
67	28/03/89	44
68	28/03/89	33
74	28/03/89	59
79	28/03/89	22
82	28/03/89	36
71	28/03/89	26
80	28/03/89	29
77	28/03/89	31
70	28/03/89	40
76	28/03/89	41
62	28/03/89	40
60	28/03/89	8
83	28/03/89	57
63	28/03/89	14
66	28/03/89	25
65	28/03/89	39
72	28/03/89	56
15	28/03/89	15
69	28/03/89	72

APPENDIX 6

SPAT GROWTH DATA

LIST OF ABBREVIATIONS AND EXPLANATIONS

DATE	Date Of Measurement
SN	Spat Tag Number
DVM	Dorso-ventral Measurement (mm)
HL	Hinge Length (mm)

DATE	SN	DVM	HL
30/05/89	1	53	56
30/05/89	2	47	48
30/05/89	3	53	51
30/05/89	4	49	43
30/05/89	5	53	55
30/05/89	6	60	50
30/05/89	7	58	51
30/05/89	8	60	64
30/05/89	9	56	58
30/05/89	10	48	45
30/05/89	11	42	34
30/05/89	12	45	43
30/05/89	13	55	56
30/05/89	14	54	55
30/05/89	15	56	50
30/05/89	16	47	50
30/05/89	17	47	50
30/05/89	18	57	48
30/05/89	19	46	45
30/05/89	20	47	48
30/05/89	21	43	42
30/05/89	22	45	49
30/05/89	23	50	53
30/05/89	24	46	46
30/05/89	25	48	50
30/05/89	26	51	52
30/05/89	27	48	50
31/07/89	1	56	57
31/07/89	2	55	53
31/07/89	3	57	61
31/07/89	4	62	54
31/07/89	5	57	58
31/07/89	6	63	65
31/07/89	7	59	54
31/07/89	8	62	64
31/07/89	9	65	65
31/07/89	10	55	55
31/07/89	11	49	52
31/07/89	12	48	44
31/07/89	13	59	57
31/07/89	14	66	69
31/07/89	15	64	60
31/07/89	16	49	63

DATE	SN	DVM	HL
31/07/89	17	50	54
31/07/89	18	63	59
31/07/89	19	47	50
31/07/89	20	52	55
31/07/89	21	48	44
31/07/89	22	48	49
31/07/89	23	54	54
31/07/89	24	52	52
31/07/89	25	52	55
31/07/89	26	57	55
31/07/89	27	49	51
26/09/89	1	56	63
26/09/89	2	58	60
26/09/89	3	70	59
26/09/89	4	76	69
26/09/89	5	70	54
26/09/89	6	66	71
26/09/89	7	67	66
26/09/89	8	67	66
26/09/89	9	65	68
26/09/89	10	66	58
26/09/89	11	59	55
26/09/89	12	52	56
26/09/89	13	56	54
26/09/89	14	69	68
26/09/89	15	70	63
26/09/89	16	53	52
26/09/89	17	63	58
26/09/89	18	62	66
26/09/89	19	59	54
26/09/89	20	58	59
26/09/89	21	49	48
26/09/89	22	59	57
26/09/89	23	63	56
26/09/89	24	61	57
26/09/89	25	64	69
26/09/89	26	71	59
26/09/89	27	64	53
18/04/90	1	78	68
18/04/90	2	98	102
18/04/90	3	101	98
18/04/90	4	83	70
18/04/90	5	73	63
18/04/90	6	100	78
18/04/90	7	0	0
18/04/90	8	94	86
18/04/90	9	88	84
18/04/90	10	95	99
18/04/90	11	94	90
18/04/90	12	0	0
18/04/90	13	86	85
18/04/90	14	85	78
18/04/90	15	105	94
18/04/90	16	87	84
18/04/90	17	92	77
18/04/90	18	88	79
18/04/90	19	92	87
18/04/90	20	85	72
18/04/90	21	70	50
18/04/90	22	87	65
18/04/90	23	90	85
18/04/90	24	75	69
18/04/90	25	85	81
18/04/90	26	0	0
18/04/90	27	70	62