COMMONWEALTH OF AUSTRALIA

COMMONWEALTH SCIENTIFIC & INDUSTRIAL RESEARCH ORGANIZATION

DIVISION OF FISHERIES & OCEANOGRAPHY

REPORT TO THE SOUTH PACIFIC COMMISSION ON AN INVESTIGATION OF THE BLACKLIP MOTHER-OF-PEARL OYSTER *PINCTADA MARGARITIFERA* (LINNAEUS) IN MANIHIKI, COOK ISLAND

By J. S. Hynd

Marine Biological Laboratory
Cronulla, Sydney
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INTRODUCTION

Pearl shell fishing has been, in the post-war period, an important source of income to the Cook Islands. In the years 1953 to 1957 it contributed an average of 25% in value of total exports. However the lagoon in Manihiki, which was the most productive fishing ground, has been closed since 1957 for conservational reasons and naturally the cutting off of this source of income has resulted in comparative hardship for many Cook Islanders.

For some years now the South Pacific Commission and the Cook Islands Administration have been actively interested in rehabilitating this industry. A number of successful transplantations of live pearl shell has been carried out by Mr H. Van Pel, Fisheries Officer of the S.P.C., and Mr Ron Powell, Fisheries Officer of the C.I.A. Mr Powell also started a series of experiments in Manihiki (Noakes 1959; Powell ms.) designed to show how the pearl oyster spat might be caught in large numbers so that they can be "farmed".

The C.S.I.R.O. Division of Fisheries & Oceanography has been engaged in research on pearl shell since 1948, and it was considered that the experience gained at the Pearl Shell Research Station at Thursday Island could help with the problem at Manihiki. The South Pacific Commission asked the Division to allow Mr Hynd to visit the Islands and advise on several aspects of the research and on management rules for the commercial fishery.

This report is based principally on data collected in a three month visit to Manihiki with Mr Powell in April-June 1959. It is intended to produce a further report in a year's time when the results are available of several experiments started during the above period and designed to run for 12 months.

PART I - THE FISHERY

HISTORY OF THE FISHERY

No records are available for the pre-war period but conversations with local residents brought out the fact that there had been no active fishery in the Cook Islands immediately pre-war. Further back the lagoons at Manihiki and Penrhyn had been known to produce pearl shell but it was impossible to obtain any accurate information on quantities or dates. However it was suggested that the fishery had lapsed for economic, not biological, reasons.

The post-war production of mother-of-pearl from Manihiki and Penrhyn is given in Table 1. Exports are given in Table 2. It will be seen that the production and export totals agree reasonably well, so the accuracy of the data may be accepted with confidence.

The production figures of M.O.P. for Manihiki are also graphed in Figure 1. Inspection shows that production increased steadily from 1945 to 1950 and stabilized at about the 300 ton level from 1951 to 1956. There are no data available on expenditure of effort to maintain this catch level but the more experienced divers stated in conversation that catch per man hour decreased severely over the years 1951 to 1956. In 1956 the lagoon was closed for conservational reasons. It was reopened in 1957 but the catch was not satisfactory (Anon.1958, p.30) so it was closed again in 1958 and 1959. Inspection by Mr Powell in 1958 showed that there were relatively few shells in the lagoon. There is no doubt that the decrease in production has been due to overfishing and that the lagoon cannot support an annual fishery of 300 tons.

The production figures for Penrhyn lagoon show that it has never contributed importantly to the yearly catch except in the years when Manihiki was closed.

TABLE I.

P. MARGARITIFERA, COOK ISLANDS

PRODUCTION STATISTICS, 1945-1958

Source - New Zealand Department of Island Territories,
Reports on the Cook, Niue and Tokelau Islands.

Year	M.O.P. Production - tons	
	Manihiki	Penrhyn
1945-46	10	Nil
1946-47	63	1
1947-48	89	15
1948-49	174	10
1949-50	228	20
1950-51	273	14
1951-52	380	25
1952-53	288	13
1953-54	294	15
1954-55	271	21
1955-56	351	31
1956-57	8*	29+
1957	213	27
1958	Nil‡	97
Totals	2634	304

Grand Total - 2938 tons.

*Lagoon closed in 1956

+Say 15 tons produced in last half of 1956

‡Lagoon closed in 1958.

TABLE 2.

P. MARGARITIFERA, COOK ISLANDS

EXPORT STATISTICS, 1942-1958

Source - New Zealand Department of Island Territories, Reports on the Cook, Niue and Tokelau Islands, and records of Customs Department, Cook Islands Administration.

Year	Quantity exported - tons	Value -£N.Z.	Price per ton -£N.Z.	Destination
1942	Nil			
1943	69	£3,113	£45	U.S.A.
1944	Nil			
1945	14	£711	£51	Unknown
1946	48	£12,410	£259	Unknown
1947	131	£24,842	£190	(100 tons N.Z. (23 tons Australia
1948	114	£13,941	£122	N.Z.
1949	288	£48,903	£170	U.S.A.
1950	313	£80,128	£256	U.S.A.
1951	459	£115,019	£251	U.S.A.
1952	301	£69,809	£232	(1 Italy, 5 Germany (222 U.S.A. (10 Aust., 63 N.Z.
1953	309	£71,747	£232	(103 N.Z., 189 U.S.A. (11 Italy, 5½ Aust. (½ India
1954	290	£74,203	£256	(220 U.S.A., 37 Italy (11 Germany, 15 Aust. (7 N.Z.
1955	242	£91,888	£380	(147 U.S.A., 26 Italy (23 Germany, 6 France (32 Aust., 1½ N.Z. (6½ Unknown
1956	149	£101,490	£681	(56 U.S.A., 34 Italy (33 Germany, 15 Holland (11 Australia
1957	222	£176,248	£794	(77 U.S.A., 54 Germany (51 N.Z., 20 Italy (12 Aust., 8 Holland
1958	97	£49,580	£511	(35 N.Z., 26 U.S.A. (23 Italy, 13 Germany

Total (1945-58) - 2977 tons

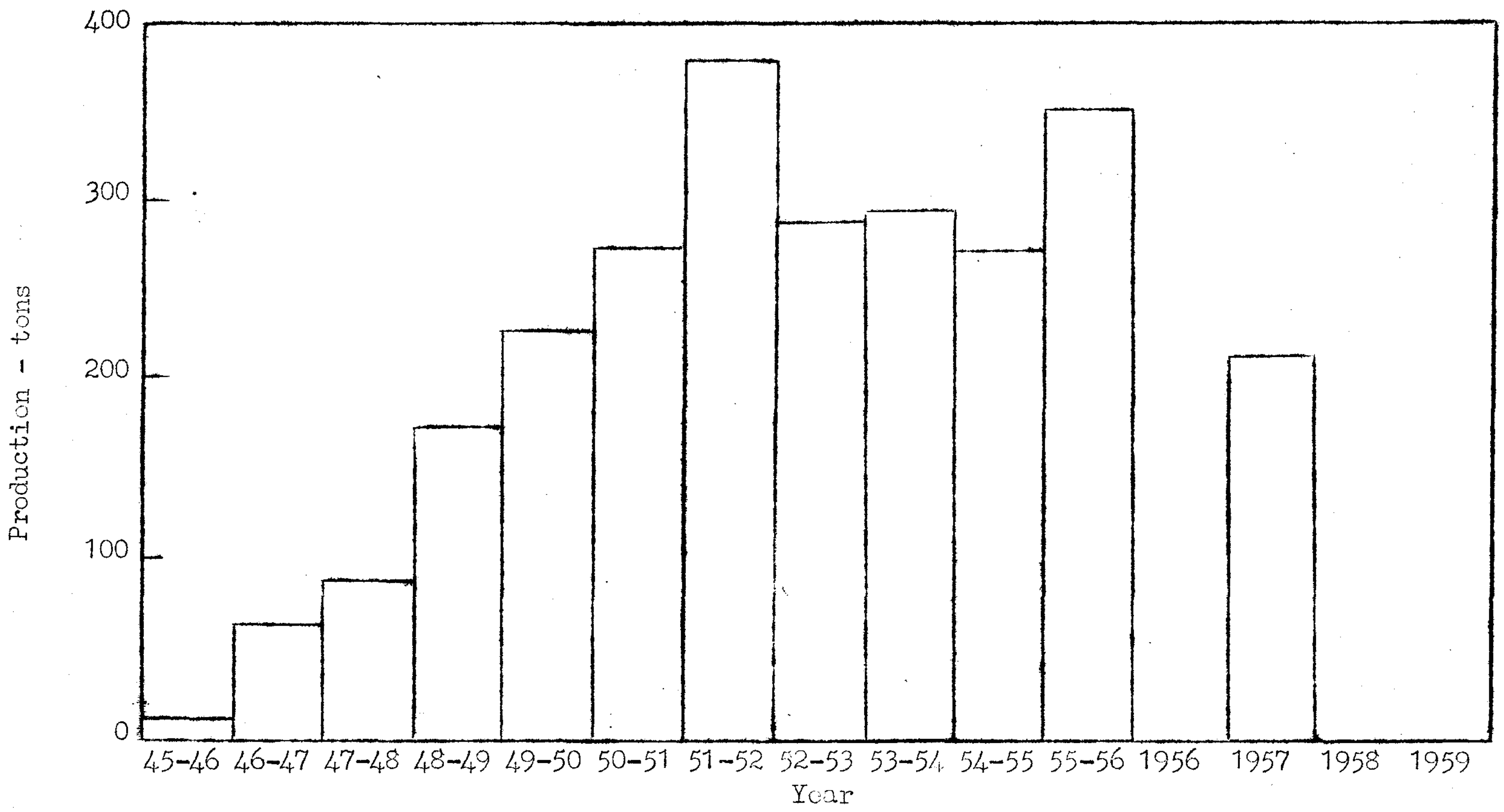

Figure 1. - P. margaritifera, Manihiki, Cook Islands. Production histogram for the years 1945 to 1959. Lagoon closed to fishing in 1956, 1958 and 1959.

MARKET STATISTICS

The market statistics for Cook Islands M.O.P. are given in Table 2. It is interesting to compare these with similar statistics for Queensland M.O.P. given in Table 3 which are indicative of the world market prices for Pinctada maxima. Prices were maximal in Queensland when the industry was starting up again post-war (45-46 to 46-47) as a result of demand exceeding production. At this time about 80% of shell was sold to U.S.A. From 47-48 to 49-50 there was a gradual drop in prices associated with increased production and stockpiling of shell in U.S.A. which continued to absorb about 80% of production. There was a gradual rise from 50-51 to 51-52 associated with an increased proportion of shell being sold to countries other than U.S.A., principally Europe. Prices remained relatively stable from 51-52 to 1958 when there was a world wide decrease in demand for pearl shell. This was the result of successful competition in the shirt button field from cheaper plastic products. At time of writing prices offered by U.S.A. buyers are still relatively low while those offered by European buyers are higher and rising.

The price of Cook Islands M.O.P. remained relatively stable from 1946 to 1954 with the exception of 1948. During these years the bulk of the exports went to U.S.A. There is no information available as to the final destination of the shell shipped via New Zealand and Australia. There is also no information available which explains the drop in price in 1948. From 1954 to 1957 there was an increasing proportion of shell being sold to Europe and an associated rise in price per ton. This phenonomen parallels the rise in Queensland M.O.P. prices in 50-51 and 51-52. The industry felt the world wide decrease in demand for pearl shell in 1958 as shown by the reduced price per ton in that year. However the relatively small proportion of shell sold to U.S.A. that year brought a higher price per ton than that sold to Europe. This shell is reported to have been used experimentally in munitions work as an antiflash ingredient in powder.

TABLE 3.

QUEENSLAND M.O.P. (P. MAXIMA) PRICES, 1944-1958

Source - Annual Report, Queensland Harbours and Marine Department and Australian Pearling Statistics, Fisheries Division, Department of Primary Industry, Commonwealth of Australia.

Year	Average price per ton - £A
44-45	183
45-46	600
46-47	625
47-48	543
48-49	406
49-50	355
50-51	420
51-52	570
52-53	505
53-54	499
54-55	504
1953	519
1954	489
1955	559
1956	550
1957	506
1958	392

It is evident that fluctuations in prices for the two types of M.O.P. have not followed a common pattern. They have one thing in common - the prices for shell sold to Europe have been higher than for that sold to U.S.A. Beyond this it seems that they have been largely independent of each other. This is reasonable because the products manufactured from the Cook Islands M.O.P. have been principally large fancy buttons which do not compete in the same market with shirt buttons. However they are not completely independent of each other as both were affected by the slump in 1958.

All this makes it difficult to predict what the future holds for Cook Islands M.O.P. prices. At the moment the European prices for Queensland M.O.P. are rising but from the above analysis it is obvious that this does not necessarily indicate a rise in Cook Islands M.O.P. prices.

PART II - BIOLOGICAL INVESTIGATIONS

THEORY AND METHODS OF INVESTIGATION

The concept of an optimum catch from a fishery formulated by Russell (1942) for edible fish applies equally well to pearl shell and has been adopted in this investigation. However it is the value of the shell fished, not the weight, that is used as the criterion of optimum catch because, when pearl shell is marketed, the shell is graded according to quality and the price per ton varies with the quality. The quality decreases with age and size of the shell so that gains in weight can be offset by depreciation in quality. To date, the Cook Islands M.O.P. has not been sold by grades. This is because the Manihiki shell has been of uniformly good quality. However it does depreciate in quality if left to grow old enough, and as marketing conditions are now relatively stringent, it was considered wise to introduce the refinement of shell gradings in this investigation. The average grading standards used for *P. maxima* in Queensland were applied.

Appreciable populations of pearl shell are found in the Cook Islands only in Manihiki and Penrhyn lagoons. The fact that these lagoons are separated from each other by nearly 100 miles of ocean and from other appreciable populations by nearly ten times this distance, renders it unlikely that there is any exchange of spat except under rare circumstances. For the purposes of this investigation therefore, the population in Manihiki was regarded as isolated.

The next step was to determine if it was homogeneous. Early in the investigation it became clear that the population was divided into two parts on the grounds of accessibility. That part living in water from 0 to 20 fathoms deep formed the basis of the fishery while that living in water over 20 fathoms was unfished. This circumstance arises because the divers are limited to 20 fathoms by the diving gear in local use. Considerable numbers of pearl shell are known to exist in the deeper waters, because they were observed from the steep slopes when shell was being sampled in the shallower parts of the lagoon.

These pearl shells thus form a virgin population, sampling of which will yield information on natural mortality and the regularity or otherwise of recruitment. As local diving equipment only was used, sampling was limited to that part of the population living in water from 0 to 20 fathoms deep. It will be seen later that it is essential that the deep water population be sampled if optimum catch is to be predicted.

In 1958 Mr Powell experienced difficulty in collecting from the shallower water several hundred pearl oysters for experimental purposes, but in 1959 large numbers of young oysters were found. These were estimated to be about 2 years old. They were not observed the previous year probably because they were too small. These young oysters have almost certainly grown from spat originating from the shell living in water over 20 fathoms deep which thus forms a protected breeding reserve. It is presumed that spat sets in the shallower water will continue to arise as the result of spawnings of these protected oysters. (The probability of this occurring could have been determined by sampling the deep water population to observe the fluctuations, if any, of spat sets in it, but as stated above it was not possible to do this).

Thus the problem of management resolves itself into how best to fish these young shells and those that presumably will result from future spat sets. It is not necessary to provide a protected breeding reserve within the shallow water population.

Before proceeding to the formulation of management recommendations it was necessary to establish the homogeneity or otherwise of this shallow water population. A number of samples, details of which are given below, were taken at various localities in the lagoon. Inspection of these samples did not reveal any important variations in the qualitative shell characters which define sub-species of

P. margaritifera.[*] These are colour of shell externally, colour of nacre and colour of shell edge internally. The quahtitative characters which can be diagnostic of pearl shell sub-species are relative proportions of shell and maximum size. Relative proportions are investigated below. Maximum size could not be investigated because none of the samples contained sufficient old specimens. Numerous examples were seen of a strong development of the posteroventral border similar to that recorded by Hynd (1955, p.130) for *P. albina* and figured by Bartsch (1931, Pl.1, Figs.1,2,7,8) for *P. margaritifera galtsoffi*. This has now been shown by Hynd (Ms) to be environmental in origin in *P. albina* and presumably the same applies to *P. margaritifera*.

It was quite possible that there were differences in growth rates or age composition within the shallow water population. Investigation of these usually requires that the age of the individual specimens be known. There are no growth rings or other serial evidence of age in this species of pearl shell (or any other) so it is necessary to use a different approach to the problem.

In a sample such as one of those taken in this investigation, the frequency distribution of any measurement is dependent on the growth rate and the age composition of the sample (result of recruitment acting with mortality). The relative proportions of the shells are dependent on growth rate only and are independent of age composition of the sample (except in so far as recruitment and mortality influence growth rate). Thus an appropriate investigation of these two

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[*] No specimens of the "albino" shell were taken in the samples. They are apparently very rare - of the order of 1 per 100,000 normal shells. However I was permitted to examine several dozen specimens in private collections. They are in all ways identical with normal shells except in colour. The differences may be genetic in origin or due to abnormal physiological conditions.

characteristics might yield information on both growth rate and age composition.

To simplify the problem, consider a group of shells all of the same age. If the individuals differ in any measurement then the resultant frequency distribution of that measurement will be an expression of the growth rate of the group and can be used as a basis for comparison with other groups. If significant differences are found between groups then there are significant differences in the growth rates. This procedure can be applied to any measurement.

At the same time, if the individuals of the group differ in one measurement only then the ratio of this to any other measurement will be different for each individual, will express the individual growth rate and the mean of the individual ratios will express the mean growth rate of the group. Similarly if the individuals of the group differ in two measurements then the ratio of these measurements will be different for some or all of the individuals, except under one set of conditions, and the mean of the individual ratios will express the mean growth rate of the group. The single exception occurs if the correlation between the measurements is 100% positive when the ratio will be the same for all individuals. These mean ratios can also be used as a basis for comparison of mean growth rates of different groups. If the difference between the mean ratios are significant then there are significant differences between the groups in mean growth rates (one or both measurements). However if the differences between the mean ratios are not significant it does not follow that there are no significant differences in the mean growth rates because it is theoretically possible for mean ratios to be the same in each group but the absolute values of the measurments from which they are derived to differ between groups. This procedure can be applied to any pair of measurements.

Thus for groups of specimens of the same age, comparison of the frequency distributions of measurements will always reveal differences in growth rates if they exist but comparison of the mean ratios of measurements may or may not reveal these differences.

The position is more complicated when samples contain specimens of different ages. As stated above the frequency distribution of any measurement is partly dependent on the age composition of the sample. In this investigation most of the specimens are fairly young (the older specimens have in fact been left out of most of the statistical treatments) and the effect of natural mortality can be neglected. Thus differences in recruitment need only be considered. Under these circumstances differences in growth rates could exist and not be revealed by comparisons of frequency distributions and ratios in these samples only if the mean ratios of each pair of measurements examined were the same in all samples and the differences in growth rates were exactly compensated for by differences in recruitment. The first condition could reasonably be expected to occur but the second is improbable. It means that spat sets would have to be distributed numerically between the various localities of the samples in the inverse ratio of the growth rates at those localities. There does not appear to be any biological process by which this is possible and the probability of it occuring by chance in an investigation of this scope is very remote. Therefore it can be concluded that if this series of samples shows no significant differences in frequency distributions or ratios of the measurements, then there were no significant differences in growth rates or recruitment at any given time. On the other hand, if significant differences in both the frequency distributions and ratios are found, then there were significant differences in the growth rates but no deduction can be made regarding differences in recruitment at any given time except that they could have existed.

A combination of significant differences in ratios but not in frequency distributions is impossible if it is correct that spat sets could not be distributed in the inverse ratio of the growth rates. However the combination of significant differences in frequency distributions but not in the ratios is possible and would occur if there were differences in the growth rates but the mean ratios of each pair of measurements examined were the same in all samples. Again no deduction can be made regarding differences in recruitment at any given time except that they could have existed.

Sampling was conducted as follows. Six random samples each containing between 143 and 231 individuals were taken by a diver from previously highly productive working grounds. As these grounds were almost cleared of older oysters the samples contained principally the newly settled oysters. The diver was instructed to take every oyster he saw. These samples took from 30 to 40 minutes to collect and the diver covered roughly the same area of bottom each time so the density of distribution was of the same order in all localities. Two purposive samples of 100 and 20 oysters were taken from areas where older oysters still remained. Two further random samples of 50 individuals each were also collected for gonad investigations. This gonad sampling will be continued monthly for 12 months. All collection localities are shown on the map, Figure 2. Details of the samples are given in Table 4. The specimens were weighed and measured according to a system which has been in use in C.S.I.R.O. for many years for P. maxima but full details of which have never been published. Those details and a specimen measurement sheet are given in Figure 3 and Table 5.

These measurements were then subjected to statistical analysis to determine if the samples showed any significant differences in frequency distributions or ratios of measurements. The differences were found to be significant but small or non-significant. In particular it was deduced that there were no differences in mean growth rate between the samples with respect to Live Weight. Accordingly this measurement was used as the basis of calculations relating grading, natural mortality and

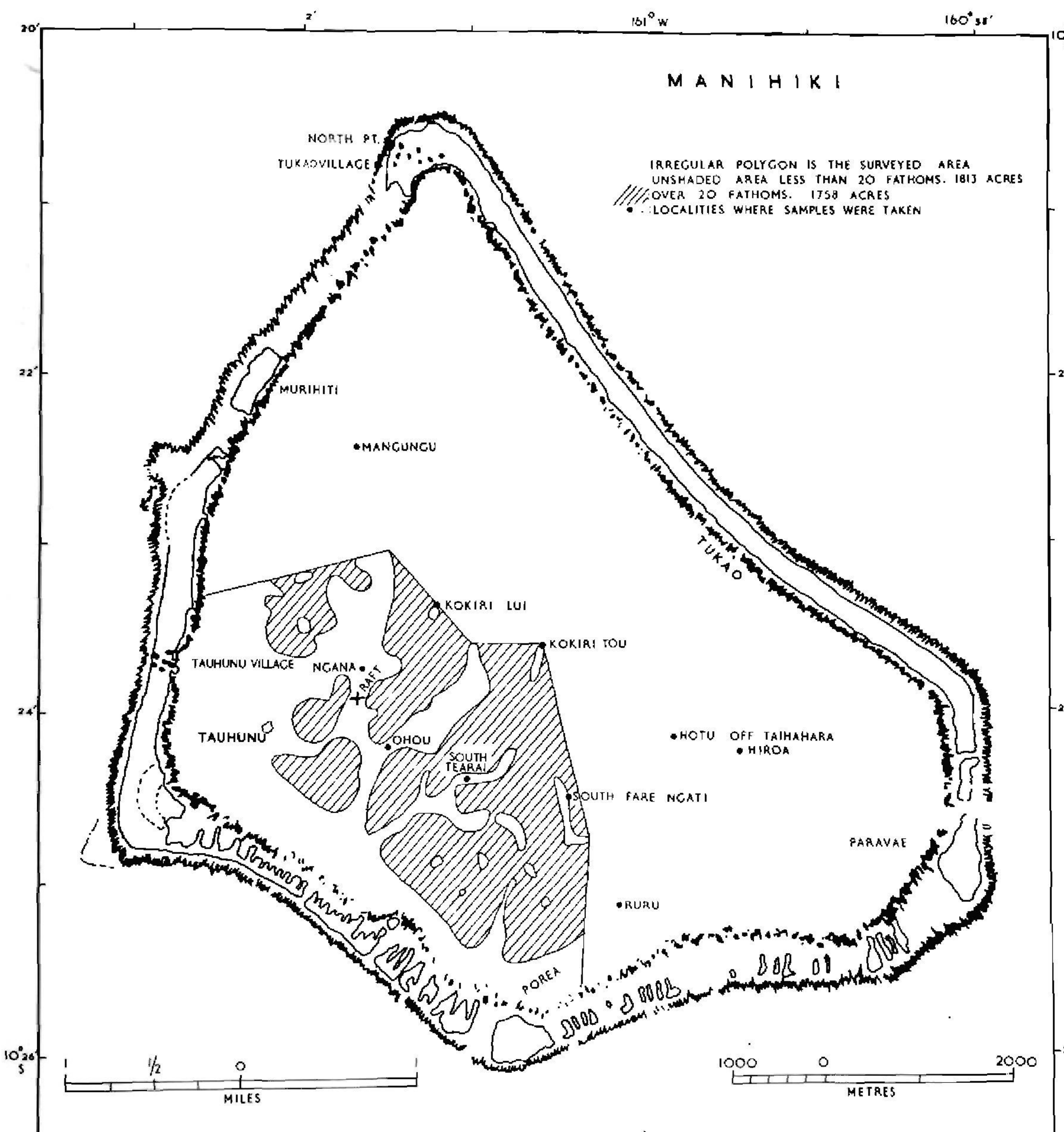

Figure 2. - Map of Manihiki Atoll showing surveyed area and sampling localities.

TABLE 4.

DETAILS OF SAMPLES

Locality	No. of Specimens	Depth	Type of Sample
Mangungu	160	14-17 fthms	Random
Kokiri Lui	173	11-12 fthms	Random
Hotu off Taihahara	203	15-18 fthms	Random
South Fare Ngati	231	10-12 fthms	Random
South Tearai	143	20-22 fthms	Random
Ohou	169	14-16 fthms	Random
Ngana	100	16-18 fthms	Purposive
Miscellaneous	20		Purposive
Hiroa	50	10 fthms	Random
Kokiri Tou	50	6-10 fthms	Random
Total	1299		

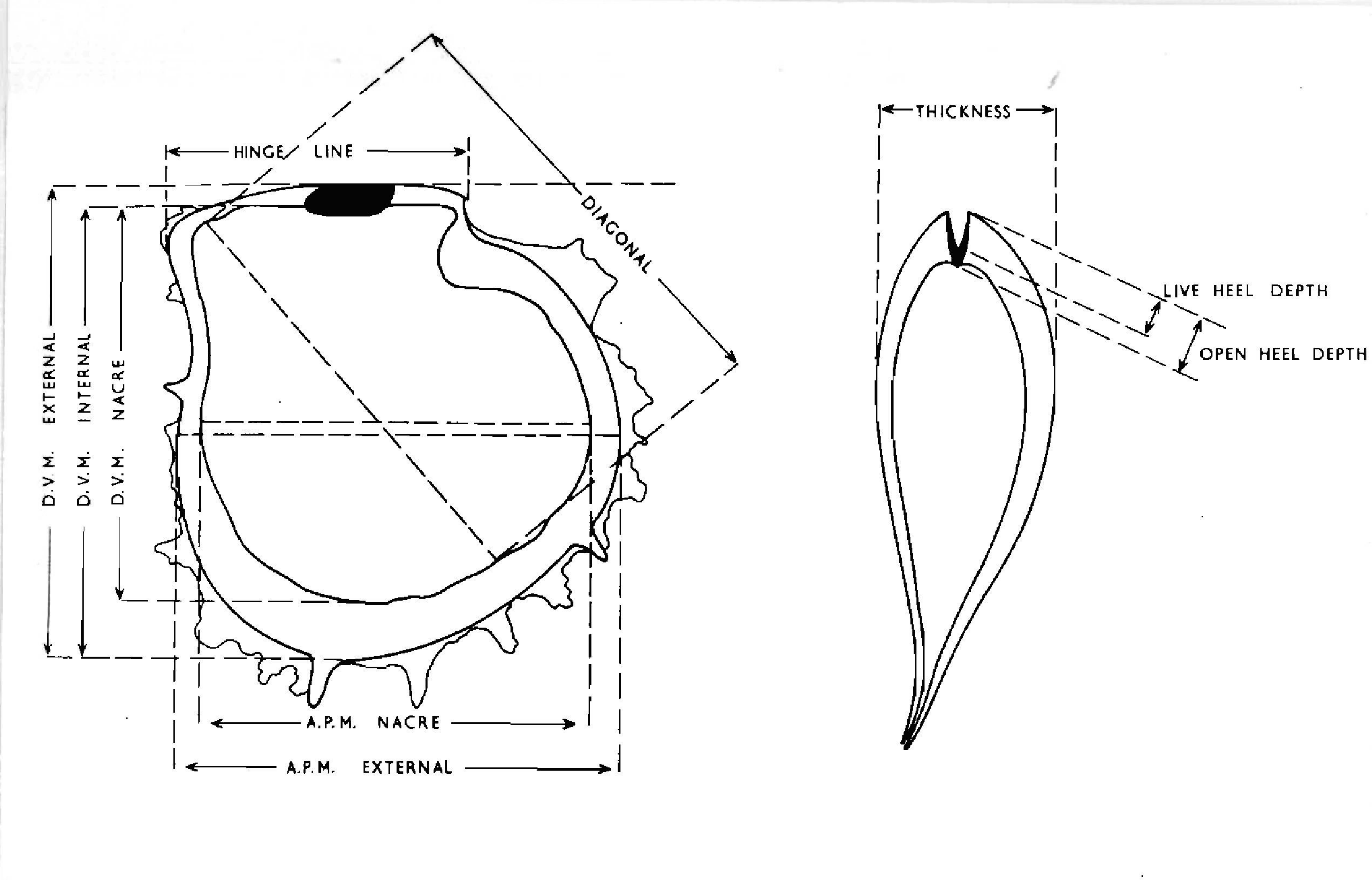

Figure 3. - The system of measurements used. Where differences between right and left valves are found, the largest measurement of the pair is taken as representative of the individual.

TABLE 5
A SPECIMEN MEASUREMENT SHEET

C.S.I.R.O. FISHERIES DIVISION

PEARLSHELL MEASUREMENT SHEET

SPECIES: P. MARGARITIFERA   DATE: 1st MAY '59   LOCALITY, ETC.: MANGUNGU, MANIHIKI 14-17 FATHOMS

NO.	Weight (ozs)			Sex	Gonad Stage	Heel-Depth (mm)			Hinge Line (cm)	A.P.M. (cm)				D.V.M. (cm)				Thickness (cm)	Grading		Chipped Weight L.V. (ozs)	Shell Edge		Int. D.V.M. (cm)		Diagonal (cm)	
							Open			R. Valve		L. Valve		R. Valve		L. Valve											
	Live	R.V.	L.V.			Live	R.V.	L.V.		Ext.	Nac.	Ext.	Nac.	Ext.	Nac.	Ext.	Nac.		R.V.	L.V.		R.V.	L.V.	R.V.	L.V.	R.V.	L.V.
121	9 3/4	3 3/8	3 5/8	♂	1 1/2	5	7	7	7·7	13·4	11·0	13·0	11·0	13·9	11·2	13·6	11·2	3·3	S	S	3 1/4	I	I	13·4	13·2	12·7	12·8
122	9 7/8	2 7/8	2 7/8	♂	2 1/2	5	7	7	7·7	13·4	10·9	13·0	10·9	12·8	10·3	13·0	9·8	3·0	S	S	2 1/2	IBr	IBr	12·4	12·4	12·2	11·9
123	9 1/4	3	2 7/8	♂	1 1/2	4	7	6	8·1	13·5	10·6	13·6	10·4	13·1	10·4	13·1	10·3	2·8	S	S	2 3/8	I	I	12·4	12·5	12·1	11·9
124	8 7/8	2 3/4	2 5/8	♀	1/2	4	5	5	7·1	13·4	10·2	13·5	10·3	12·8	10·1	12·7	9·8	3·0	S	S	2 1/4	B	B	12·4	12·3	12·4	12·0
125	18 1/2	7 3/8	7 1/2	♀	2 1/2	11	12	12	8·2	15·9	14·2	16·0	14·4	16·8	14·1	17·1	14·5	4·1	D	D	7 1/8	Br	Br	15·6	16·0	15·5	15·6
126	14 3/8	5 1/2	5 3/8	♀	1 1/2	8	11	10	7·6	15·0	13·0	14·6	13·0	14·7	11·9	14·4	11·8	4·0	S	S	5 1/8	Gr	Gr	13·6	13·5	13·3	13·3
127	7 3/8	2 3/8	2 5/8	♀	1	5	6	5	6·7	12·5	9·7	12·6	9·6	11·9	9·1	11·9	9·2	3·2	S	S	2 3/8	B	B	11·3	11·5	11·0	11·0
128	8	2 5/8	2 3/4	♀	2	4	6	6	7·2	13·2	10·5	13·5	10·8	13·4	10·5	13·5	10·4	3·3	S	S	2 3/8	B	B	12·9	13·0	12·3	12·3
129	6 7/8	2 3/8	2 3/8	♀	1/2	3	5	5	6·0	12·3	9·5	12·0	9·6	12·4	9·9	12·4	10·0	2·7	S	S	2 1/8	Br	Br	12·0	12·0	11·3	11·3
130	8 1/8	2 3/4	3	♂	1/2	4	6	6	7·5	13·6	10·7	13·7	10·6	13·2	10·5	13·3	10·4	2·9	S	S	2 5/8	B	B	12·8	12·9	12·0	12·0
131	10	3 3/4	3 3/4	♀	1/2	7	9	9	7·4	13·6	11·5	13·5	11·3	13·2	10·8	13·2	10·8	3·2	S	S	3 1/2	B	B	12·5	12·4	12·5	12·5
132	13 3/8	4 3/8	4 1/2	♀	2	6	9	9	7·8	15·0	11·7	14·4	11·6	14·2	11·0	14·5	11·1	3·7	S	S	4	B	B	13·6	13·6	12·6	12·5
133	6 7/8	2 1/2	2 5/8		Tr	4	6	5	6·9	12·4	10·2	12·5	10·3	12·7	10·5	13·0	10·6	3·2	S	S	2 1/8	B	B	12·4	12·5	12·0	12·1
134	9 3/4	2 7/8	2 3/4	♂	1 1/2	4	7	7	7·2	13·5	10·9	13·4	10·8	13·8	11·1	13·8	11·0	3·0	S	S	2 1/2	Br	Br	13·3	13·4	12·5	12·5
135	6 3/8	1 7/8	2	♂	2	3	6	5	7·2	11·8	9·3	11·8	9·0	11·0	8·9	11·3	8·7	2·8	S	S	1 3/4	I	I	10·6	10·8	10·7	10·7
136	8 7/8	3 5/8	3 1/4	♂	1/2	6	8	8	7·0	12·5	10·8	12·5	10·7	13·3	10·9	13·2	11·1	3·2	S	E	3 1/8	Br	I	12·5	12·6	12·3	12·4
137	6	2 1/8	2 1/4	♂	2	3 1/2	5	5	7·5	12·4	10·3	12·5	10·5	11·6	9·3	11·5	9·2	2·8	S	S	2	Br	Br	11·2	11·1	11·6	11·3
138	9 1/2	3 7/8	3 5/8	♂	1 1/2	5	7	7	8·0	15·0	11·7	14·5	11·5	14·1	10·9	14·0	11·4	3·0	S	S	3 1/4	Br	Br	13·5	13·4	12·6	12·6
139	13 1/4	4 7/8	4 7/8	♂	1/2	7	9	9	8·4	15·8	13·5	15·5	13·3	15·3	12·5	14·8	12·4	3·4	S	S	4 1/2	G	G	14·7	14·4	13·3	13·3
140	11 1/8	3 3/4	4 1/8	♂	1/2	6	7	7	7·9	14·0	11·5	14·4	11·6	15·0	11·9	14·9	11·7	3·4	S	S	3 3/4	I	I	14·4	14·3	14·1	14·1

value for the population as a whole. Other relationships applicable to the whole population have been calculated from other measurements but their value is in proportion to the variation found in the samples.

To determine the optimum catch for a fishery it is necessary to know the recruitment, the growth rate and the natural mortality. In this case there is no information on recruitment or natural mortality. If growth rate and natural mortality only are known it is possible to determine the optimum age or size at which individuals should be fished and then to frame management rules which will ensure that the percentage of the population fished at this age or size is maximal. This has been done here, using in the calculations two estimates of natural mortality which, it is believed, represent the probable maximum and minimum values. If and when the natural mortality of the deep water population is determined, it can be substituted in the calculations as an estimate of the natural mortality in the shallow water population.

Finally 1,000 oysters were tagged and measured and returned to the lagoon in various environments. These will be left alone for 12 months after which they will be remeasured. Thus it will be possible to determine the growth rates in these various environments. Some are conditions usually experienced in shell culture, others are natural conditions.

RESULTS

(a) Comparison of Frequency Distributions of Measurements

The frequency distributions of certain of the measurements in the six larger random samples were compared by contingency tables and X^2 tests of significance. As the time available for this investigation was limited, comparisons were made only of External Dorsovantral Measurement (External D.V.M.) Open Heel Depth and Live Weight. The results were as follows:-

(i) External D.V.M.: The frequencies in the class intervals 6.0 = 6.9 cm, 7.0 = 7.9 cm, 8.0 = 8.9 cm, etc. in each sample are given in Table 6. This forms a contingency table. The upper figure in each cell is the observed frequency. The next is the calculated frequency assuming that Sample and External D.V.M. are independent. The third figure is the difference between expected and observed frequency and the fourth is X^2. Frequencies for the class intervals below 11.0 cms and above 14.9 cms have been pooled to remove low frequencies. The total X^2 is 91.576 on 25 degrees of freedom which is significant at the 0.1 per cent. level. Inspection shows that the larger individual X^2's occur in the first and last columns. The first column contains the young oysters which we know from experience are not sampled efficiently by divers. Many of the specimens in this size range were only obtained because they were attached to older oysters. Thus significant differences between their frequencies in the samples do not necessarily mean there were significant differences within the population. The last column contains the older oysters which are the remnants of the fished stock and consequently the frequencies can supply no evidence on recruitment or growth rates.

These two columns were omitted and the X^2's recalculated. This omission leaves only just fishable or nearly fishable oysters. The total X^2 was then 38.721 on 15 degrees of freedom which is again significant at the 0.1 per cent. level. Inspection showed that the samples which contributed most to the total X^2 were Hotu off Taihahara and Kokiri Lui. When these were omitted separately and X^2 recalculated

TABLE 6.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

FREQUENCY DISTRIBUTIONS OF EXTERNAL D.V.M. IN SIX SAMPLES

Sample	External D.V.M. - cm						Totals
	10.9 & below	11.0-11.9	12.0-12.9	13.0-13.9	14.0-14.9	15.0 & above	
Mangungu	11 15.867 - 4.867 1.493	18 14.235 + 3.765 0.996	30 36.033 - 6.033 1.010	55 49.824 + 5.176 0.538	29 29.509 - 0.509 0.088	17 14.532 + 2.468 0.419	160
South Fare Ngati	42 22.908 + 19.092 15.912	22 20.552 + 1.448 0.102	47 52.023 - 5.023 0.485	76 71.933 + 4.067 0.230	35 42.603 - 7.603 1.357	9 20.981 - 11.981 6.842	231
South Tearai	20 14.181 + 5.819 2.388	6 12.723 - 6.723 3.553	35 32.205 + 2.795 0.243	42 44.530 - 2.530 0.144	23 26.373 - 3.373 0.431	17 12.988 + 4.012 1.239	143
Ohou	9 16.759 - 7.759 3.592	25 15.036 + 9.964 6.603	43 38.060 + 4.940 0.641	48 52.627 - 4.627 0.407	31 31.169 - 0.169 0.092	13 15.349 - 2.349 0.359	169
Hotu off Taihahara	13 20.131 - 7.131 2.526	16 18.061 - 2.061 0.235	66 45.717 + 20.283 8.999	51 63.214 - 12.214 2.360	44 37.439 + 6.561 1.150	13 18.438 - 5.438 1.604	203
Kokiri Lui	12 17.156 - 5.156 1.550	9 15.392 - 6.392 2.654	22 38.961 - 16.961 7.383	64 53.872 + 10.128 1.904	37 31.906 + 5.094 0.813	29 15.713 + 13.287 11.236	173
Totals	107	96	243	336	199	98	1079

$X^2 = 91.576^{***}$ on 25 degrees of freedom

it was found that P lay between 0.05 and 0.02 i.e. the differences were only just significant. When both were omitted and X^2 recalculated P equalled 0.20 which is not significant. Thus there are no significant differences between the majority of the samples in frequency distribution of External D.V.M. of the just fishable or nearly fishable oysters.

(ii) Open Heel Depth: The Open Heel Depth frequencies for each sample are given in Table 7. Open Heel Depths of 4 mm and below and 10 mm and above have been pooled to remove low frequencies. Expected frequencies have been calculated assuming independence of Sample and Open Heel Depth. The figures within each cell are arranged as for External D.V.M. The total X^2 is 121.928 on 30 degrees of freedom which is significant at the 0.1 per cent. level. Inspection shows that column 10 mm and above is the largest contributor to the total X^2. This column contains the older oysters which are the remnants of the fished stock. Column 4 mm and below which contains the young, inefficiently sampled oysters does not contribute importantly to the total X^2.

These two columns were omitted and the X^2's recalculated. The total X^2 was then 60.780 on 20 degrees of freedom which is significant at the 0.1 per cent. level. Inspection showed that the sample which contributed most to the X^2 was Hotu off Taihahara. This sample was omitted and X^2 recalculated. It was 26.978 on 16 degrees of freedom which is just significant at the 5 per cent. level. Mangungu and Ohou were then the largest contributors to X^2. When either of these were omitted X^2 was reduced to a non-significant figure. Thus there are no significant differences between the majority of the samples in frequency distribution of Open Heel Depth of the just fishable or nearly fishable oysters.

(iii) Live Weight: The Live Weight frequencies in the class intervals $3\frac{1}{2}$ - $4\frac{3}{8}$ oz, $4\frac{1}{2}$ - $5\frac{3}{8}$ oz, etc. in each sample are given in Table 8. Live Weights of $4\frac{3}{8}$ oz and below and $12\frac{1}{2}$ oz and above have been pooled to remove low frequencies. Expected frequencies have been calculated

TABLE 7.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

FREQUENCY DISTRIBUTION OF OPEN HEEL DEPTH IN SIX SAMPLES

Sample	Open Heel Depth - mm							Totals
	4 & below	5	6	7	8	9	10 & above	
Mangungu	11 12.011 - 1.011 0.851	17 15.570 + 1.430 0.131	52 33.661 + 18.339 9.991	33 38.851 - 5.851 0.881	18 25.357 - 7.357 2.135	17 15.570 + 1.430 0.131	12 18.980 - 6.980 2.570	160
South Fare Ngati	25 17.341 + 7.659 3.383	29 22.479 + 6.521 1.892	39 48.598 - 9.598 1.896	56 56.091 - 6.091 0.015	39 36.609 + 2.391 0.156	26 22.479 + 3.521 0.552	17 27.403 - 10.403 3.949	231
South Tearai	8 10.735 - 2.735 0.697	13 13.916 - 0.916 0.060	29 30.084 - 1.084 0.391	40 34.722 + 5.278 0.802	28 22.663 + 5.337 1.257	15 13.916 + 1.084 0.844	10 16.964 - 6.964 2.859	143
Ohou	10 12.687 - 2.687 0.569	28 16.446 + 11.554 8.117	45 35.554 + 9.446 2.510	36 41.036 - 5.036 0.618	33 26.783 + 6.217 1.443	7 16.446 - 9.446 5.425	10 20.048 - 10.048 5.036	169
Hotu off Taihahara	10 15.239 - 5.239 1.801	3 19.754 - 16.754 14.210	31 42.707 - 11.707 3.209	66 49.292 + 16.708 5.663	28 32.172 - 4.172 0.541	27 19.754 + 7.246 2.658	38 24.082 + 13.918 8.044	203
Kokiri Lui	17 12.987 + 4.013 1.240	15 16.835 - 1.835 0.200	31 36.396 - 5.396 0.800	31 42.007 - 11.007 2.884	25 27.417 - 2.417 0.213	13 16.835 - 3.835 0.874	41 20.523 + 20.477 20.431	173
Totals	81	105	227	262	171	105	128	1079

$X^2 = 121.929^{***}$ on 30 degrees of freedom

TABLE 8.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

FREQUENCY DISTRIBUTIONS OF LIVE WEIGHT IN SIX SAMPLES

Sample	Live Weight - oz										Totals
	$4\frac{3}{8}$ & below	$4\frac{1}{2}$-$5\frac{3}{8}$	$5\frac{1}{2}$-$6\frac{3}{8}$	$6\frac{1}{2}$-$7\frac{3}{8}$	$7\frac{1}{2}$-$8\frac{3}{8}$	$8\frac{1}{2}$-$9\frac{3}{8}$	$9\frac{1}{2}$-$10\frac{3}{8}$	$10\frac{1}{2}$-$11\frac{3}{8}$	$11\frac{1}{2}$-$12\frac{3}{8}$	$12\frac{1}{2}$ & above	
Mangungu	8 15.570 - 7.570 3.680	5 7.562 - 2.562 0.868	15 14.977 + 0.023 0.003	12 20.315 - 8.315 3.403	31 27.136 + 3.864 0.550	19 21.056 - 2.056 0.201	30 21.650 + 8.350 3.220	11 11.715 - 0.715 0.583	6 8.156 - 2.156 0.570	23 11.863 + 11.137 10.455	160
South Fare Ngati	40 22.479 +17.521 13.657	11 10.918 + 0.082 0.616	18 21.623 - 3.623 0.676	25 29.330 - 4.330 0.639	31 39.178 - 8.178 1.707	34 30.400 + 3.600 0.426	28 31.257 - 3.257 0.339	25 16.913 + 8.087 3.867	12 11.775 + 0.225 0.430	7 17.127 - 10.127 5.988	231
South Tearai	15 13.916 + 1.084 0.844	9 6.759 + 2.241 0.743	8 13.386 - 5.386 2.167	19 18.157 + 0.843 0.391	19 24.253 - 5.253 1.138	20 18.819 + 1.181 0.741	22 19.349 + 2.651 0.363	6 10.470 - 4.470 1.908	10 7.289 + 2.711 1.008	15 10.602 + 4.398 1.824	143
Ohou	10 16.446 - 6.446 2.527	9 7.988 + 1.012 0.128	19 15.819 + 3.181 0.640	25 21.458 + 3.542 0.585	31 28.663 + 2.337 0.191	28 22.241 + 5.759 1.491	16 22.868 - 6.868 2.063	12 12.373 - 0.373 0.112	9 8.614 + 0.386 0.017	10 12.530 - 2.530 0.511	169
Hotu off Taihahara	14 19.754 - 5.754 1.676	7 9.595 - 2.595 0.070	25 19.002 + 5.998 1.893	35 25.775 + 9.225 3.302	44 34.429 + 9.571 2.661	22 26.715 - 4.715 0.832	26 27.468 - 1.468 0.079	15 14.863 + 0.137 0.013	8 10.348 - 2.348 0.533	7 15.051 - 8.051 4.307	203
Kokiri Lui	18 16.835 + 1.165 0.806	10 8.177 + 1.823 0.406	16 16.194 - 0.194 0.023	21 21.966 - 0.966 0.042	27 29.341 - 2.341 0.187	19 22.767 - 3.767 0.623	24 23.409 + 0.591 0.015	10 12.666 - 2.666 0.561	10 8.818 + 1.182 0.158	18 12.827 + 5.173 2.086	173
Totals	105	51	101	137	183	142	146	79	55	80	1079

$X^2 = 91.540^{***}$ on 45 degrees of freedom

assuming independence of Sample and Live Weight. The figures within each cell are arranged as for External D.V.M. The total X^2 is 91.540 on 45 degrees of freedom which is significant at the 0.1 per cent. level. Columns $4\frac{3}{8}$ oz and below and $12\frac{1}{2}$ oz and above contain the young, inefficiently sampled oysters and the older oysters which are the remnants of the fished stock respectively. These were omitted and X^2 recalculated. It was 38.243 on 35 degrees of freedom which corresponds to the value of P of 0.30 approximately i.e. there are no significant differences between the samples in frequency distributions of Live Weight of the just fishable or nearly fishable oysters.

(b) Comparison of Ratios of Measurements

The comparisons of the ratios of the pairs of measurements have been carried out as follows. A transformation of one variable which would enable a straight line to be fitted to the data was found by inspection of each pair. Then regression lines of the form $y = \underline{a} + \underline{b}x$ were fitted to the transformed data of each of the six larger random samples by the least squares method. The values of $\underline{b}$ (slopes) so obtained were compared by an analysis of variance to determine the significance or otherwise of the observed differences. Where the differences were non-significant parallel lines having a slope calculated from the combined data were fitted and the distances apart of these lines tested for significance by another analysis of variance.

The pairs of measurements selected were External D.V.M. and Open Heel Depth, External D.V.M. and Live Weight and Open Heel Depth and Live Weight. There are many others possible but lack of time precluded their use. Each measurement of a pair was treated both as the dependent and the independent variable, thus giving 6 sets of lines altogether. The results obtained are given below.

(i) External D.V.M. - Open Heel Depth: A logarithmic transformation of Open Heel Depth was used. The lines were fitted to the data of each sample over the range 5 to 9 mm Open Heel Depth inclusive. The calculations of the values of $\underline{b}$ are summarised in Tables 9 and 10. It will be seen that whereas the differences in slope of the regressions of log. Open Heel Depth on External D.V.M. are non-significant, those of External D.V.M. on log. Open Heel Depth are significant at the 0.1 per cent. level. When parallel regression lines were fitted to the data of Table 10 it was found that the distances apart of the lines were significant at the 0.1 per cent. level.

The coefficients of correlation for each sample have been calculated and are given in Tables 9 and 10. They show that the correlation is moderately strong in all samples.

(ii) External D.V.M. - Live Weight: A cube root transformation of Live Weight was used. The lines were fitted to the data of each sample over the range $4\frac{1}{2}$ to $12\frac{3}{8}$ oz Live Weight inclusive. The calculations of the values of $\underline{b}$ are summarised in Tables 11 and 12. It will be seen that in both sets of regressions the differences in slopes are non-significant but when parallel lines are fitted the distances apart are significant at the 0.1 per cent. level.

TABLE 9.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

REGRESSIONS OF EXTERNAL D.V.M. ON LOG. OF OPEN HEEL DEPTH

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	b	Regression S.S.	Residual S.S.	r
Mangungu	197.470	6.4061	0.7900	136	8.1090	51.9470	145.5230	0.51
Kokiri Lui	146.339	6.3444	0.7831	120	8.1016	51.4001	94.9389	0.59
Hotu off Taihahara	183.729	6.8912	1.0495	167	6.5662	45.2488	138.4802	0.50
South Farc Ngati	382.080	14.3534	1.2180	188	11.7844	169.1462	212.9338	0.67
South Tearai	258.519	9.1535	0.6773	124	13.5147	123.7067	134.8123	0.69
Ohou	209.227	7.1862	0.8620	148	8.3367	59.9089	149.3181	0.54
Totals	1377.3640	50.3348	5.3799	883		501.3577	876.0063	
						470.9366 30.4211		

ANALYSIS OF VARIANCE

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	470.9366	470.9366	471.46 xxx
Between Regressions	5	30.4211	6.0842	6.09 xxx
Residual	877	876.0063	0.9989	
Totals	883	1377.3640		

TABLE 10.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

REGRESSIONS OF LOG. OF OPEN HEEL DEPTH ON EXTERNAL D.V.M.

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	b	Regression S.S.	Residual S.S.	r
Mangungu	0.7900	6.4061	197.470	136	0.0324	0.2078	0.5822	0.51
Kokiri Lui	0.7831	6.3444	146.339	120	0.0434	0.2751	0.5080	0.59
Hotu off Taihahara	1.0495	6.8912	183.729	167	0.0375	0.2585	0.7910	0.50
South Fare Ngati	1.2180	14.3534	382.080	188	0.0376	0.5392	0.6788	0.67
South Tearai	0.6773	9.1535	258.519	124	0.0354	0.3241	0.3532	0.69
Ohou	0.8620	7.1862	209.227	148	0.0343	0.2468	0.6152	0.54
Totals	5.3799	50.3348	1377.3640	883		1.8515	3.5284	
						1.8394 0.0121		
Combined Data	5.4771	49.6265	1406.0400	888	0.0353	1.7516	3.7255	

ANAYLSIS OF VARIANCE - DIFFERENCE IN SLOPES

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	1.8394	1.8394	459.85***
Between Regressions	5	0.0121	0.0024	0.60 N.S.
Residual	877	3.5284	0.0040	
Totals	883	5.3799		

ANAYLSIS OF VARIANCE - COMBINED DATA

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	1.7516	1.7516	437.90***
Between Regns. (Slope)	5	0.0121	0.0024	0.60 N.S
Distance Apart	5	0.1310	0.0262	6.55***
Residual	877	3.5284	0.0040	
Totals	888	5.4771		

TABLE 11.

<u>P. MARGARITIFERA</u> - MANIHIKI, COOK ISLANDS

REGRESSIONS OF EXTERNAL D.V.M. ON CUBE ROOT OF LIVE WEIGHT

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	b	Regression S.S.	Residual S.S.	r
Mangungu	134.776	14.3388	2.8082	128	5.1060	73.2146	61.5614	0.74
Kokiri Lui	124.807	12.5283	2.7948	130	4.4827	56.1608	68.6462	0.67
Hotu off Taihahara	192.916	19.5943	3.6898	181	5.3104	104.0535	88.8625	0.73
South Fare Ngati	205.898	20.1886	4.5345	183	4.4522	89.8841	116.0139	0.66
South Tearai	135.581	15.2353	2.9113	112	5.2332	79.7288	55.8522	0.77
Ohou	183.363	18.5059	3.4023	148	5.4392	100.6579	82.7051	0.74
Totals	977.341	100.3912	20.1409	882		503.6997	473.6413	
						500.3943 3.3054		
Combined Data	999.35	101.121	20.5023	887	4.9322	498.7468	500.6032	

ANALYSIS OF VARIANCE - DIFFERENCE IN SLOPES

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	500.3943	500.3943	925.46***
Between Regressions	5	3.3054	0.6611	1.22 N.S.
Residual	876	473.6413	0.5407	
Totals	882	977.3410		

ANALYSIS OF VARIANCE - COMBINED DATA

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	498.7468	498.7468	922.41***
Between Regns.(Slope)	5	3.3054	0.6611	1.22 N.S
Distance Apart	5	23.6565	4.7313	8.75***
Residual	876	473.6413	0.5407	
Totals	887	999.3500		

TABLE 12.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

REGRESSIONS OF CUBE ROOT OF LIVE WEIGHT ON EXTERNAL D.V.M.

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	b	Regression S.S.	Residual S.S.	r
Mangungu	2.8082	14.3388	134.776	128	0.1064	1.5255	1.2827	0.74
Kokiri Lui	2.7948	12.5283	124.807	130	0.1004	1.2576	1.5372	0.67
Hotu off Taihahara	3.6898	19.5943	192.916	181	0.1016	1.9902	1.6996	0.73
South Fare Ngati	4.5345	20.1886	205.898	183	0.0981	1.9795	2.5550	0.66
South Tearai	2.9113	15.2353	135.581	112	0.1124	1.7120	1.1993	0.77
Ohou	3.4023	18.5059	183.363	148	0.1009	1.8677	1.5346	0.74
Totals	20.1409	100.3912	977.341	882		10.3325	9.8084	
						10.3121 0.0204		
Combined Data	20.5023	101.121	999.35	887	0.1012	10.2321	10.2702	

ANALYSIS OF VARIANCE - DIFFERENCE IN SLOPES

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	10.3121	10.3121	859.34***
Between Regressions	5	0.0204	0.0041	0.34 N.S.
Residual	876	9.8084	0.0120	
Totals	882	20.1409		

ANALYSIS OF VARIANCE - COMBINED DATA

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	10.2321	10.2321	852.68***
Between Regns.(Slope)	5	0.0204	0.0041	0.34 N.S.
Distance Apart	5	0.4414	0.0883	7.36***
Residual	876	9.8084	0.0120	
Totals	887	20.5023		

The coefficients of correlation for each sample have been calculated and are given in Tables 11 and 12. They show that the correlation is moderately strong in all samples and stronger than that between External D.V.M. and Live Weight.

(iii) Open Heel Depth - Live Weight: A logarithmic transformation of Live Weight was used. The lines were fitted to the data of each sample over the range $4\frac{1}{2}$ to $12\frac{3}{8}$ oz Live Weight inclusive. The calculations of the values of b are summarised in Tables 13 and 14. It will be seen that in both sets of regressions the differences in slopes are significant.

The coefficients of correlation for each sample are given in Tables 13 and 14. They show that there is a moderately strong correlation of the same order as that found between External D.V.M. and Open Heel Depth.

(c) Assessment of Results of Analyses

In the preceding two sections it has been demonstrated that for the just fishable or nearly fishable oysters (a) there are no significant differences between any of the samples in frequency distributions of Live Weight and none between the majority of the samples in frequency distributions of External D.V.M. and Open Heel Depth; (b) there are significant differences between the samples in the regression lines fitted to the pairs of these measurements, either in the slopes of the lines or in the distance apart of parallel lines. Thus the samples do not fit exactly into any one of the four categories listed in the section on Theory and Methods of Investigation.

However the fact that there are no significant differences in the Live Weight frequency distributions is important because it shows that there were no differences in mean growth rate between the samples with respect to that measurement (for if there were the spat sets

TABLE 13.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

REGRESSIONS OF OPEN HEEL DEPTH ON LOG. OF LIVE WEIGHT

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	$\underline{b}$	Regression S.S.	Residual S.S.	r
Mangungu	235.8140	8.9204	1.2147	128	7.3437	65.5088	170.3052	0.53
Kokiri Lui	518.5955	14.9247	1.1684	130	12.7736	190.6425	327.9530	0.61
Hotu off Taihahara	549.9790	13.8949	1.5686	181	8.8581	123.0832	426.8958	0.47
South Fare Ngati	382.8700	15.0842	1.9357	183.	7.7926	117.5456	265.3244	0.55
South Tearai	186.4602	8.5927	1.2553	112	6.8451	58.8182	127.6420	0.56
Ohou	302.5910	11.4182	1.4672	148	7.7823	88.8599	213.7311	0.54
Totals	2176.3097	72.8351	8.6099	882		644.4582	1531.8515	
						$\frac{616.1455}{28.3127}$		

ANALYSIS OF VARIANCE

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	616.1455	616.1455	352.34***
Between Regressions	5	28.3127	5.6625	3.24**
Residual	876	1531.8515	1.7487	
Totals	882	2176.3097		

TABLE 14.

P. MARGARITIFERA – MANIHIKI, COOK ISLANDS

REGRESSIONS OF LOG. OF LIVE WEIGHT ON OPEN HEEL DEPTH

Sample	Corrected y^2	Corrected xy	Corrected x^2	d.f.	b	Regression S.S.	Residual S.S.	r
Mangungu	1.2147	8.9204	235.8140	128	0.0378	0.3374	0.8773	0.53
Kokiri Lui	1.1684	14.9247	518.5955	130	0.0288	0.4295	0.7389	0.61
Hotu off Taihahara	1.5686	13.8949	549.9790	181	0.0253	0.3510	1.2176	0.47
South Fare Ngati	1.9357	15.0842	382.8700	183	0.0394	0.5942	1.3415	0.55
South Tearai	1.2553	8.5927	186.4602	112	0.0461	0.3959	0.8594	0.56
Ohou	1.4672	11.4182	302.5910	148	0.0377	0.4308	1.3064	0.54
Totals	8.6099	72.8351	2176.3097	882		2.5388	6.0711	
						2.4376		
						0.1012		

ANALYSIS OF VARIANCE

Variation	d.f.	S.S.	M.S.	V.R.
Due to Regression	1	2.4376	2.4376	353.28^{***}
Between Regressions	5	0.1012	0.0202	2.93^{*}
Residual	876	6.0711	0.0069	
Totals	882	8.6099		

would have had to be distributed numerically between the various localities of the samples in the inverse ratio of the "weight growth rates" at those localities which is improbable). Thus the population is homogeneous with respect to weight growth rate in so far as these samples represent the population adequately.

It also follows that the population is homogeneous with respect to density of spat settlement at any given time. Therefore the differences between the samples in frequency distribution of External D.V.M. and Open Heel Depth must be attributed to differences in growth rate and as these were non-existent in the majority of the samples it follows that in that majority there were no differences in mean growth rate with respect to External D.V.M. and Open Heel Depth.

This deduction is supported in the main by the evidence of the regression lines. When External D.V.M. frequencies were compared the samples Hotu off Taihahara and Kokiri Lui were omitted to reduce X^2 to a non-significant value. If these two samples are also omitted when the regressions of External D.V.M. and Live Weight are analysed, the differences between the remaining samples becomes non-significant also. This supports the statement that in the majority of samples there were no differences in mean growth rate with respect to External D.V.M. However when the samples Hotu off Taihahara and Ohou are omitted from the analysis of the regressions of Open Heel Depth and Live Weight (these two samples were omitted in the comparison of the frequency distributions of Open Heel Depth to reduce X^2 to a non-significant figure) the differences between the remaining samples are still significant. For the regressions of Live Weight on Open Heel Depth the differences in slopes are now non-significant while the distances apart are significant at the 5 per cent. level. For the regressions of Open Heel Depth on Live Weight the level of significance of the differences in slopes is <u>increased</u> to 0.1 per cent. This anomalous result is due to the high value of <u>b</u> of the Kokiri Lui sample. If it is omitted the differences in slope are not significant but the distances apart are significant at the 0.1 per cent. level.

It is clear that these relative growth rates deserve more thorough analysis but for the present it is sufficient that Live Weight furnishes the best criterion of age and that all calculations relative to management rules should use it as a basis. External D.V.M. is the next best measurement because it shows a higher correlation with Live Weight than Open Heel Depth.

The question arises as to whether these differences in growth rate are genotypic or phenotypic in origin. The values of b and a of the various regression lines were plotted on a map of Manihiki but no directional trends could be found. Having regard to the reproductive habits of pearl oysters it is difficult to imagine any mechanism by which the observed differences could be maintained on a genetic basis in a population of this size so it is probable that they are phenotypic in origin. However the bottoms from which the samples were taken were all superficially identical so it is not possible to test for associations between ecological niche and growth rate. Also there is no obvious association with depth. Thus the differences remain unexplained.

(d) Relationship between Weight Measurements

There are four weight measurements on the standard measurement sheet - Live Weight, Left Valve Weight, Right Valve Weight, and chipped Left Valve Weight. Live Weight was selected as the basic measurement for weight comparisons as it is the only one measurable in live (tagged) specimens. The most important commercial measurement is the Chipped Shell Weight. This was not measured in the samples because of the time consumed in "chipping" or "trimming" the valves. Instead the left valve only was chipped and weighed. By determining the relationship between Live Weight and Left Valve Weight, Left Valve Weight and Right Valve Weight, Left Valve Weight and Chipped Left Valve Weight and assuming that the relationship between Right Valve Weight and Chipped Right Valve Weight is the same, the relationship between Chipped Shell Weight and Live Weight has been calculated.

In addition the relationship between Chipped Left Valve Weight and Live Weight has been calculated from the above relationships. This relationship is used in comparing the weight frequencies of commercial catches with those of live samples on the same basis. The chipped weights of the left valves only of the commercial catch are required. Calculation of the relationship in this way is an interim procedure only. A better method is to determine the regression of Live Weight on Chipped Left Valve Weight directly. This will be completed later.

Figure 4 shows the Left Valve Weights (pooled data of all samples) plotted against Live Weights grouped in 1 oz class intervals. It will be seen that the relationship is linear. The scattering of the points in the upper right corner is due to low frequencies in the class intervals. The regression equation of Left Valve Weight on Live Weight has been calculated. It is -

$$\text{L.Valve Wt. (oz)} = -0.1828 + 0.3738 \text{ Live Wt. (oz)}$$

Figure 5 shows the differences between Left Valve Weights and Chipped Left Valve Weights (i.e. loss of weight in chipping) plotted against Left Valve Weights grouped in 1 oz class intervals. Again the scattering of the points in the upper right corner is due to low frequencies. In the absence of any definite indication that the relationship is curvilinear, a straight line was fitted. The regression of Loss of Weight in Chipping on Left Valve Weight is -

$$\text{Loss } (\tfrac{1}{8}\text{oz}) = 1.5286 + 0.3863 \text{ L.Valve Wt. (oz)}$$

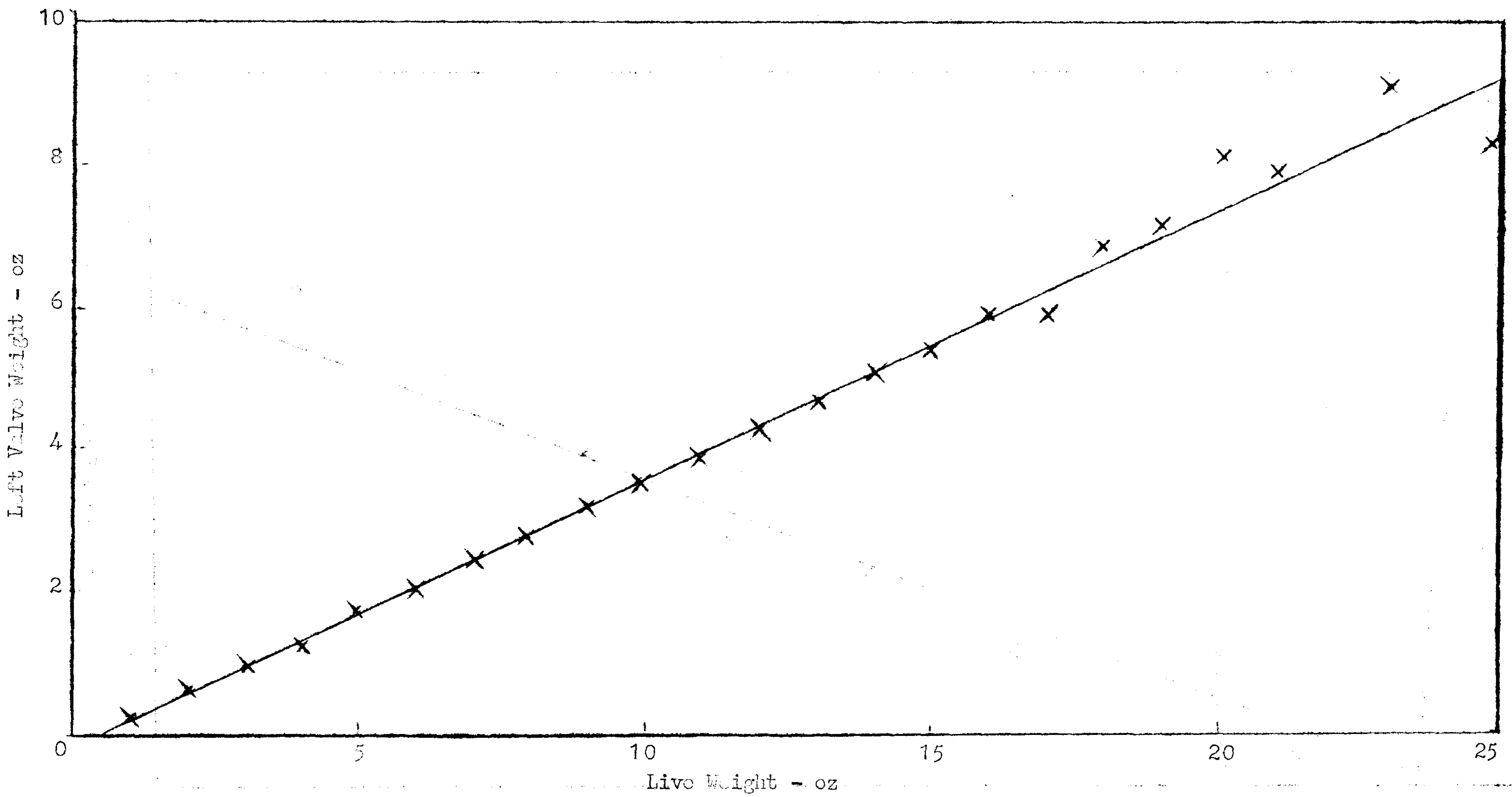

Figure 4. - P. margaritifera, Manihiki, Cook Islands. Left Valve Weight plotted against Live Weight. Line is $y = -0.1828 + 0.3738x$ fitted by least squares.

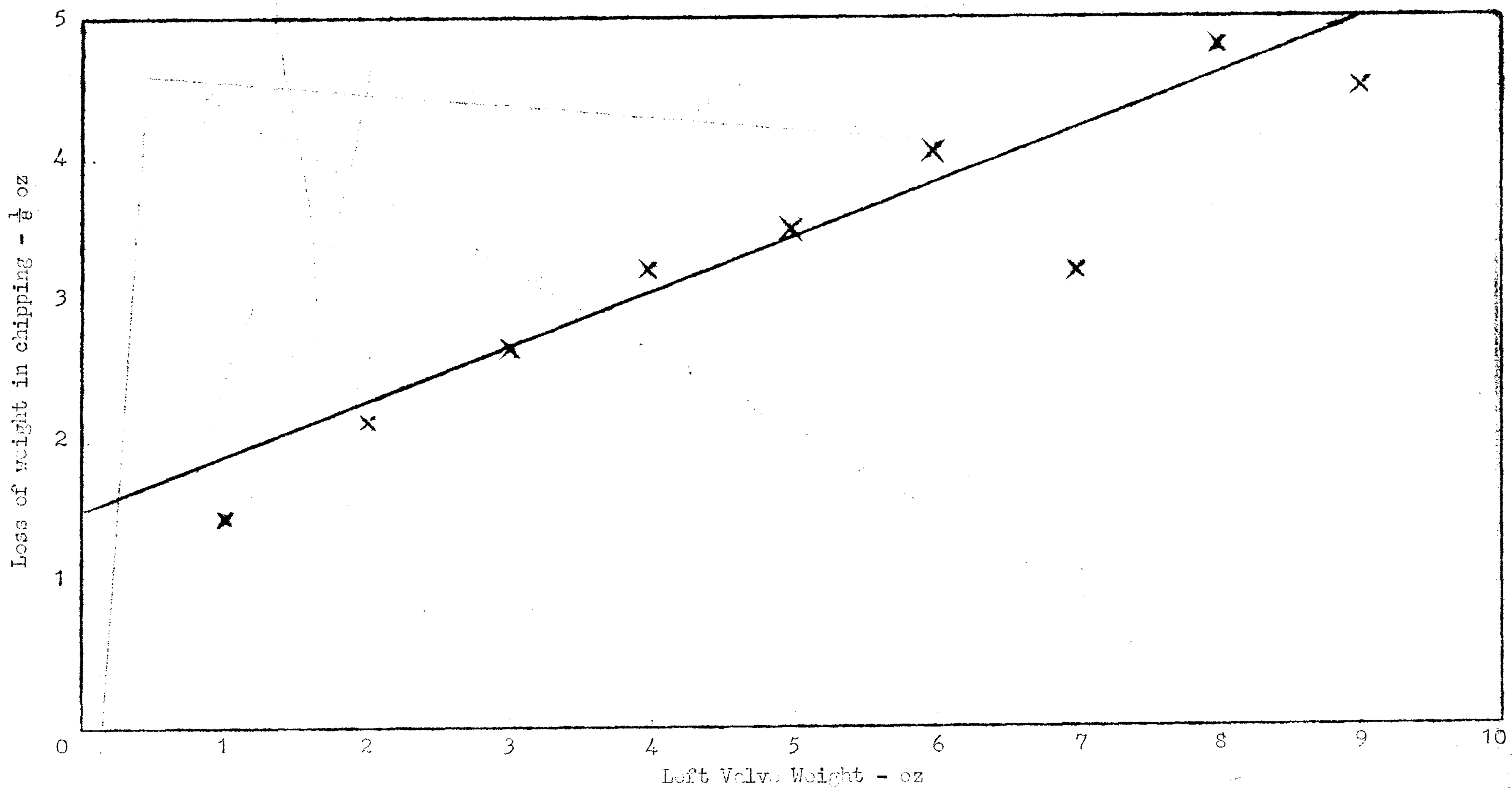

Figure 5. - *P. margaritifera*, Manihiki, Cook Islands. Loss of Weight in chipping plotted against valve weight for Left Valve. Line is $y = 1.5286 + 0.3863x$ fitted by least squares.

Figure 6 shows the differences between Left Valve Weights and Right Valve Weights plotted against Left Valve Weights grouped in 1 oz class intervals. Again in the absence of any definite indication that the relationship is curvilinear, a straight line was fitted. It is -

$$\text{L. - R. Valve Wt. } (\tfrac{1}{8}\text{oz}) = 0.2568 + 0.2896 \text{ L.Valve Wt. (oz)}$$

The following relationships were then calculated:

$$\text{Chipped Shell Weight (oz)} = -0.5024 + 0.6989 \text{ Live Weight (oz)}$$

$$\text{Chipped Left Valve Weight (oz)} = -0.3651 + 0.3557 \text{ Live Weight (oz)}$$

These are graphed in Figure 7.

(e) Relationship between Grading, Weight & Value.

The grading system employed was that in current use in Australia. There are 4 basic grades - S (Sound), D (Defective), E and EE, the last two being progressively lower in standard than Defective. The quality is judged on the number and sizes of the blemishes on the nacre, the amount of boring on the back of the shell by sponges or date mussels and the chalkiness of the shell near the heel. The grading standards vary from grader to grader and time to time and are partly dependent on the demand for shell. Recently an attempt was made by the Otto Gerdau Company to set a rigid standard for gradings. This was more rigorous than other standards previously used and was not universally adopted. The standards applied herein were somewhat easier than the Gerdau standards and would conform to the average used in Thursday Island at the present time.

The percentages of each combination of gradings in specimens grouped into ounce class intervals of Live Weight are given in Table 15. (Each valve was graded separately and the individual specimens were recorded as S/S, D/EE etc.). Inspection shows that there is a steady decrease in quality with increase in weight.

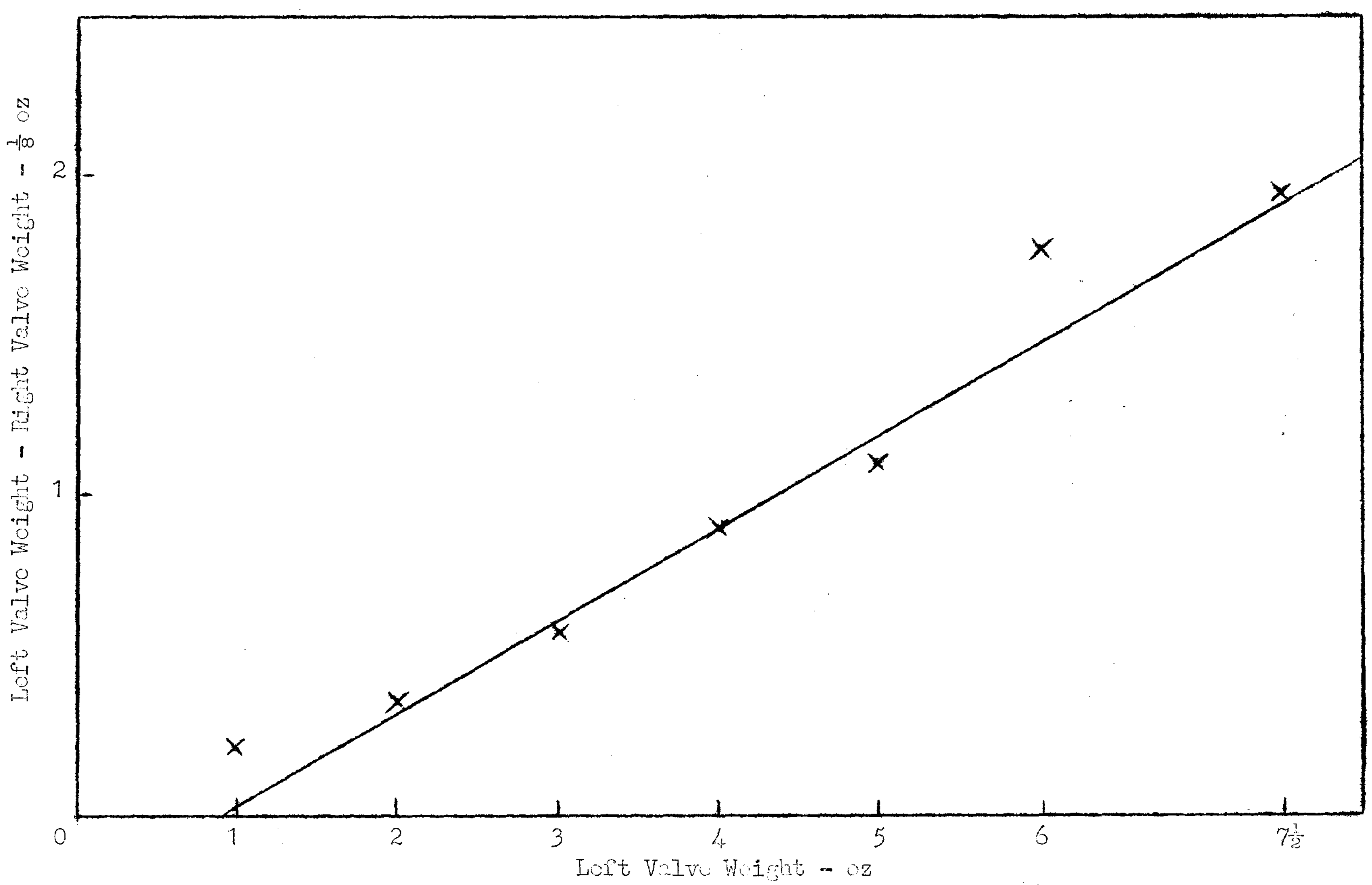

Figure 6. - P. margaritifera, Manihiki, Cook Islands. Difference between Left and Right Valve Weights plotted against Left Valve Weight. Line is $y = -0.2568 + 0.2896x$.

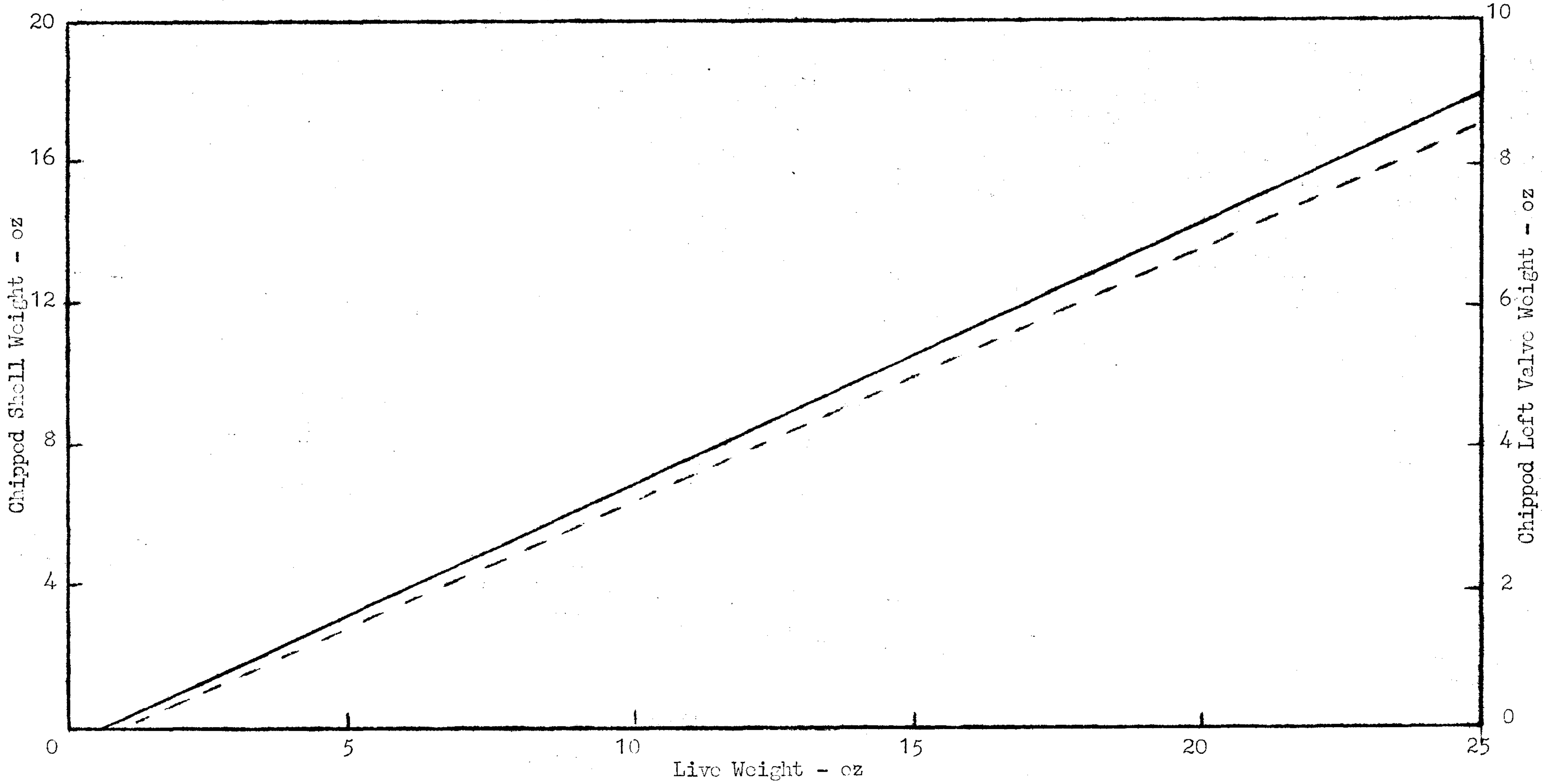

Figure 7. - P. margaritifera, Manihiki, Cook Islands. Relationship of Chipped Shell Weight to Live Weight (full line) and Chipped Left Valve Weight to Live Weight (broken line).

TABLE 15.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

PERCENTAGES OF EACH COMBINATION OF GRADINGS FOUND IN 527 SPECIMENS GROUPED IN OUNCE CLASS INTERVALS OF LIVE WEIGHT

Live Weight - oz

Gradings	½-1½	1⅝-2⅜	2½-3½	3⅝-4⅜	4½-5½	5⅝-6⅜	6½-7½	7⅝-8⅜	8½-9½	9⅝-10⅜	10½-11½	11⅝-12⅜	12½-13½	13⅝-16⅜	16½-25½
EE/EE															5.3
EE/E or E/EE													3.1		
EE/D or D/EE															
EE/S or S/EE											1.5		3.1		
E/E														2.6	
E/D or D/E									1.2	1.4	3.0			2.6	10.5
E/S or S/E								1.8	2.5				6.3	2.6	5.3
D/D							2.4		4.9	1.4	4.5	3.2	3.1	2.6	5.3
D/S or S/D			6.7			4.2	4.9	5.3	4.9	5.4	6.0	3.2	15.6	15.8	15.8
S/S	100	100	93.3	100	100	95.8	92.7	93.0	86.4	91.9	85.1	93.5	68.8	73.7	57.9
Totals	100	100	100.0	100	100	100.0	100.0	100.1	99.9	100.1	100.1	99.9	100.0	99.9	100.1
Frequency	18	10	15	10	10	24	41	57	81	74	67	31	32	38	19

Total Frequency - 527

The prices offered in Australia for the various grades of shell have varied in absolute values in the post-war period but the ratios have remained much the same. For this purpose the ratios only are important, so the Otto Gerdau Company's set of prices at present ruling has been adopted:-

S	=	£A650	D	=	£A425
E	=	£A300	EE	=	£A115

Using these data, the data of Table 15 and simplifying the relationship between Chipped Shell Weight and Live Weight to Chipped Shell Weight = 0.7 Live Weight[x], the values of 100 shells of Live Weights 1, 2, 3 etc. ounces have been calculated. They are plotted in Figure 8.

It will be seen that there is no appreciable loss due to down grading until about 12 oz Live Weight is reached. Thereafter the loss is not large within the limits of the present data but outside these it is suspected that it would increase considerably. Thus if shells of Live Weight 20 oz or less are involved in the fishery, gradings may be ignored in framing administrative rules.

(f) Natural Mortality and Optimum Size

The Live Weight frequency histogram for the combined samples is shown in Figure 9. It will be seen that there is a pronounced peak at 8 oz, with a steep slope either way. The ages of the specimens appearing in this figure are not accurately known but almost certainly cover a range of 4 to 5 years. Therefore the peaked curve cannot be the result of differential growth among the progeny of one spawning. The peak is probably the result of a spat set in 1956 the individuals now

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x This assumption causes the Chipped Shell Weights to be overestimated by $\frac{1}{2}$ oz per specimen approximately which is negligible here.

approaching legal minimum size while the slope to the right represents the remains of the 1955, 1954 and earlier sets which were subjected to fishing in 1957. The steep slope to the left could have arisen in two ways - (1) The spat sets since 1956 may have been poor. (2) The smaller shell which are not so easily visible to divers were not sampled efficiently. This effect is equivalent to that of mesh selection in fish samples taken by net and has been found to be much more prominent in pearl shell samples than might be expected. e.g. in collecting samples of P. maxima for research similar to this the divers were instructed to make special efforts to locate young shells. Experience finally showed that shells as small as 5 cm External D.V.M. could be recognised by the divers but the number seen was only a small fraction of the actual number present. The weight frequency curves took exactly the same form as that in Figure 9. That there were much greater numbers of small specimens than the samples indicated was confirmed by samples taken 12 months later. As stated above it was probably for this reason that Mr Powell had difficulty obtaining a few hundred specimens last year while this year thousands were obtained with ease. There is no evidence to suggest which of these two causes may have produced the observed effect. Sampling in 12 months time will be necessary to determine this.

The full sigmoid curve in Figure 9 represents the actual frequencies in the population assuming that the spat sets have been regular since 1956 and natural mortality slight to moderate in the first few years of life. If this is a true representation of the population at the present time and assuming that there is no further fishing and that mortality increases rather rapidly, after a few more years the population will stabilize itself and the frequency distribution will then be as represented by the broken line in Figure 9. This is considered to give the highest estimate of natural mortality likely to be found in this population. The dotted line is the natural mortality curve for P. margaritifera margaritifera in the Red Sea (Crossland 1957). The age scale is for this sub-species but probably gives a rough approximation for the Manihiki sub-species also. It is considered that this dotted line gives the lowest estimate of natural mortality likely to be found in that sub-species.

From these two curves the pereentage of specimens surviving at each ounce of Live Weight was read off. When this information was combined with the data of Figure 8 it gave two estimates, one maximum and one minimum, of the value of an initial 100 shells at any given Live Weight, allowing for loss dud to natural mortality. These two curves are shown in Figure 10. It will be seen that both curves have peaks, one at about 10 oz Live Weight, the other at about 16 oz Live Weight. This means that the optimum weights at which to fish shell are 10 oz and 16 oz for the high and low mortality rate conditions respectively. These weights correspond to 13.9 cm (= 5.5 in) and 16.2 cm (= 6.4 in) External D.V.M. and 12.5 cm (= 4.9 in) and 14.5 cm (= 5.7 in) Diagonal respectively.

(g) Estimation of Total Population

It was stated above that the density of distribution of the oysters was of the same order in all localities sampled. The diver covered approximately 100 square yards each dive and brought up approximately 200 shells. This estimate of 2 shells per square yard was confirmed by visual observation. It is the concentration of visible oysters on the highly productive grounds. If the full line in Figure 9 is an accurate estimate of the size composition of the population then the actual concentration is probably twice this.

Unfortunately nothing is known of the concentration of oysters in areas other than highly productive ones. Also it proved impossible to obtain even an approximate idea of the extent of the highly productive areas. Thus it is impossible to estimate the total population and therefore the quantity of shell that is fishable.

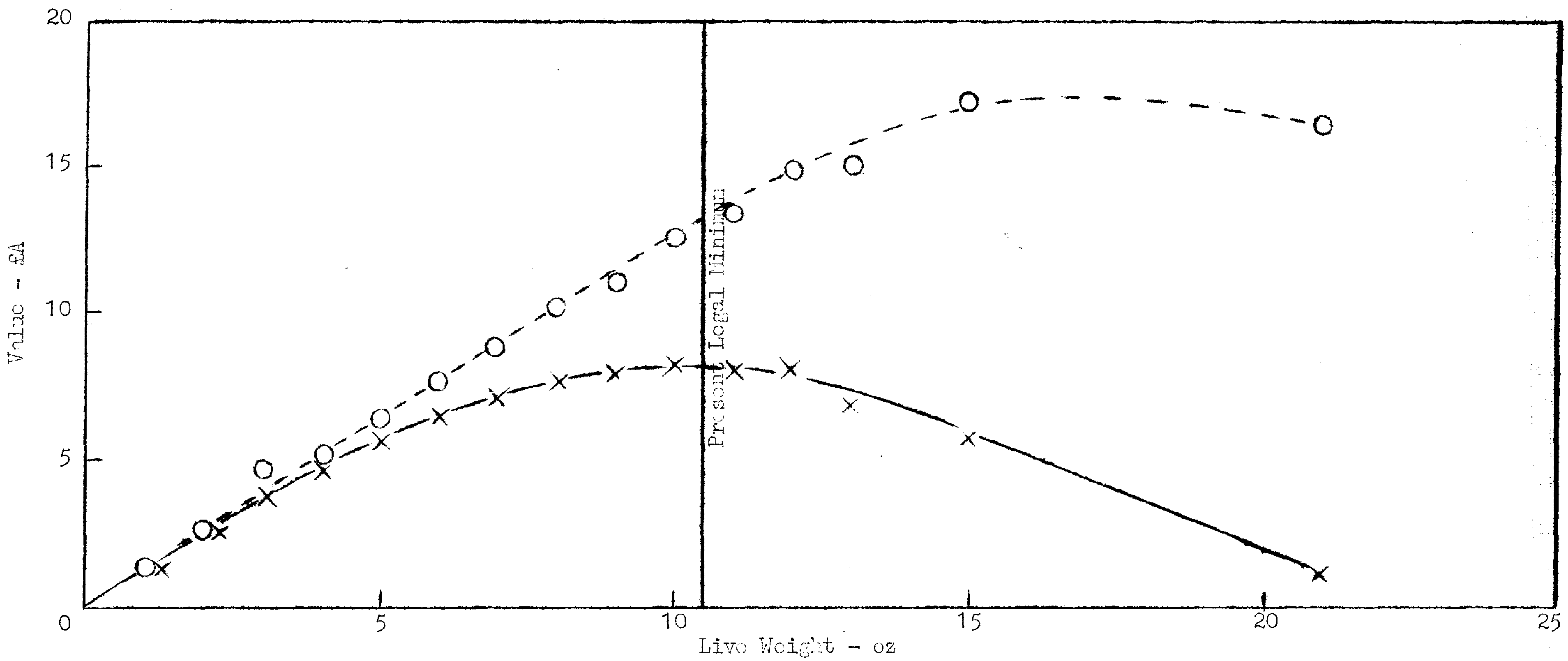

Figure 10. - Calculated value of an initial 100 shells at Live Weights 1, 2, 3 etc. oz allowing for natural mortality and depreciation due to down grading. The full line corresponds to the highest estimate of natural mortality, the broken line to the lowest.

(h) Relationship between Open & Live Heel Depths

Open Heel Depth has been selected as the basic measurement for comparison of thickness of valves as it is the only one possible on shells which have been opened. The only heel depth measurement possible on live specimens is the Live Heel Depth and thus if the increases in the Live Heel Depth with age which will be determined in the growth rate experiments are to be of general application, it is necessary to know the relationship between the two measurements.

Accordingly a scatter diagram was prepared which showed that the relationship was linear. The regressions of Open Heel Depth and Live Heel Depth were determined for five of the six larger random samples (there were no Live Heel Depth data for one sample) over the range 2 to 11 mm O.H.D. inclusive and the results subjected to an analysis of variance. The differences in slopes were significant at the 5 per cent. level for both sets of regression lines. Again the Kokiri Lui sample had a high value of b for the regression of Open on Live Heel Depth. When this sample was omitted there were no significant differences between the samples in the regressions of Open on Live Heel Depths but the differences in slope of the regressions of Live on Open Heel Depth remained significant at the 5 per cent. level.

It is clear therefore the Heel Depths need further investigation before they can be used as a criterion of age. It is proposed to investigate later on the regressions of Live Heel Depth on Live Weight.

(j) Relationship between External D.V.M. and Diagonal

The Cook Islands Pearl Shell Fisheries Regulations 1950, Ammendment No.2 of 1957 imposes penalties for fishing or possessing pearl shell of a size less than 5 inches measured along the greatest axis after trimming. It is impossible to be certain before opening a shell what this left on the average by approximately 0.2 mm. The greatest observed differences between the two valves of a pair was 7 mm.

Thus in all but young specimens the left External D.V.M. and the right Diagonal tend to be the greater measurements of their respective pairs. This could be explained by an association between them in individual specimens. Accordingly a table was prepared (Table 18) of the contingencies of External D.V.M. and Diagonal for specimens over 10.0 cm Diagonal in which there were differences within each pair of measurements Expected frequencies were calculated assuming no relationship. The resultant X^2 was 15.556 on 1 degree of freedom which is significant at the 0.1 per cent. level and the signs of the differences show that the greater measurements of each pair tend to occur on the same valve. There were 279 of these specimens and a total of 471 specimens with Diagonal over 10.0 cm. Therefore it follows that in the remaining 191 there must be a preponderance of shells in which, when the External D.V.M.'s are equal, the Right Diagonal is larger then the left or, when the Diagonals are equal, the left External D.V.M. is larger than the right.

This is in fact the case There were 32 specimens in which both measurements of each pair were equal. Of the remaining 159 there were 80 in which the Diagonal measurements were equal. Of these 42 had the left External D.V.M. greater than the right and 38 had the right greater than the left which difference is not significant. Of the remaining 79 in which the two External D.V.M.'s were equal, there were 22 in which the left Diagonal was greater than the right and 57 in which the right was greater than the left. This difference is significant.

It is now clear that (1) Differences between individual valves of a pair in External D.V.M. or Diagonal or both often occur. (2) There is an association between the two measurements in individuals which is not simple. (3) On the average the differences between the

TABLE 18.

P. MARGARITIFERA - MANIHIKI, COOK ISLANDS

CONTINGENCIES OF EXTERNAL D.V.M. AND DIAGONAL

		EXTERNAL D.V.M.		TOTALS
		L.V. > R.V.	R.V. > L.V.	
DIAGONAL	L.V. > R.V.	90 74.215 + 15.785 X^2 = 3.3574	29 44.785 - 15.785 X^2 = 5.5636	119
	R.V. > L.V.	84 99.785 - 15.785 X^2 = 2.4970	76 60.215 + 15.785 X^2 = 4.1379	160
TOTALS		174	105	279

$X^2 = 15.556^{***}$ on 1 degree of freedom pairs of measurements, though significant, are negligible for practical purposes. (4) In individual cases the differences are appreciable for practical purposes. (5) The differences are of the same order in both measurements. Thus other things being equal, either measurement would be equally useful as a basis for a legal minimum size.

A proposal is put forward below to use the External D.V.M. in this way so it was necessary to determine the mathematical relationship between the two measurements. A scatter diagram was prepared which showed that this relationship was linear. Accordingly the linear regressions of External D.V.M. and Diagonal were calculated. The equations are -

(i) Regression of External D.V.M. on Diagonal

$$y \text{ (cm)} = 0.2369 + 1.0860\, x \text{ (cm)}$$

(ii) Regression of Diagonal on External D.V.M.

$$y \text{ (cm)} = 0.7933 + 0.8441\, x \text{ (cm)}$$

The correlation coefficient $r = 0.957$ which shows that the two measurements are very highly correlated. A Diagonal measurement of 5 inches corresponds to an External D.V.M. of 5 2/3 inches.

These relationships have not been calculated from measurements of all the specimens in the samples. Diagonal measurements were made only on specimens selected so as to give a reasonably even distribution of frequencies over the range of the measurements. This has resulted in very low numbers of Diagonal measurements in some samples so no comparison is possible between samples. However it is not likely that differences between localities, if they exist, would be of practical importance.

PART III - EXPERIMENTS IN SPAT COLLECTION

REVIEW OF PREVIOUS WORK

Crossland (1957) working in Sudan and Ranson (1955) in French Oceania have succeeded in obtaining the spat of P. margaritifera in large numbers. Crossland provided floating collectors with laths of wood or bamboos arranged as vertical shelves spaced at regular intervals. He found that the spacing of the shelves was critical - "4 in. wide gave but half the number of spat found in spaces 3 in. wide and............ spaces 2 in. wide gave nothing except at the edges". The failure of the 4 in. spacing to produce as many spat as the 3 in. was attributed to relatively greater exposure to wave action and that of the 2 in. was attributed to lack of circulation. This work has been continued in recent years by Mr W. Reed who has obtained slightly different results (personal communication). Using split bamboos and 3 in. spacing he found that P. margaritifera occupied the inside of the frames while P. fucata occupied the outer more exposed areas. Ranson used faggots of "miki-miki" wood moored on wires at different depths. No details are available of the distribution of the spat within the faggots or the relative catching power of faggots at different depths.

I have found that split bamboos are quite effective for collecting the spat of P. fucata and P. albina sugillata, the two commonest species in Torres Straits. (The other species in Torres Straits, including P. margaritifera, have never settled on the spat collectors in large numbers). I have also found that wire netting is more effective for these species than split bamboo. Using netting coated with a mixture of sand, cement and a water miscible bitumen-clay emulsion, spat sets of a density comparable to that obtained by Crossland with P. margaritifera and Japanese commercial operators with P. fucata, have been procured. These materials are fairly readily available in the Cook Islands while bamboos are not, so it was decided to utilize them in making up the collectors for these experiments.

The collectors laid down by Mr Powell (Powell Ms) had been examined at more or less regular intervals over a period of 12 months and were still in place when we arrived. No appreciable numbers of P. margaritifera had settled on any of the collectors at any time but on occasions there had been large quantities of "pipi" spat (P. maculata), sometimes hundreds per square foot. There were about 25 young P. margaritifera on the collectors in April 1959 and several hundreds on the mooring chain of the raft between 1 and 3 fathoms depth. There were no pipi or M.O.P. spat on the cement slabs which were lying on the bottom. These were covered with slimy algal and ascidian growth.

It is uncertain from these results whether the sparse settlement of M.O.P. spat is due to unsuitability of the collectors, absence of setting larvae or the heavy competition from pipi spat. There is a suggestion that 1 - 3 fathoms may be the most suitable depth for setting out collectors.

PLANNING OF EXPERIMENTS

The new experiments planned for Manihiki were designed to provide solutions to three problems. First, the most satisfactory type of collector had to be found. This may not necessarily be the type that collects the greatest number of spat per unit volume or area as cost is also important. Second, it is a fact well known in bivalve culture operations that spat sets are not always evenly distributed. Thus, certain areas or localities may be outstanding in receiving regular and heavy spat sets. Crossland (1957) found this to be so for certain areas in Dongonab Bay. There was a possibility that the same might be true of Manihiki lagoon. Third, it was necessary to determine the best time to set out collectors. If set out too early the surfaces may become covered with algae, hyroids, other bivalves etc. thus preventing the settlement of spat.

A standard collector using the materials referred to above was designed. By conducting experiments in which this and other types of collector were used simultaneously, a solution of the first problem might be obtained; by placing these standard collectors in different localities and at different depths the best positions for spat collecting could be determined; and by changing and counting them monthly the best time to set out collectors could be determined.

The standard collector consisted of 12 rectangular wooden frames each 3' x 3', constructed of 2" x 1" *radiata* pine and sheeted with 1" galvanised wire netting. Netting was coated with a cement, sand and bitumen-clay emulsion mixture. These frames were spaced out by 2" wooden blocks and held together by four $\frac{3}{8}$" dia. throughbolts. Thus the wire netting sheets were spaced 3" apart and the finished collector, which is shown in Figure 11, occupied a space

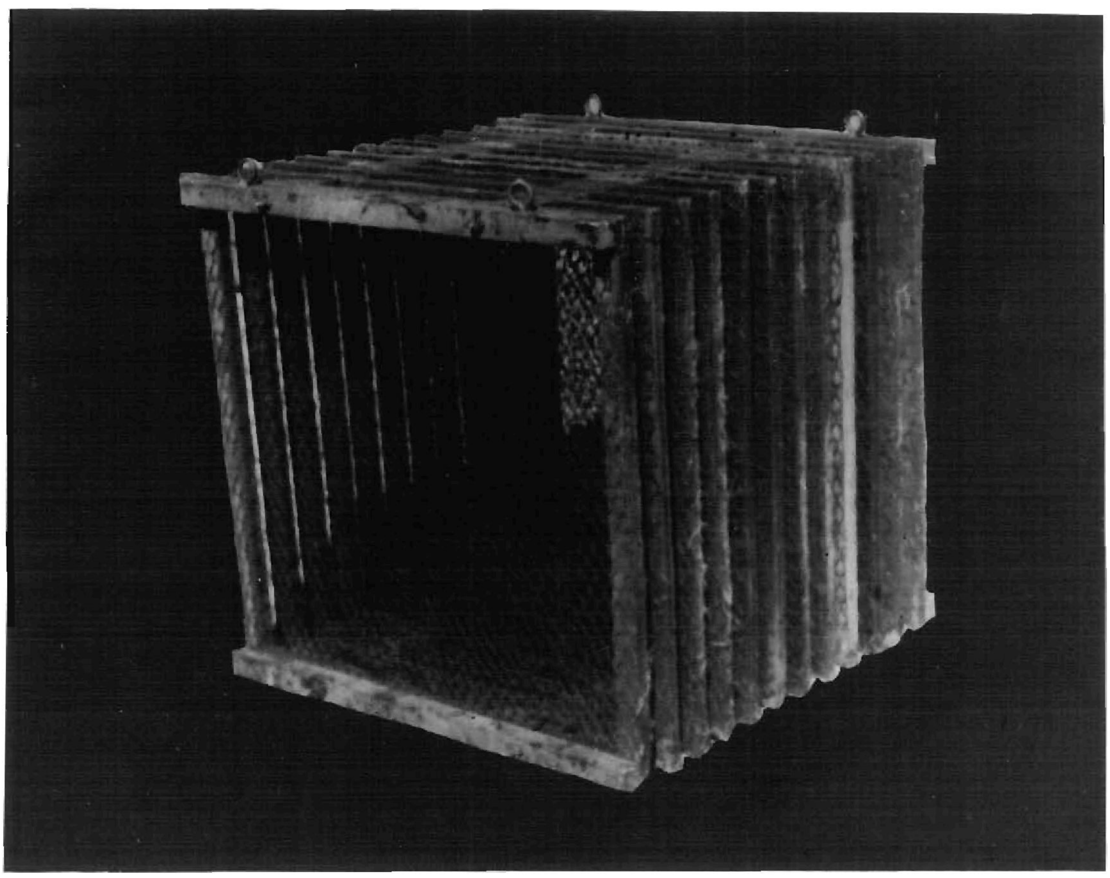

Figure 11.- A standard collector

approximately 3' x 3' x 3'. When counting spat it was proposed to dismantle the collector and count the spat on each square foot of each frame. By grouping these frame counts in three series of four frames each, a count for each of the twenty-seven one foot cubes of the collector would be obtained. Comparisons could then be made between the various parts of the collector which might suggest modification leading to increased efficiency.

It was anticipated that there would be differences in yield between individual standard collectors so for each locality or depth, a group of collectors would be required. Originally it was intended to use the collectors in groups of three, the individual collectors being allotted positions within the group by a random method (3 x 3 Latin Squares). This would permit an analysis of variance to be conducted on the results so that total variance could be dissected into variation between individual collectors, variation between positions in the group and variation between localities, depths or periods. This scheme proved too elaborate as there were sufficient materials available for 15 standard collectors only. It was finally modified so that collectors were used in pairs, the individual collectors being allotted their positions by tossing a penny.

Mr Powell's earlier experiments had shown that there was serious competition from pipi spat. It was anticipated that the same problem would arise in the new experiments. During a preliminary survey of the lagoon it was observed that pipis outnumbered M.O.F. oysters many times in the shallow water but the numbers were not so unequal in the deeper water. It was reasoned that it might be possible to reduce the competition from pipi spat by placing the collectors in the deeper water.

Further, a rough inspection of the frequency distributions of the various measurements in the samples indicated that there was probably not very much difference between areas in the density of spat sets (this is confirmed herein). Accordingly it was resolved to use the available collectors in an experiment designed to show differences in density of spat sets at various depths at one locality and at the same time monthly variation at that locality.

A position was selected where a raft could be moored in 13 fathoms of water on a bottom which carried a reasonable stock of shell. This position is shown in the map in Figure 2. The raft used by Mr Powell in the previous experiments was anchored there and two collectors hung from it at 1 fathom and two at 7 fathoms by means of ½" R.M.S. rods. Two more collectors were set on two concrete beams laid on the bottom a little distance from the raft. Thus at any one time there are six collectors in operation, six being counted or drying out and three spares.

The collectors were "aged" before being placed in position by soaking in seawater for two weeks followed by drying out. This brings the surfaces into a condition suitable for spat sets. The collectors floated initially and had to be weighted with concrete slabs. Later they became waterlogged and remained in position without weights.

RESULTS TO DATE

The first set of collectors were put out on 13th-15th May. They were not in a condition suitable for the immediate settlement of spat as during the ageing process the wire had become clogged by drifts of fine filamentous algae. This took several weeks to rot off the 1 and 7 fathom collectors and they were not in suitable condition until about 6th June. The 13 fathom collectors were still coated with this rotting weed after eight weeks indicating that movement and sections have not been combined in further analyses.

Differences between the samples in proportion of gonad stages from month to month were also tested by contingency tables and X^2 tests. In all these tests the frequencies of stages 0 and 1 combined were compared with the frequencies of stages 2 and 3 combined. In the under 10 oz section, differences significant at the 0.1 per cent. level were found to exist. Further investigation showed that there were no significant differences between the May to October samples but combined they differed significantly at the 0.1 per cent. level from the two April samples combined. There were no significant differences between the two April samples. This difference is due either to spawning or resorption of gonad after spawning. Histological examination of the gonads is necessary to confirm this.* In the 10 oz and over section, differences significant at the 0.1 per cent. level were also found. There were no significant differences between the June to October samples but combined they differed significantly at the 1 per cent. level from the May sample and it in turn from the two April samples combined at the 5 per cent. level. Again this difference is due to spawning or resorption of gonad after spawning.

It is clear that there has been no significant gonad activity between 25th June and 28th October. Prior to 25th June it is possible that a spawning or a spawning followed by resorption of gonad occurred. As the first collectors were not in a condition to receive spat until 6th June it is possible that they were not available to the larvae derived from this spawning so that the sparse settlement on them may not be any indication of their efficiency.

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* Gonad sections are not yet available.

PART IV.

CONCLUSIONS AND RECOMMENDATIONS

The results of the spat setting work to date are inconclusive. One fact that has emerged is that the present method of supporting collectors is unsatisfactory. Reports indicate that the tagged shell attached to nylon ropes supported by submerged floats are doing extremely well and the ropes and floats are unaffected by bad weather. Mr Powell has suggested in correspondence that this method be used to support the collectors also. However, it is recommended that the change be made only after the experiment has been running twelve months.

The results of the biological investigations may be summarised as follows:-

1. The population is biologically isolated and there is no evidence of internal genotypic variation.

2. For practical purposes it is divided into two parts, one in 0 to 20 fathoms which is accessible to divers, the other below 20 fathoms which is net.

3. The shallow water population was depleted by overfishing but is regenerating from spat sets probably derived from the deep water population.

4. The growth rate of the shallow water population is uniform with respect to Live Weight but shows diversity between localities with respect to Heel Depth and External D.V.M. The actual growth rates are not yet known.

5. For the highly productive areas spat sets are evenly distributed with respect to locality. There is no evidence as to the distribution in time.

a regulation it is not recommended that the External D.V.M. be adopted as the basis for a legal minimum size. One such difficulty easily envisaged is that the regulations could be evaded by trimming the shells as soon as fished. However, from the biological point of view there would be no objection to the application by the divers of 5 2/3rd inches External D.V.M. as a preliminary yardstick before opening and subsequent impounding and sale by the Administration of those shells less than 5 inches Diagonal measurement (or broken shells). If the minimum size of 5 inches is adhered to, it is recommended that this practice be adopted.

The tagged shell will be remeasured in April-June of 1960 to determine growth rates. While this is being carried out it is recommended that the random samples of 150-250 individuals at the six localities - Mangungu, Kokiri Lui, Hotu off Taihahara, South Fare Ngati, South Tearai and Ohou - be repeated. This will assist in the determination of recruitment and natural mortality. These samples should be taken as close to the end of April as possible. Only Live Weight, External D.V.M., External A.P.M., Open Heel Depth, Live Heel Depth, Hinge Line and Thickness need be measured. It is also recommended that the survey commenced by Mr Powell be completed and that an effort be made to estimate density of stocks on bottoms other than highly productive ones.

For reasons given above it is stressed that sampling of the deep water population be given urgent consideration. Mr Powell has already recommended to the Resident Commissioner, Cook Islands, that the New Zealand Navy be approached for assistance with divers and gear. This recommendation is supported.

It has recently become a practice in Manihiki for the diving boats to retain any undersize shell taken and place them in shallow water in "banks" where they can be watched. These banks are located on areas of sandy bottom at the edges of the lagoon adjacent to the two villages. The planters claim proprietorial rights over these banks. The legal and moral implications of these actions do not concern us here but the biological ones do. As a general rule, removal of young shell from their natural surroundings and planting out in a different area is only justifiable if the young shells are overcrowded and growth rate is less than maximal or the subsequent harvesting is made appreciably easier. At the same time these advantages may be offset by increased mortality due to the handling and planting or slowing up of growth due to unsuitable conditions in the banks. In this case there is no evidence of overcrowding of young shells but subsequent harvesting is made considerably easier. However sandy bottoms are not a natural environment for the M.O.P. oyster and growth may be slower and mortality higher than normal. One of the banks was inspected and no evidence of increased mortality was found. However there was no way of telling from this inspection whether growth rate was normal. Accordingly it is recommended that 500 shell in one of these banks be measured, tagged and returned to the bottom. There was not time to do this during April-June 1959.

The Cook Islands Pearl Shell Fisheries Regulations 1950 Section 11 requires that all shell be opened immediately it is taken and the "spawn" returned to the water. Presumably the intention is that the eggs may have an opportunity to be fertilized and develop into adult oysters. This is impossible as the eggs at that stage are immature, still retaining the germinal vesicle and are unfertilizable. They become mature and fertilizable only during the act of spawning. Thus the returning of the spawn to the water achieves nothing and results in the loss of a great food delicacy. It is recommended that the section be deleted.

Finally it is recommended that if the lagoon is opened for fishing one of the six areas already sampled be permanently closed to fishing for experimental purposes. The object of this is to determine how long an overfished area takes to return to equilibrum conditions. Also when this condition is achieved the frequency distribution in the population will give an accurate measure of natural mortality. The most suitable area for this purpose would be either Ohou or South Tearai. A "rahui" placed on the waters surrounding either of these islets for a radius of ¼ mile would provide adequate space for the experiment and the actual loss to the fishery as a result would be minute.

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JSHynd
J.S. Hynd
Thursday Island, 20/1/60.

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