DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Victorian Fisheries Research Institute

Development of Commercial Field Nursery and On-growing Systems for Production of the Flat Oyster (*Ostrea angasi*) in Open Waters.

By:

David Reilly and Neil Hickman

Final Report to F.R.D.C.
on Project DCL5Z.

December 1994

MARINE SCIENCE LABORATORIES

CONTENTS

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BACKGROUND

The Aquaculture Initiative of the Victorian Government's 1987 Economic Strategy selected the Flat Oyster (*Ostrea angasi*) as a species with aquaculture potential. Three projects were established at the Victorian Fisheries Research Institute (V.F.R.I.), Queenscliff, to investigate the different aspects of Flat Oyster culture.

1.) A hatchery was established to produce oyster seed which was available for sale to prospective oyster growers.

2.) A storage and shelf life project was initiated to determine the best handling and storage procedures for the flat oyster to ensure that the oysters remained alive and in good condition throughout the distribution chain.

3.) Commercial nursery and on-growing systems, suitable for the production of flat oysters in exposed waters were developed and trialled. This project forms the basis of this report.

The report is divided into two sections, namely:

1.) Field nursery systems for *O. angasi* production

2.) Growout systems for *O. angasi* production.

This division reflects major differences in the husbandry requirements for oysters during these stages of their growth.

The project was a joint effort of the V.F.R.I., Queenscliff and the Australian Flat Oyster Company (A.F.O.C.) who operated a shallow water nursery and a deep water site suitable for longline culture.

SECTION 1.

Field nursery systems for *O. angasi* production.

The nursery stage is the initial phase of open water culture which deals with juvenile oysters or spat obtained from either collectors placed at sea or from oyster hatcheries. Oyster spat are small in size (3-10 mm) and therefore require special treatment. An innovative deep-water rotating system was developed and compared with more traditional static nursery systems.

ABSTRACT

Development and trial of field-based nursery systems for the Flat Oyster *Ostrea angasi*, showed that there was a great potential to improve growth performance of seed oysters. Design and operation of innovative rotating and static nursery systems are described. Traditional bottom and rack culture growing methods were not viable in Victoria because of the incidence of the deadly flat oyster disease Bonamiasis which attacked mature two year old stock. Development of a new suspended culture method produced exceptionally fast growth rates with low mortalities. The use of husbandry techniques to grow flat oysters quickly is proposed as a management tool to control the disease Bonamiasis which has devastated flat oyster production throughout the world.

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1.1 Deep-water rotating systems

1.1.1 Introduction

Traditional methods of oyster culture have relied on the collection of naturally produced oyster spat. A good example of this is the classical style of oyster culture still practised today in Brittany, France. Spat of the European flat oyster (*Ostrea edulis*) are caught on ceramic tile collectors that are bundled together to form 'bouquets'. The 'bouquets' are coated in lime before being placed on supports in the intertidal zone. In the spring of the following year, the tiles are brought ashore for detachment of the spat (Korringa, 1976a).

The capture of oyster spat in sufficient quantities for culture is often fraught with problems and the unpredictable spatfall of *O. angasi* in Victoria required hatchery production (Hickman and O'Meley, 1988). Severe setbacks in the culture of the Pacific oyster (*Crassostrea gigas*) in Tasmania caused by unreliable sets in the 1970's and early 1980's, led to experimentation with hatchery production (Sumner, 1980) and today, Tasmania's oyster industry is almost solely reliant on hatchery produced spat. Hatchery techniques developed for the Sydney rock oyster (*Saccostrea commercialis*) have enabled the production of single-seed oysters which are less likely to grow together and therefore greatly reduce the labour and mortality associated with separating them (Holliday et. al., 1988).

Despite the advantages that oyster hatcheries provide, the small size of the culchless spat makes it difficult to handle. Oyster seed of 3 to 5 mm must be held in fine meshes to both contain the oysters and to protect them from the threat of crabs and other predators (Walne and Davies, 1977). These fine meshes are prone to rapid fouling in most marine environments. Once meshes become blocked, water flow becomes restricted which greatly reduces the availability of planktonic food and leads to marked reductions in oyster growth (Michael and Chew, 1976). Large variability in size is another common feature of seed oyster growth in static growing systems, such as fine mesh bags. In such systems, all the oysters do not grow at an even rate and often a small proportion of the population grow quickly to the detriment of the rest (Sumner, 1980). Optimal growth performance from oyster seed can only be achieved by intensive labour, requiring frequent bag changes and gradings. In some instances, the fouling of trays is so rapid that labour costs for thinning the oysters and cleaning the meshes can become prohibitive (Korringa, 1976b).

In an attempt to overcome the problems of handling small oyster seed, a rotating cylinder was designed by Stan and Wayne Moxham and is currently being used to grow Pacific oysters in the tidal estuaries of New South Wales. The Stanway cylinder as it is known, consists of a mesh cylinder with removable end caps which provide flotation and allow easy access to the oysters held inside. The end caps are linked by a pipe which runs along one side of the cylinder. An oyster stick, passed through the pipe and fixed to an oyster rack, acts as a pivotal point. As the tide rises and falls the cylinder moves through an arc and the oyster seed is tumbled backwards and forwards. It was suggested that this system produces oysters of uniform shape and size and removes silt from around the spat due to the constant washing motion (Moxham, 1985). In using the Stanway cylinder, spat must be size graded frequently

to avoid overcrowding and inhibition of growth and the meshes should be cleaned regularly to prevent a build up of fouling (Ayres, 1988).

To overcome the problems of fine meshes becoming fouled and of the competition between neighbouring oysters for available food, a prototype underwater field nursery system was designed to contain oyster seed in a cylinder which was turned by the tide and possessed meshes which were self-cleaning. A number of field trials were run to test the operation of the system and the growth performance of oyster seed contained in it.

1.1.2 Materials and Methods

Seed oyster growth in prototype rotating system.

Graded oyster seed (mean $\pm$ S.D.; 4.4 $\pm$ 0.84 mm) for the experiment was obtained from the V.F.R.I.'s oyster hatchery and allocated to two treatments as follows:-

Treatment 1 - 100,000 seed in prototype tumbler (see Appendix 2).
Treatment 2 - 5,000 seed in each of three 1.5 mm plastic mesh bags held on a bottom mounted oyster tray.

The tumbler mechanism was adjusted so that the cylinder would complete four revolutions per day. With each rotation of the cylinder, static brushes cleaned the meshes to remove fouling organisms. Both the oyster seed in the tumbler and that contained in the bags was supported at approximately one metre above the bottom.

An area at Blairgowrie (see Appendix 1) was selected for this growth trial because its depth (8 metres) provided protection from wave action and because the site had sufficient current (> 0.8 km/h) to operate the tumbler lever arm and sail.

The experiment was deployed on 11 April 1989 and ran until 16 August 1989, a period of approximately eighteen weeks. The tumbler cylinder and the three bags were brought aboard a research vessel each fortnight. At each sampling, the total weight and volume of oysters was recorded for both treatments and a subsample was collected from each bag and from the tumbler. These subsamples were digitised electronically onto computer for later length frequency analysis.

At the conclusion of the experiment, similar grades of oysters were taken both from the tumbler and the bags. These oysters were placed into 6 mm plastic mesh bags which were held in an oyster tray supported approximately 0.5 m above the bottom. These oysters were on-grown in bags over a four month period (summer months) to determine if there was any inherent growth advantage as a result of overwintering oyster seed in a rotating system. The oysters were sampled bimonthly at which time subsamples were taken from the bags to provide length data.

Effects of rotation on seed growth.

To determine the effects of rotation on seed growth, a second tumbler was constructed. The drum in the first tumbler was designed to revolve a full turn with each tidal change (four revolutions per day). The second tumbler was modified so that the drum would complete a half revolution on the ebb tide (twelve hourly cycle), or one revolution per day. Both tumblers possessed brushes to clean the fine mesh as the drums revolved.

Failure of the Victorian hatchery required that seed for the experiment was obtained from Shellfish Culture Ltd. Bicheno, Tasmania. The only seed available was two year old stunted stock. Whilst the growth achieved using this seed may not give a true indication of the full potential of the rotating drum system, the initial quality of the oysters should not have affected the comparative nature of this trial, since the oyster seed was divided randomly between the two treatments.

To reduce the large size range which existed, the seed was sieved using a 4000-5640 µm sieve. Equal volumes of seed (390 ml.) with a mean length of 3.79 $\pm$ 0.04 mm, were placed in each rotating drum and the two tumblers were deployed at Blairgowrie (see Appendix 1) on 29 May 1990. The weight and volume of oysters were recorded at one intermediate sampling and again at the final sampling on 19 July 1990, after a period of 51 days. A subsample was also taken from each tumbler at this final sampling to compare the length distribution of oysters resulting from the two tumbling regimes.

1.1.3 Results

Seed oyster growth in prototype rotating system.

The oysters grown in the rotating cylinder exhibited a more uniform distribution of lengths, with less variation than bag grown oysters. The standard deviation of shell lengths was only 2.3 mm for oysters in the rotating cylinder compared to a mean standard deviation of 4.3 mm for oysters in the mesh bags (Fig 1). Analysis of the length frequency distributions, revealed that the bags produced non-normally distributed growth patterns after only two weeks and that the length distribution became more skewed throughout the eighteen week period. The tumbler on the other hand, maintained a population of oysters with a normally distributed length frequency throughout the experiment.

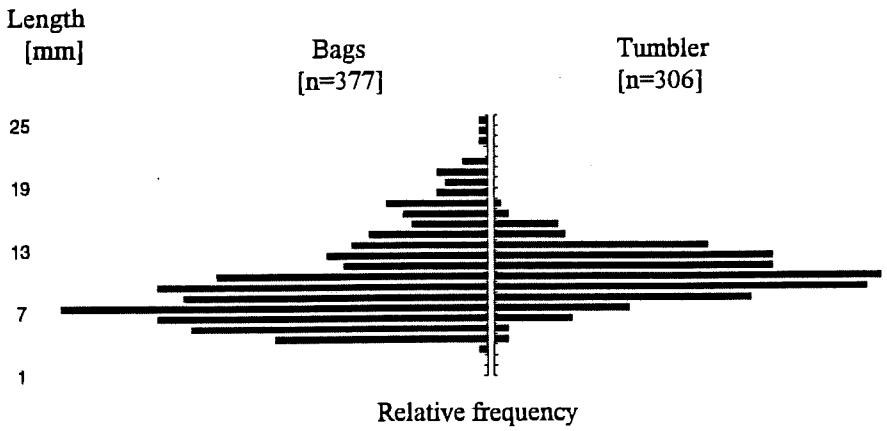

Fig 1. Length frequency distributions show the uniform growth of seed grown in the tumbler compared to seed grown in static bags.

Prior to the 18 July sampling, the mean length of oysters grown in bags was significantly greater ($p<0.05$) than the mean length of oysters grown in the tumbler (Table 1.). At 18 July sampling, the median lengths achieved by the tumbler grown seed and seed grown in bags of 9.9 mm and 9.6 mm respectively, were very similar and the mean lengths, although greater for the bag grown oysters, were not significant at the 5 percent significance level. After 18 July, there appeared to be a negative growth trend for bag grown seed, whereas, the tumbler seed maintained a positive growth trend, although at a reduced rate (Fig 2). The final sampling showed that the oysters from the tumbler had a larger median length and a significantly greater ($p<0.001$) mean length than the oysters grown in the bags (Table 1).

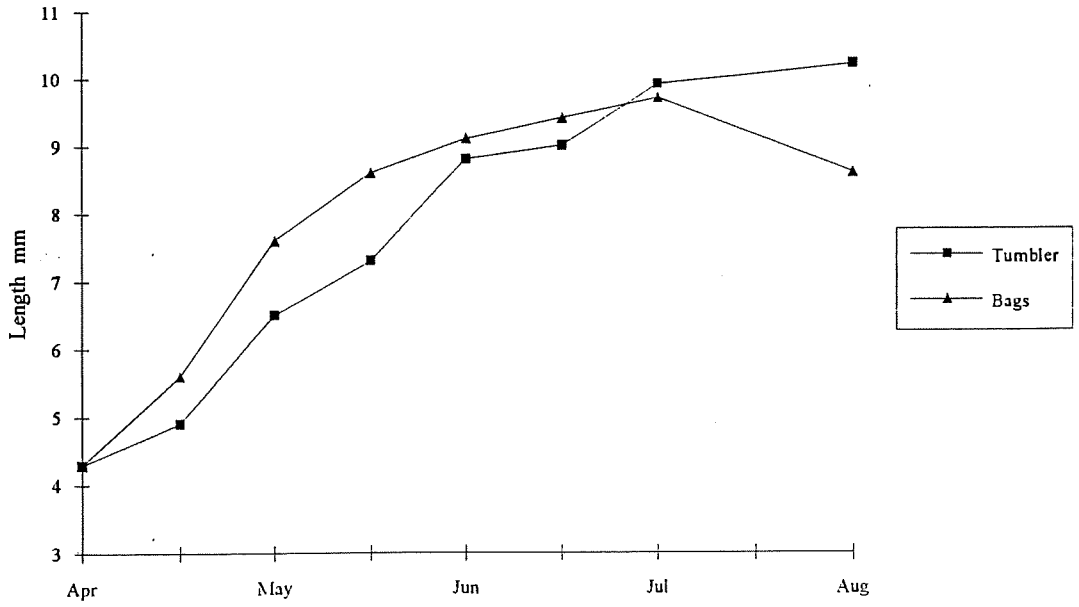

Fig 2. Plot of median oyster lengths (millimetres) with time for oysters grown in the tumbler compared to oysters grown in bags.

Table 1. Lengths (in millimetres) and standard error of oyster seed grown in the tumbler and in soft mesh bags.

Dates	11 Apr	27 Apr	11 May	25 May	6 Jun	22 Jun	18 Jul	16 Aug
Tumbler								
Mean	4.4	4.9	6.5	7.3	8.8	9.0	9.9	10.2*
Median	4.3	4.9	6.5	7.3	8.7	8.9	9.9	10.1
S.E.	0.04	0.05	0.09	0.10	0.15	0.14	0.14	0.13
Bags								
Mean	4.4	5.7	7.8	9.3	9.9	10.2	10.8	9.5
Median	4.3	5.6	7.6	8.6	9.1	9.4	9.7	8.6
S.E.	0.04	0.04	0.08	0.17	0.17	0.18	0.19	0.22

* Mean length of tumbler grown seed is significantly greater at the 5% level of significance.

During the initial three months of the experiment, from 11 April until 18 July, the mean weight of the bag grown oysters was greater than that of the oysters grown in the tumbler. A decline in the growth of oysters in the bags during the latter part of the experiment meant that their final mean weight was approximately 7 percent less than the mean weight of the oysters grown in the revolving cylinder (Table 2).

Table 2. Mean weights and mean volumes of oysters grown in the tumbler compared to those grown in plastic mesh bags on a tray.

Date	Tumbler		Bags	
	Mean wt. (mg)	Mean vol. (µL)	Mean wt. (mg)	Mean vol. (µL)
11 Apr	7.5	12.6	8.4	12.6
27 Apr	11.5	17.2	13.6	25.2
11 May	24.7	33.3	32.9	61.7
25 May	40.2	53.3	56.6	111.7
6 Jun	48.8	60.8	60.2	133.3
22 Jun	65.7	85.0	79.4	154.0
18 Jul	92.4	123.0	106.7	173.3
16 Aug	122.0	150.0	113.4	186.0

The mean volume of oysters in the bags was greater than the mean volume of oysters in the tumbler throughout the experiment (Table 2) and is clearly depicted in Fig. 3. It is interesting to note that increases in both oyster mean weight and mean volume for the tumbler grown seed followed similar curves, whereas a large disparity existed between the mean volume and mean weight of oysters grown in the bags (Fig 3).

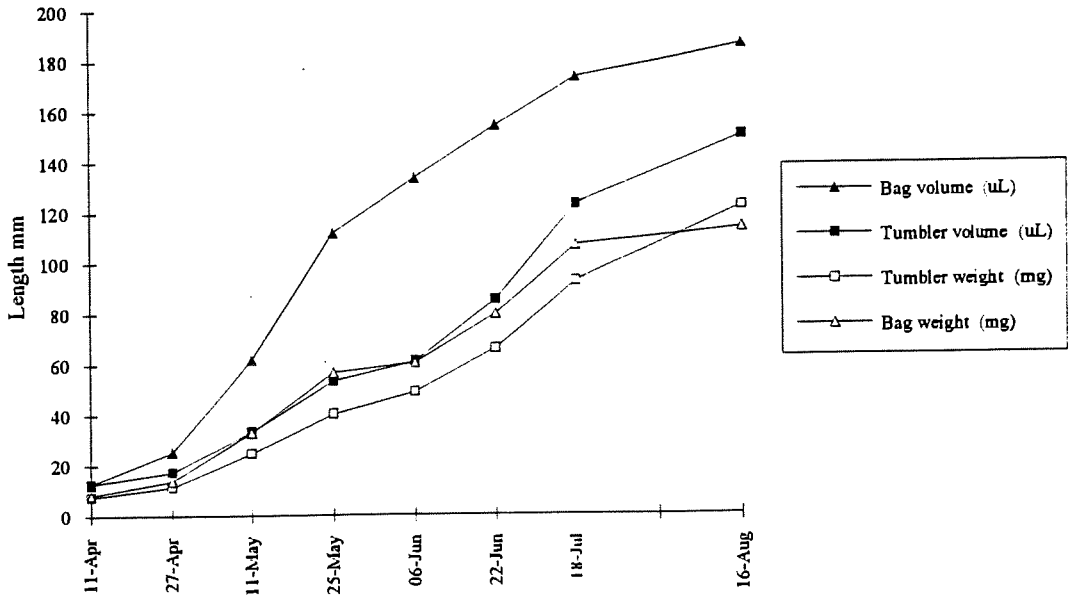

Fig 3. Mean weights (mg) and volumes (uL) of oysters overwintered in the tumbler and in static, soft-mesh bags.

The tumbler grown oysters appeared 'cupped' and regular in shape. The meat in the tumbler oysters completely filled their shells. In contrast to this, bag grown seed was variable in shape, with the largest oysters having fine, frilly margins.

The mesh of the cylindrical drum of the tumbler was only slightly fouled (<5% mesh occluded) by hydroids and a small number of oysters in the drum were stuck together by ascidians. In contrast, the bags were badly fouled (80% mesh occluded) by hydroid and silt, and the tray upon which they were supported was extensively colonised by small red macroalgae. The oysters in the bags were covered in a fine layer of silt whereas the oysters in the tumbler were clean.

Tumbler oyster mortalities were less than one percent. When bags were replaced regularly, mortalities were similarly low.

Although the same sieve (10 mm mesh size) was used to grade the oysters from the tumbler and the nursery bags prior to on-growing in mesh bags, it was found that the mean length of oysters obtained from the tumbler was significantly greater ($p<0.05$) (Table 3). After a period of 48 days of on-growing, there was no difference ($p>0.05$) between the mean lengths of oysters in the two treatments. A further 57 days of on-growing failed to produce any significant difference between the mean lengths of oysters originating from the tumbler and those from the mesh bags.

Table 3. Mean lengths (millimetres) and standard error of oysters on-grown in 6 mm mesh bags after being overwintered in a tumbler and nursery bags.

Date	Treatment	Mean length	S.E.
28/09/89	ex-tumbler	12.9*	0.13
	ex-bag	11.8*	0.32
15/11/89	ex-tumbler	18.7	1.02
	ex-bag	17.3	0.29
11/01/90	ex-tumbler	29.9	0.53
	ex-bag	30.0	0.82

* Significant at 5% level of significance.

Effects of rotation on seed growth.

The stunted stock which had not grown for two years produced noticeable winter growth during the seven weeks of the trial from May to July. While growth occurred in both tumblers, growth was superior in the drum which turned four times daily. The relative increase in volume was 27% greater for oysters grown in the cylinder which turned four times per day than for those oysters grown in a cylinder which turned only once per day (Table 4.). Likewise, the relative increase in weight was 30% greater for the oysters grown in the drum which revolved four times per day. Although the mean length of oysters tumbled four times per day was significantly greater ($p<0.05$) than the mean length of oysters tumbled only once per day (Table 4.), the difference in growth was very small.

Table 4. Volumes, weights and mean lengths $\pm$ S.E. for oysters exposed to two levels of rotation in tumblers, namely four revolutions per day and one revolution per day.

Date	4 revolutions / day			1 revolution / day		
	Volume (ml)	Weight (g)	Mean length (mm)	Volume (ml)	Weight (g)	Mean length (mm)
29/05/90	390	616	3.8 $\pm$ 0.04	390	620	3.8 $\pm$ 0.04
03/07/90	910	1354	N/A	800	1194	N/A
19/07/90	1075	1650	5.5 $\pm$ 0.05*	970	1474	5.3 $\pm$ 0.05

* Significant difference at 5% level of significance.

1.1.4 Discussion

Seed oyster growth in prototype rotating system.

The more uniform distribution of lengths associated with tumbler grown seed was attributed to frequent abrasion and regular mixing of the oysters in the drum. The latter ensured that oysters had equal exposure times to the available food. The lack of mixing in the mesh bags meant that the oysters towards the outside would deplete the water of available food (Michael and Chew, 1976), thereby increasing in size to the detriment of oysters towards the middle of the bags. This would explain the non-normal distribution of lengths of oysters grown in the mesh bags.

The frequent mixing of the oysters grown in the tumbler also resulted in abrasion of the oysters' frill which gave them their rounded, polished, 'cupped' appearance. The loss of fine frill due to abrasion also explains why the volume/weight ratio was much greater for the bag grown oysters than those grown in the tumbler. The elevated volume for the oysters grown in the bags was due to fine frill present on the oysters in the absence of abrasion. The frill, whilst causing a dramatic increase in volume, had less of an effect on oyster weight due to its thin nature.

In evaluating the tumbler growth results, the most important factor was that the tumbler was self-cleaning and ran maintenance free for eighteen weeks. A comparable result in the bags was only achieved through the high labour of fortnightly cleaning. When only one cleaning trip was missed at the end of the experiment, growth in the bags almost stopped. The regular cleaning of the bags provided a growth advantage which may not occur in many commercial nursery operations in which bag meshes are cleaned less frequently. After a period of eighteen weeks, oysters grown in the revolving drum were significantly larger ($p<0.05$) than oysters contained in soft mesh bags, but more importantly, were very even in shape and size and of excellent quality.

Oysters from both the tumbler and the bags, when on-grown at the conclusion of the tumbler trial, showed no significant ($p>0.05$) difference between their growth rates. Whilst the tumbling of oysters did not pass on any characteristics which resulted in enhancing subsequent growth performance, the abrasion received by the oysters held in the rotating drum did not inhibit future growth in any way.

The uniform growth achieved in the tumbler, low mortality, limited fouling and low maintenance all indicate that this system has great potential as a cost effective tool for overwintering seed during a post-hatchery/pre-nursery stage. Thus it could be used for value adding to convert A$15/1000 seed as purchased from a hatchery at 2-3 mm into A$35/1000 seed of 10 mm in length.

Unfortunately, sufficient quantities of oyster seed for these experiments only became available during the two winters of the study. In order to test the full potential of this rotating system, trials should be repeated over the main summer growing period.

Effects of rotation on seed growth.

The rotating drum created conditions suitable for winter growth of stunted oysters which had not grown for two seasons.

The higher tumbling intensity of four complete revolutions per day resulted in better overall oyster growth than did the lower intensity of one revolution per day. It was apparent from the results that any retardation in growth due to the greater abrasion experienced by the oysters which underwent four revolutions per day, was more than adequately compensated for by the more frequent cleaning of the meshes to remove fouling organisms and to improve water flow.

The optimum frequency of rotation to maximise the growth of oyster seed is likely to be dependent on such things as water temperature, food availability, current strength and the presence of fouling organisms which vary with growing site and season. Therefore, the particular nursery site and season will determine the frequency at which the seed should be tumbled to achieve the best growth results. However, the superior performance of the seed grown in the drum which revolved four times per day stressed the importance of keeping the fine meshes free of fouling organisms and the oysters well mixed so as to both improve water flow and increase the availability of food. Therefore a rotating drum which completes four revolutions per day is probably closer to the ideal than one which completes only one revolution per day.

1.2 Shallow water static systems.

1.2.1 Introduction

O. angasi is a subtidal species and for this reason all growth trials were restricted to the use of growing modules which operated subtidally. A.F.O.C. initially adopted traditional static tray and bag culture for the nursery phase of their commercial operation. Design and field testing revealed several limitations with this method and led to the development of an improved system, named the 'nursery corf', which consisted of stackable plastic mesh boxes.

1.2.1 Materials and Methods

Comparison of growth in a nursery corf with that in a bag and tray system.

Oyster seed used for the experiment, was produced at the V.F.R.I. hatchery (summer 88/89) and overwintered in the A.F.O.C. field based nursery, in Swan Bay (Appendix 1). The oyster seed was approximately twelve months old prior to the experimental trial.

A quantity of grade 3 seed (approx. 15L; estimated 38,600 oysters) was obtained by hand sieving. Oysters which passed through a number 4 sieve (11.2 x 11.2 mm; diag. 15.8 mm) and were retained on a number 3 sieve (8 x 8 mm, diag. 11.3 mm), were used in the experiment. Therefore the potential size range of the seed, based on sieve sizes, was between 8.0 mm and 15.8 mm.

One nursery corf consisting of two columns of ten, 6 mm plastic mesh growing boxes and two trays (Appendix 3) each containing nine, 6 mm soft mesh bags, were used for the experiment. Seed was randomly distributed between treatments by volume; 750 ml per rigid plastic nursery box and 375 ml per soft mesh bag, thus giving a total volume of 6,750 ml of seed per treatment. Approximately 1900 oysters were allocated to each of nine nursery boxes, which filled one side of the nursery corf. The tenth box was left empty, which is common practice, since this box tends to collect silt when in direct contact with the seabed. The second column of the nursery corf was filled with empty boxes to simulate, as closely as possible, the water flow characteristics of a fully loaded corf. Approximately 950 oysters were distributed randomly into eighteen mesh bags. The bags were laid out, side by side, in the two trays at a density of nine bags per tray. The two trays were sandwiched in between two empty trays to simulate a commercial stack of trays. The densities of oysters in the boxes of the nursery corf and the bags in the trays were the equivalent of 8000 oysters/m^2 and 8200 oysters/m^2 respectively.

Both growing systems were deployed in Swan Bay and left for a period of four weeks before they were retrieved and the appropriate measurements taken. Volumes of oysters in the nine nursery boxes were recorded, along with the volumes of the eighteen soft mesh bags contained in the trays. Subsamples of oysters were collected to enable the comparison of mean lengths of oysters in the two treatments.

Effects of handling on the growth of oyster seed contained in soft mesh bags.

Graded seed with a mean length of 4.4 $\pm$ 0.84 mm, produced at the V.F.R.I.'s hatchery, was randomly assigned to nine, soft mesh, oyster bags (1.5 mm mesh size). The bags, each containing an estimated 5000 oysters, were placed in a static tray, constructed from 120 mm galvanised, reinforcement mesh. A 12 mm 'Nylex' oyster mesh was used to line the tray to protect the oysters in the fine mesh bags from predation. A mesh lid fully enclosed the oysters in the tray. The tray containing the oysters was deployed at the growing site at Blairgowrie, in Port Phillip Bay (Appendix 1) on 11 April, 1989 and was supported approximately one metre above the sea floor on steel pickets. The experiment was run for approximately seventeen weeks and was concluded on 16 August, 1989.

The bags were randomly assigned a number from one to nine. Bags numbered 1, 2 & 3 were sampled at two weekly intervals; bags numbered 4, 5 & 6 were sampled at six weekly intervals; and bags numbered 7, 8 & 9 were sampled at the conclusion of the experiment (17 weeks). At each sampling interval, the respective bags were removed from the tray, washed out in seawater to remove silt and any fouling organisms present and the total weight and volume of the contents of each bag was recorded. A subsample from each bag was also taken and photocopied for later length frequency analysis. Data was analysed in SAS using a two level, nested ANOVA (Sokal and Rohlf, 1969). The level of mortality for each treatment was also recorded. The oysters were not graded and the densities in the bags were not adjusted in any way. The oysters were then returned to clean bags and placed back on the trays until the next sampling.

Effects of cleaning on the growth of oyster seed 'warehoused' in nursery corfs.

Oyster seed was obtained from stocks produced by Shellfish Culture Ltd., Pipe Clay Lagoon, Tasmania and was part of a shipment of 160,000 seed, ranging in size from 2240 µm to 7000 µm. The seed had been held at the hatchery for some time, and was quite atypical in appearance for oysters of such size, having thick, stunted shells and showing little sign of new shell growth. The seed was variable in size and was graded using a sieve of 5.3 mm mesh (7.5 mm diagonal). Seed passing through this mesh was used in the trial.

Three nursery corfs (Appendix 3), containing 2 mm mesh boxes were supplied by A.F.O.C. A volume of 150 ml of oyster seed was measured into each of twelve boxes. Four boxes were placed into each corf; two boxes were located at the middle positions on each side of the corfs. Empty boxes were used to fill the corfs to achieve the water flow characteristics normally experienced by this system when fully loaded with seed.

The three nursery corfs were then deployed at the Swan Bay experimental site where the experiment was run for approximately seven months. Each corf was appropriately labelled with coloured tags and positioned so that it could be retrieved independently, without disturbing the corfs in the other two treatments. The first corf was cleaned monthly; the second was cleaned every two months; and the third corf was cleaned every three months. The cleaning process involved retrieving each corf at the

respective time interval and placing it on the deck of the oyster barge where the corf was dismantled. The four growing boxes were put to one side while the other boxes were cleaned using a high pressure cleaner. The seed was given a gentle dousing with water to remove any accumulated silt and was then transferred carefully to clean growing boxes, ensuring that abrasion of new shell was kept to a minimum. The corf was then reassembled and placed back in the water as quickly as possible to minimise exposure time.

The combined weight of oysters in the four growing boxes was recorded for each of the three corfs, both prior to deployment and at the conclusion of the experiment, seven months later. Volumes of oysters were also recorded. A stratified random sample was taken from each corf to enable a more accurate measure of mean oyster length for each treatment. The oysters were graded over a series of sieves to produce four separate strata or grades as follows:-

Grade 1- passed through 11 mm sieve
Grade 2- retained on 11 mm sieve
Grade 3- retained on 15 mm sieve
Grade 4- retained on 21 mm sieve.

The large variation in sizes contained in grade 1 presented problems when trying to accurately estimate the numbers of oysters present, so the first stratum was excluded from the results. This would have effectively increased the observed mean length of oysters. However, the relative growth due to the different treatments was still discernable. A SAS programme was used to calculate statistics for the stratified samples. The number of dead oysters was also recorded to establish if there was any difference in mortality between the treatments.

1.2.2 Results

Comparison of growth in a nursery corf with that in a bag and tray system.

During the course of the experiment, crabs gained access to the lower tray (tray no. 398) causing serious predation in the bags. This tray was therefore omitted from the comparitative study. The differences in total oyster volume between the nursery corf and bag and tray system was marked after a period of only 27 days. A volume increase of 109% was noted for oysters grown in the nursery corf compared to only 75% for oysters grown in the nursery tray (Table 5). For completeness the data from the predated tray was also shown (Table 5).

The mean length of oysters grown in the nursery corf was 20.2 mm compared to a mean length of 19.2 mm for oysters grown in the static tray and fine mesh bag system after 27 days' growth (Table 6). A Wilcoxon Rank Sum Test showed that the oysters grown in the nursery corf were larger at the 5 percent level of significance.

Table 5. Percentage increase in the volume of oysters grown in nursery boxes and nursery trays after 27 days.

Corf No. 433			Tray No. 183			Tray No. 398		
Init. vol.	Final vol.	Vol. inc. %	Init. vol.	Final vol.	Vol. inc. %	Init. vol.	Final vol.	Vol. inc. %
750	1350	80	375	600	60	375	(455)	21
750	1330	77	375	650	73	375	(190)	-49
750	1535	105	375	675	80	375	(25)	-93
750	1610	115	375	665	77	375	(350)	-7
750	1610	115	375	650	73	375	(530)	41
750	1580	111	375	710	89	375	(200)	-47
750	1835	145	375	610	63	375	650	73
750	1850	147	375	675	80	375	675	80
750	1425	90	375	675	80	375	730	95
			% increase in non-predated 75%			% increase in predated -13%		
Total % increase in corf 109%			Total % increase in trays 44%					

N.B. All volumes are in millilitres; ( ) represent bags which showed obvious signs of predation by crabs.

Table 6. Mean length of oysters, in millimetres, grown in a nursery corf compared to oysters grown in nursery trays.

Treatment	n	length (mm)	std.	std. err.	95% C.I.
Nursery corf	1034	20.2*	4.45	0.14	19.9 to 20.4
Tray	708	19.2	3.93	0.15	19.0 to 19.5

*Mean lengths are significantly different ($p<0.05$).

Effects of handling on the growth of oyster seed contained in soft mesh bags.

Analysis of the length frequency data of 16 August 1989 using SAS, showed that the different cleaning frequencies of two, six and seventeen weeks, had a significant effect ($p<0.01$) on the growth rates of oysters. Significant variation ($p<0.01$) in growth rates of oysters was also noted between bags, within the treatments. The overall mean length of oysters cleaned every six weeks (10.4 ± 0.29 mm), obtained by pooling the three bags in each treatment, was significantly greater ($p<0.05$) than the mean length of oysters cleaned every two weeks (9.5 ± 0.02 mm) and the mean length of oysters left untouched for seventeen weeks (9.7 ± 0.78) (Table 7). There was no significant difference ($p>0.05$) between the mean length of oysters cleaned two weekly and those left undisturbed for the duration of the experiment.

Table 7. Mean lengths in millimetres for oysters grown in mesh bags over a 17 week period. Bags were cleaned at three different intensities during this time, namely 2, 6 and 17 weekly intervals. The end column shows the mean of the bags combined and the standard error of mean (S.E.M).

Treatment	Bag	Mean length (mm)	Mean ± S.E.M.
Frequent (2 weeks)	1 (n=122)	9.2	
	2 (n=140)	9.4	9.5 ± 0.20
	3 (n=115)	10.0	
Intermed. (6 weeks)	1 (n=113)	9.9	
	2 (n=129)	10.2	10.4 ± 0.29*
	3 (n=176)	11.1	
Infrequent (17 weeks)	1 (n=178)	8.9	
	2 (n=123)	11.6	9.7 ± 0.78
	3 (n=157)	8.6	

* Significant at 5 percent.

The mean weight and mean volume of oysters in the bags decreased as the interval between subsequent cleaning increased from two weeks to six weeks and finally to seventeen weeks (Table 8). However, there was no significant difference ($p>0.05$) in mean oyster weights and volumes between the three treatments due to the large variability in size which existed in the bags.

Table 8. Mean weights and volumes for the three handling regimes at the final sampling, 16 August 1989.

Treatment	Bag no.	Weight (g)	Volume (l)	Mean wt. (mg)	Mean vol. (ul)
Frequent	1	584	0.97	116.8	194
(2 weeks).	2	551	0.90	110.2	180
	3	566	0.92	113.2	184
				113.4 ± 1.56	186 ± 3.4
Intermediate	1	489	0.89	97.8	178
(6 weeks).	2	460	0.80	92.0	160
	3	489	0.92	97.8	184
				95.9 ± 1.58	174 ± 5.9
Infrequent	1	456	0.82	91.2	164
(17 weeks)	2	534	0.98	106.8	196
	3	325	0.51	65.0	102
				87.6 ± 9.96	154 ± 22.5

The estimated mortality for oysters grown in bags handled every two weeks was 1.2% compared to 11% for oysters in bags that were left undisturbed for seventeen weeks.

The degree of fouling on the bags was relative to the period for which they had been left without being cleaned. The bags left uncleaned for two weeks were covered in a light silt which was quite easily removed, whereas the bags which were left untouched for seventeen weeks were heavily fouled with hyroid, epiphytic algae and silt; the fouling was such that the oysters were no longer visible in the bags.

Effects of cleaning on the growth of oyster seed 'warehoused' in nursery corfs.

There were no significant differences ($p>0.05$) between either the mean weights or the mean volumes of seed contained in the boxes of the three nursery corfs at the beginning of the experiment. However, after seven months' growth the mean weight of oysters cleaned monthly was significantly greater ($p<0.05$) than that of oysters cleaned every two months and oysters cleaned every three months (Table 9). There was no significant difference in mean oyster weights between the corf cleaned at two monthly intervals and the corf cleaned at three monthly intervals.

The final mean volumes for the three treatments were significantly different ($p<0.05$), with the greatest volume (1975.0 ml) occurring in the corf cleaned monthly (Table 9). The mean volumes decreased sequentially with increasing time intervals between cleanings.

Table 9. Mean weights and mean volumes of oysters grown in nursery corfs which were cleaned at intervals of one month, two months and three months.

Treatment	mean box weight (g); n=4		mean box volume (ml); n=4	
	initial	final	initial	final
1 month	251.2^a	1039.2^a	150^a	1975.0^a
2 months	246.9^a	783.3^b	150^a	1487.5^b
3 months	245.9^a	685.9^b	150^a	1062.5^c

Values within the same column, having different superscripts, are significantly different at $p<0.05$.

A mean length of 25.2 mm was attained by oysters grown in the nursery corf cleaned once a month. This was 7% greater than the mean length of oysters cleaned every two months, and 12% greater than oysters cleaned every three months (Table 10).

Table 10. Mean lengths of oysters subjected to three different cleaning intensities. The values are given in millimetres ± standard error of mean.

Treatment	Initial	Final
1 month	7.2 ± 0.07	25.2 ± 0.22
2 months	7.2 ± 0.07	23.5 ± 0.21
3 months	7.2 ± 0.07	22.5 ± 0.16

The type and degree of fouling varied both with the season and with the relative handling of the three corfs. After the first month, the corfs were lightly fouled with silt which was easily removed. In August, the corfs were quite heavily fouled with silt and algae and some oysters were clumped together by polychaete worms. The degree of fouling was noticeably less for the corf cleaned monthly. A light fouling of sponge was noted in October. In November, the corfs were heavily fouled with filamentous green algae and the boxes were badly fouled with small, solitary ascidians. The ascidians were cleaned off the 'monthly' corf with a high pressure jet. At the conclusion of the experiment, in January, the corf which had been cleaned the previous month, was relatively clean while the other corfs which had been left, were covered in epiphytic algae and ascidians which were, by this stage, very difficult to remove.

Mortality was relatively low for the three treatments, however, there was a noticeable interaction between the degree of mortality and the frequency at which the nursery corfs were cleaned. The percentage mortality was 5.2% for the seed handled every month, 6.1% for seed handled every two months and 7.4% for the seed handled every three months (Table 11). Mortality was noticeably higher in the smaller grades of oysters. There was no observed mortality in grades 2, 3 & 4 for the oysters that were cleaned every month and less than one percent mortality for grade 2 oysters in the corf cleaned bimonthly. The mortalities found in grade 2 & 3 oysters were a little higher (1.7% & 2.6% respectively) for the corf cleaned every three months but were considerably less than the 8.2% mortality found in the smallest grade.

Table 11. The percentage mortality of oysters resulting from monthly, bimonthly and three monthly cleaning frequencies.

Treatment	Percentage mortality in each grade				Total mortality %
	grade1	grade2	grade3	grade4	
1 month	6.0	0	0	0	5.2
2 months	6.9	0.1	0	0	6.1
3 months	8.2	1.7	2.6	0	7.4

1.2.3 Discussion

Comparison of growth in a nursery corf with that in a bag and tray system.

The nursery corf was superior in performance in every regard to the static trays. The fewer components of the nursery corf made for easier handling which would greatly reduce time and labour in a full size nursery operation. The boxes in the nursery corfs, unlike the fine mesh bags of the trays, were easily emptied of their seed during cleaning or grading operations and easily restocked prior to being returned to the water.

The rigid mesh of the nursery corf was found to be resistant to predators such as crabs. The boxes are so designed that the box above forms the lid of the box below, creating a tight seal through which predators are unable to pass. The soft mesh bags in the static trays however, were not resistant to predation. Crabs, once they gained entry to the tray, were able to crush the small oysters through the mesh without having to actually gain entry into the bags. A number of bags were predated upon, with one bag losing over 90% of its contents.

In addition to the convenience of the nursery corf for handling large quantities of small seed and resistance of the system to predation, the growth rates of oysters in the nursery corf were greater ($p<0.05$) than the growth rates achieved in the static tray. This was probably due to the improved water flow characteristics of the nursery corf which has only one layer of mesh between the oysters and the outside, whereas the oysters in the trays are held in mesh bags within a mesh lining on the tray.

Effects of handling on the growth of oyster seed contained in soft mesh bags.

Oysters which were cleaned at six weekly intervals showed superior growth to both oysters which were cleaned every two weeks and those which remained uncleaned for seventeen weeks. The frequent handling of the oysters cleaned on a two weekly cycle resulted in a greater amount of physical abrasion which is the probable cause for the lower mean lengths observed in this treatment. The lower mean length of oysters in the bags left for seventeen weeks without a clean was probably due to the heavy fouling of the fine meshes, leading to a reduced water flow through the bags and thus a reduction in available food. The higher level of mortality experienced in the bags which were uncleaned, stresses the importance of keeping the meshes of oyster containers clean so as to maximise water flow rate past the oysters held inside.

It is suggested that bags cleaned on a six weekly cycle was close to the optimum for maximum oyster growth. It should be pointed out that biofouling is seasonal and that this experiment was performed during the colder months (Autumn-Winter) when biofouling is usually less of a problem (Michael and Chew, 1976). However, fouling was still shown to significantly reduce oyster growth. It is quite possible that during the warmer months, increased prevalence of fouling will necessitate more frequent cleaning of the oyster meshes.

Effects of cleaning on the growth of oyster seed 'warehoused' in nursery corfs.

The superior growth and lower mortality observed for the seed grown in the nursery corf and cleaned monthly, further suggests that frequent cleaning of small oyster seed is important if the full growth potential is to be achieved. Reduction of water flow through the meshes, due to fouling, was the most probable cause for the reduced growth in the nursery corfs cleaned less frequently. Less frequent cleaning can also result in the build up of oyster wastes and silt, the presence of which can lead to colonisation by oyster pathogens such as mudworm.

Conclusions for Section 1 - Nursery Production of *O angasi* :

1. A field nursery tumbler has great potential to increase the profitability of an oyster farm by:

   a) Allowing the grower to purchase hatchery produced seed at a much smaller size and hence cheaper cost.

   b) Potentially saving a whole year on the grow-out by producing 10mm seed early in the growing season.

   c) Allowing the over-wintering of large quantities of seed with zero maintenance costs.

   d) Satisfying what the hatchery wants to sell [small sized seed] and what the grower wants to purchase [large sized seed].

   e) Converting 2mm sized seed to 10mm sized seed with minimum labour costs (This represents a saving of approximately $20,000 for every million seed purchsed).

2. Nursery 'corfs' used in shallow warm water have the capacity to produce large numbers of juvenile oysters if 10mm sized seed can be made available prior to the main summer growing season.

   This early season 10mm seed production will now be possible by using the field tumbler.

SECTION 2.

Growout systems for *O. angasi* production.

In the growout stage of oyster culture, oysters are grown to a marketable size ready for harvest. Methods employed in the growout stage are often diverse but can generally be classified into three broad categories: bottom culture; off-bottom culture; and suspended culture. We investigated each of these categories for *O. angasi* and reported the experimental results from each category in the following three sub-sections.

2.1 Bottom Culture

2.1.1 Introduction

Records of the culture and harvesting of flat oysters (*Ostrea edulis*) in Europe, go back to Roman times (Ayres, 1988). In its most basic form, the oyster industry relied solely on direct harvesting of naturally occurring beds, using a variety of implements including dredges, rakes and tongs. Over exploitation and increasing demand for oysters led to the development of oyster culture.

The most primitive methods of oyster culture involved little more than scattering cleaned oyster shells, called 'cultch', on the bottom to provide additional substrate upon which the oyster larvae may settle. The oysters were then left till harvest, some years later (Bardach et al., 1972). A definite drawback in the use of 'cultch' is that oyster larvae settle, by preference, in sites with low current velocities. This can lead to poor nutrition since oysters rely on tidal currents to transport planktonic food (Korringa, 1976b). The seventeenth century Japanese culturists overcame this problem by using spat collectors such as rocks, branches, and other objects of such a size that they could be easily moved from place to place with oysters attached. Thus oysters could be transferred to more favourable sites for growout.

In Brittany, France, where the traditional method of bottom culture is still practised today, ceramic tile collectors are placed at sea to collect the spat (Korringa, 1976a). The spat, once settled on the tiles, are overwintered before being detached from the collectors. The spat is then transferred to parks where it is planted out in specially prepared beds. Silt is removed from the parks and the beds are hardened by the addition of sand. Workers tend the parks each day at low tide and physically remove any predators such as crabs or starfish. At approximately eighteen months of age, the oysters are collected and relaid in parks in the Anse de Paimpol where they are on-grown. From these beds, the oysters may be dredged up again and replanted on a clean plot prior to the final harvest. After approximately 3½, years the oysters are ready for sale. Oysters grown on the bottom in this way invariably become covered with silt and are susceptible to predators (Korringa, 1976a). As a result losses are often high.

Three alternative bottom culture methods were investigated in this study. The growth performance of oysters was compared to the growth of oysters in trays.

2.1.2 Materials and Methods

Oysters (total 1200) were obtained from the Australian Flat Oyster Company for the bottom growout trials. The oysters were approximately two years old, having been raised at the Swan Bay nursery site (Appendix 1). The oysters were distributed randomly amongst four treatments. Three hundred oysters were placed directly on the sea floor in three, 1m x 1m plots which were bordered by frames made from 20 mm P.V.C. conduit and held in place by a number of wire pegs. One hundred oysters were scattered evenly over each plot.

A further three hundred oysters were placed into 6 mm plastic mesh bags at a density of one hundred oysters per bag (equivalent to 500 oysters.m^{-2}). Each bag was tied at the top and attached to a clip line at half metre intervals. The line was then stretched out along the bottom and pegged out at each end. The bags were arranged by divers so that they lay flat and the oysters were spread out as much as possible.

A set of three rigid, 20 mm plastic mesh bags, each containing one hundred oysters (equivalent to 345 oysters.m^{-2}) were attached to a clip line as described above and similarly laid on the bottom. The slightly larger surface area of the rigid bags meant that the effective density was less than that present in the soft mesh bags.

Three additional 20 mm plastic mesh bags, each containing 100 oysters were placed in an oyster tray which was supported approximately half a metre off the bottom. This final treatment represented an off-bottom method of culture against which the other treatments were to be compared.

The lengths of all the oysters were recorded prior to being deployed at Capel Sound [Lat. 38° 20.50'S Long. 144° 49.50'E] in Port Phillip Bay (Appendix 1) on 13 September 1990 and on each of four sampling occasions. The number of oysters which died during the experiment were also recorded for each treatment. The experiment was concluded on 23 May 1991, after a period of approximately eight months.

2.1.3 Results

The initial measurements prior to the deployment of the oysters on the 13 September 1990, showed that there was no significant difference ($p>0.01$) in the mean lengths of oysters for the four treatments.

On the first sampling cruise, after two months' growout, oysters grown in rigid bags, supported above the bottom in a tray, were significantly larger ($p<0.01$) than oysters in the other treatments which were placed directly on the bottom (Table 12). The oysters scattered loosely on the bottom in 1m x 1m plots showed the lowest mean length of all treatments and only 68% of the oysters could be recovered. Of those which were found, many were covered with up to 10 cm of silt.

The oysters grown in the tray maintained their growth advantage throughout the experiment and remained significantly larger ($p<0.01$) than the oysters in the other treatments. At the final sampling on 23 May 1991, after a period of eight months' growout, there was no difference in the mean length of oysters in the two bag treatments placed directly on the bottom and the oysters grown freely in the plots.

Table 12. Lengths of oysters (mean ± S.E.) in millimetres, grown in bags on a tray and in three other treatments on the sea floor, over an eight month period.

Date	Off bottom tray	Seabed		
	Rigid bags	Soft bags	Rigid bags	Plots
Sep 90	47.8 ± 0.27	46.7 ± 0.27	47.7 ± 0.26	47.0 ± 0.27
Nov 90	61.3 ± 0.38	56.8 ± 0.47	57.3 ± 0.43	53.3 ± 0.47
Jan 91	70.4 ± 0.51	61.9 ± 0.64	64.8 ± 0.59	62.0 ± 0.59
Mar 91	75.3 ± 0.57	63.1 ± 0.88	67.5 ± 0.79	66.5 ± 1.04
May 91	74.6 ± 0.74	65.6 ± 1.07	67.7 ± 0.81	68.9 ± 1.33

The mortality was highest for the oysters which were spread directly on the bottom, achieving losses of 89% over an eight month period. A total of 40 % of the oysters in the plots were not located at the final sampling. If it was assumed that these oysters were either preyed upon or covered in silt, the overall mortality for the oysters grown on the bottom was 93%.

The mortalities for oysters contained in the soft mesh bags and the rigid bags resting on the bottom, were less than for the oysters grown in the plots, but were still very high, reaching values of 73% and 78% respectively. The oysters in bags held in the tray had a mortality rate of 66%.

2.1.4 Discussion

The growth of oysters placed directly on the bottom was shown to be inferior to that achieved in the off-bottom tray method. After eight months' growout, the lengths of the oysters in the off-bottom tray were significantly greater ($p<0.01$) and the mortality lower than for oysters in the three bottom treatments.

One reason for the poor growth performance of the oysters grown on the bottom was siltation. Shifting sands are unsuitable for the culture of flat oysters (Korringa,1976a) and the accumulation of silt can cause oysters to be smothered or prevent them from feeding properly, thus reducing growth (Utting 1988, Rhoads 1974, Bardach et. al. 1972). At the site at Capel Sound, sand movement was an obvious problem for the oysters placed on the bottom. The oysters grown loosely in the plots were particularly susceptible to siltation, often becoming completely buried. The oysters housed in the two types of bags resting on the bottom also became partially covered in silt. This would also explain the higher level of mortality experienced by the oysters grown on the bottom.

Despite the better growth of oysters in the tray, mortality was higher than expected for all treatments. An outbreak of the deadly oyster disease Bonamiasis was detected at the growing site during these growth trials. The oysters were almost two years old and

it has been documented (Anon., 1991b) that oysters are more susceptible to oyster pathogens after the second summer growout.

These results therefore cannot be used to evaluate growth performance. However, the findings did highlight the possible problems caused by shifting sand and tended to suggest that the practice of supporting oysters above the bottom in trays is likely to produce faster growth compared to oysters grown directly on the bottom.

The development of 'traditional' bottom culture as practised elsewhere in the world is not practical now that *Bonamia* is known to infect Victorian Flat Oysters. Although this is likely to be the cheapest on-growing method, the slower growth rates would make the oysters highly susceptible to this disease. In later sections we describe methods which produced extremely fast growth rates. It has been postulated (Anon., 1991b) that if improved husbandry methods, resulting in rapid growth can be developed, then it may be possible to 'manage around' the disease Bonamiasis which has now devastated flat oyster culture industries all over the world.

2.2 Culture on bottom mounted racks.

2.2.1 Introduction

Off-bottom methods of culturing are generally carried out in shallow waters of 2 to 4 m depth during low tide. Oysters are held above the seabed on racks or trestles, in clear water where the effects of siltation and predation by starfish and crabs are reduced. In Matsushima Bay, Japan, seed oysters of the species *Crasostrea gigas* are collected and grown on 'rens' which are hung from horizontal bamboo poles supported on frames (Milne, 1979). Off-bottom culture is used in the Sydney Rock Oyster (*Crassostrea commercialis*) industry in Australia. Spat of the Sydney Rock Oyster are caught on sawn hardwood sticks and then grown intertidally for approximately 3 years before harvesting. The sticks are supported on wooden racks which keep them above the bottom (Korringa, 1976b). In recent times the trend has been to transfer the oysters from the sticks to wire trays after two years, prior to the final year's growout. Results have shown increased yields for oysters grown in the trays (Milne, 1979).

We investigated off-bottom culture by conducting experimental commercial growth trials with the Australian Flat Oyster Company (A.F.O.C.) by using stackable steel trays supported on timber racks. Modifications were made to the trays to improve water flow and thus productivity of the system. The effect of stocking density and grading frequency on the growth of oysters in trays was assessed to determine the importance of capital and labour costs associated with productivity gains.

2.2.2 Materials and Methods

The effects of stocking density and grading frequency on the growth of oysters.

Three stocking densities, 0.2, 0.6 and 2.0 $g.cm^{-2}$ are referred to throughout the experiment as low, medium and high density respectively. The medium density of 0.6 $g.cm^{-2}$ was equivalent to the biomass of oysters per tray used by A.F.O.C. in their commercial operations. Oysters were generally distributed into the growing trays by volume, however, volumetric measurement can lead to variability in oyster numbers which was considered undesirable for this experiment. To minimise inaccuracy, oysters were counted manually for distribution to the different treatments. In order to keep the experiment to a manageable size, oysters were held in 20 mm oyster mesh bags (800 mm L x 360 mm W x 110 mm H) rather than commercial oyster trays. To maintain the densities described previously, it was calculated that 300 oysters per bag was equivalent to the medium density and that 100 oysters per bag and 900 oysters per bag was eqivalent to the low and high densities respectively.

In addition to stocking density, there were three handling frequencies, designated as high, medium and low. The handling frequency refers to the regularity that oysters were cleaned and graded. The oysters in the high frequency treatment were graded every three weeks, those in the medium frequency treatment were graded every six weeks and those in the low frequency treatment were left for nine weeks between subsequent gradings.

A total of 7600 size 7 oysters (43.0 $\pm$ 0.12 mm) were obtained from A.F.O.C. and distributed amongst five treatments (Table 13). Initially there were four bags per treatment, with two of the four bags acting as a replicate.

Table 13. Distribution of oysters amongst the five treatments and the frequency at which they were graded.

Treatment	No. oysters/bag	Total no/treatment	Grading frequency
Medium density/High freq.	300	1200	3 weeks
Medium density/Medium freq.	300	1200	6 weeks
Medium density/Low freq.	300	1200	9 weeks
High density/High freq.	900	3600	3 weeks
Low density/Low freq.	100	400	9 weeks

The number, weight and volume of the oysters in each of the bags was recorded prior to being placed in Swan Bay on 1 March 1990. The bags were held in a single layer of un-lined oyster trays (five bags per tray) which were positioned end to end across the current in order to prevent any growth differences due to bag position (Appendix 3). Bags were randomly distributed along the line of trays in an attempt to further reduce any variability due to location.

Oysters were retrieved at the end of each respective time interval and cleaned with a high pressure water jet. The oysters were then passed over a mechanical grader possessing two sieve sizes; a number 8 sieve (33 mm, diag. 47 mm) and a number 9 sieve (42 mm, diag. 59 mm). Oysters remaining on the number 9 sieve were classified as size class 9 while those falling through this sieve and remaining on the number 8 sieve were classified as size class 8. Oysters which passed through both sieves were labelled size class 7. The size 8 oysters were re-stocked at a density of 100 per bag while the size 9 oysters were re-stocked at a density of 70 per bag for the medium density treatment in order to maintain a biomass of 0.6 $g.cm^{-2}$. The numbers of size 8 and size 9 oysters per bag were adjusted accordingly for the low and high stocking densities so that they were equivalent to the initial densities of 0.2 and 2.0 $g.cm^{-2}$ respectively. On occasion, there were insufficient numbers of a particular size class to maintain the predetermined density. Advantage gained by this reduction in density was justified as a direct result of grading frequency; that is, grading always results in a lowering of density so that any interaction is an inseparable component of the treatment.

The weights, volumes and number of oysters in each size class were recorded. In addition, at the conclusion of the experiment on 4 July 1990, subsamples were taken from each of the treatments to determine the mean lengths of oysters grown at the different stocking densities and grading frequencies.

Variation in oyster growth throughout a commercial growing stack.

Two commercial stacks (Nos 88 and 104.) of size seven oysters (sieve size 25 mm) were deployed in Swan Bay (Appendix 1) by the Australian Flat Oyster Company on 22 March 1989. The trays in each stack were aligned longitudinally with the direction of tidal flow (Fig. 4). Water therefore entered at one end, passed through adjacent bags containing oysters and exited from the far end of the stack. Each tray held six, 20 mm plastic mesh bags which contained the oysters. Oysters were measured into the bags by volume (6L/bag). The trays were placed on top of each other and held together by polyester packing tape. Neighbouring stacks were placed beside each other at about half metre intervals.

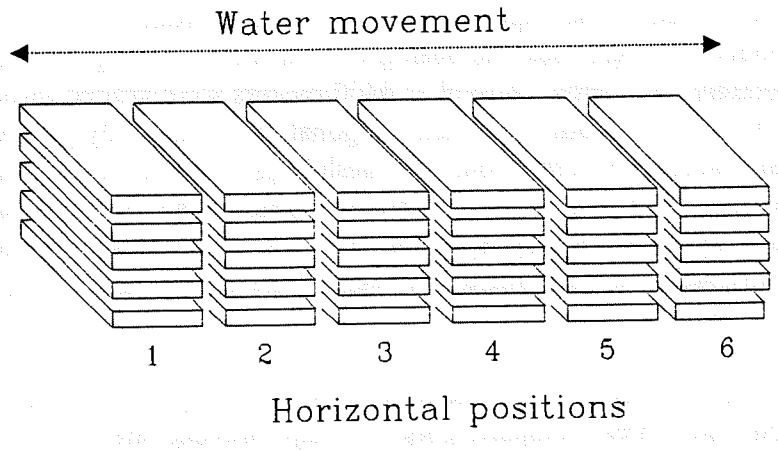

Figure 4. Bags in trays aligned longitudinally with the direction of tidal flow.

A subsample of oysters from three of the bags was collected prior to the stacks being placed in the water to enable the initial variability of oyster length to be determined. Stack #88 was sampled on 2 May 1989, after approximately six weeks' growout. Individual bag weights were recorded, taking note of the horizontal position of each bag on the tray as well as the vertical position within the stack. The numbers of oysters in each bag were also recorded. Subsamples of oysters were collected from three bags from each of the top, middle and bottom trays (nine bags in total) to provide additional data on oyster length. The oysters were photocopied and later digitised to measure their size.

Stack #104 was sampled on 18 May 1989. Individual bag weights and numbers per bag were measured. The mean weight of oysters in each bag was calculated by dividing the total weight for a particular bag by the total number of oysters in that bag. The mean weight for each bag was thus standardised to the mean number of oysters throughout the stack. Analysis of the data was performed using the SAS General Linear Models Procedure. The horizontal and vertical positions of the bags were classified as the treatment variables and the number of oysters per bag as a covariable. The dependant variable was mean weight.

Tray culture of oysters at two potential oyster culture sites in Victoria.

Two sites, widely separated geographically, were chosen for this off-bottom oyster growout trial (Appendix 1). The first site was in Port Phillip Bay, situated at Grassy Point [Lat. 38° 06.43'S Long. 144° 40.77'E]. The water was 9 to 10 metres in depth and the currents slight, rarely exceeding 15 $cm.s^{-1}$ (M.M.B.W. and F.W.D., 1973). The second site was at Port Albert (Appendix 1) and was situated on the bank of Snake Channel [Lat. 38° 44.5'S Long. 146° 37.5'E] in 9 metres of water. The current at this site, was 50-60 $cm.s^{-1}$ during periods of spring tide (pers. comm. Vic. Inst. Mar. Sci., 1989).

The oysters utilised in the experiment were obtained from AFOC's nursery in Swan Bay (Appendix 1), where they had been grown in soft mesh bags on trays, for a period of approximately 14 months. A total of 8400 oysters were graded through a number 5 sieve with 15 mm x 15 mm mesh size (diagonal 21.2 mm). Oysters were selected at random and placed into twenty four soft mesh bags (10 mm mesh) at a density of 350 oysters per bag. This was necessary since the larger mesh (18 mm) generally used to line the trays for growout may have led to losses of the smaller oysters. The mesh bags were discarded at subsequent gradings as the oysters grew large enough to be held in the lined trays.

The steel trays used for growout measured 1.8 m in length by 0.8 m wide. Each tray was divided into three compartments to help prevent the oysters all becoming congested in the one corner of the tray. Initially, 700 oysters were placed into each compartment (i.e. 2 soft mesh bags per tray section). A total of two trays, each containing 2100 oysters, were placed at each station. The trays containing oysters were sandwiched between two empty trays to simulate a commercial stack of 4 trays. The trays were suspended approximately one metre off the bottom on a set of timber rails, supported by star pickets. Oysters were graded bimonthly using a hand operated sieving device with interchangeable sieves of differing mesh sizes. Oysters were then restocked at commercial densities (Table 14.). If, at a grading, there was less than half the required number of oysters of a particular size to make up the desired density, they were evenly spread over the tray containing the next smallest size class. Additional trays were utilised as volumes increased and oyster densities were reduced.

Table 14. Dimensions of the nominal sieve sizes and the stocking densities of oysters used throughout the experiment.

Size	Sieve size (mm)	Stocking density
5	15 x 15 mm ; diag. 21.2	2100 per tray; 700 per compartment
6	20 x 20 mm ; diag. 28.3	1500 per tray; 500 per compartment
7	25 x 25 mm ; diag. 35.3	960 per tray; 320 per compartment
8	33 x 33 mm ; diag. 46.7	540 per tray; 180 per compartment
9	42 x 42 mm ; diag. 59.4	360 per tray; 120 per compartment

At both sites, the weight and volume of oysters in each grade were recorded bimonthly from 14 March 1990 until 16 April 1991. Volume was measured using a set of large volumetric cylinders. Oysters were placed into a cylinder to determine their volume. The procedure was kept consistent between sites and subsequent samplings. The number of oysters in each grade was also estimated by volume at each sampling. The weight and volume of oysters was recorded both prior to and after grading so that the amount of shell lost during the grading process could be quantified. The number of dead oysters present was noted for each size class in an attempt to determine size specific mortality. The temperature was recorded bimonthly at a height of approximately 1 metre above the bottom. Water samples were also taken and analysed for salinity, particulate nitrogen, suspended solids and chlorophyll *a*.

2.2.3 Results

The effects of stocking density and grading frequency on the growth of oysters.

After a period of eighteen weeks, only 8% of the original grade 7 oysters stocked at a high density (2.0 $g.cm^{-2}$) and graded on a 3 weekly cycle, had grown to grades eight or nine, compared to 41% of the oysters held at a low density (0.2 $g.cm^{-2}$) and graded every 9 weeks (Fig. 5). Comparison of the three treatments, all with the medium density of 0.6 $g.cm^{-2}$, revealed that of the oysters graded most frequently, only 21% grew to size class 8 or greater, whereas 40% of the oysters graded at a low frequency reached grade 8 or 9.

The highest levels of mortality were observed in the two treatments in which the oysters were graded every three weeks (Fig. 5). Of these treatments, the oysters stocked at a medium density had a total mortality of 5.9% compared to 5.8% for oysters stocked at a high density.

It was shown that for the three treatments with a medium stocking density, the oysters which were graded once every three weeks had the highest mortality of 5.9%. Conversely, the oysters graded every nine weeks had the lowest mortality of only 2.7%, whilst the oysters graded every six weeks had a total mortality of 3.6%.

The oysters stocked at the lowest density and graded every nine weeks had a mortality of 4%. This was higher than expected and comparable with that of the oysters stocked at a medium density and graded on a six weekly cycle.

The percentage weight increase was greatest for the oysters stocked at a low density and graded infrequently (Fig. 6). These oysters showed a 120% weight increase during the eighteen week growing period. The other extreme, in which oysters were stocked at a higher than normal density and graded at frequent intervals, produced only a 36% increase in oyster weight. The weight of oysters stocked at a high density increased steadily for the first six weeks and then reached a plateau, with 'negative' growth observed towards the end of the experiment.

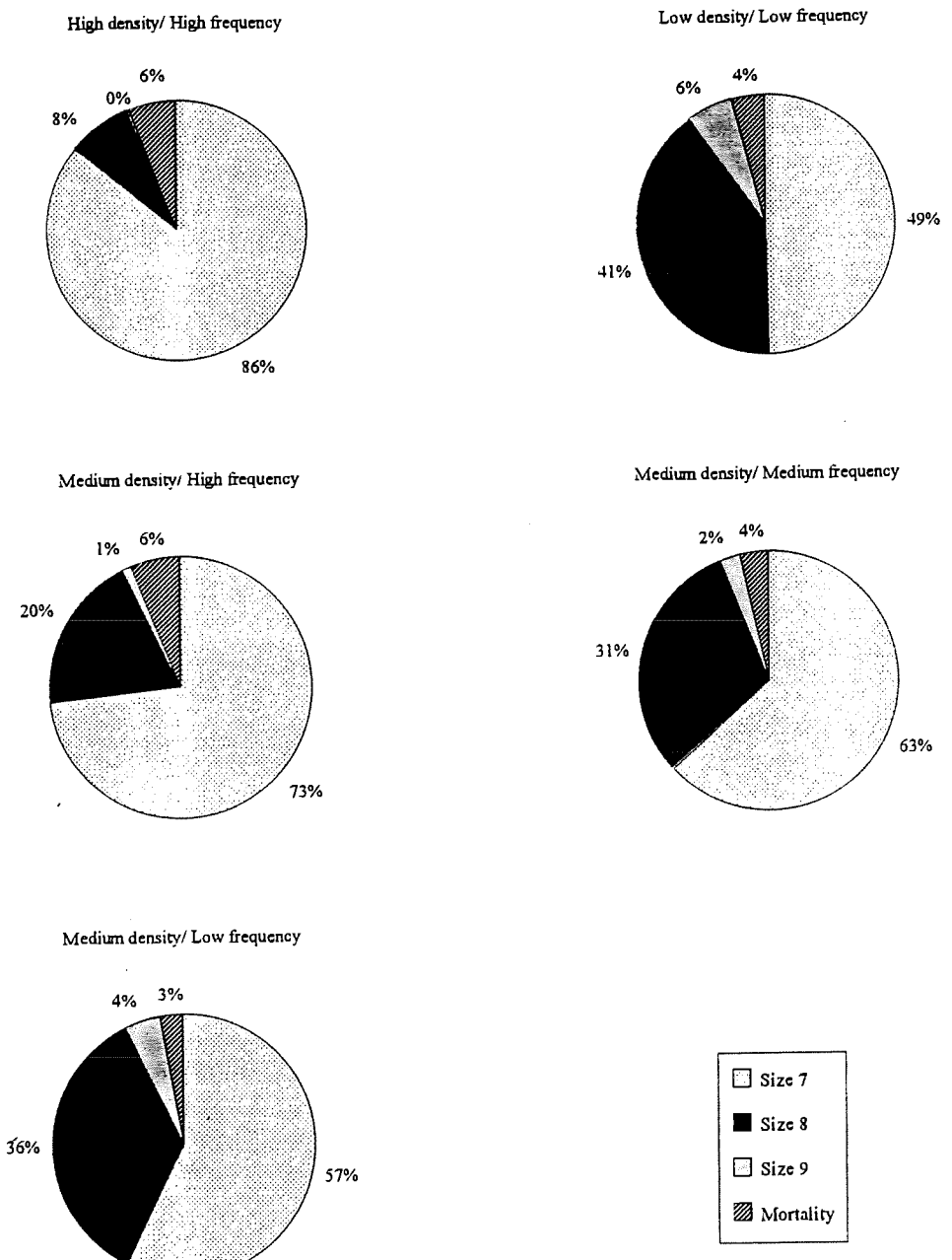

Figure 5. Percentage of oysters in each grade as a result of different stocking densities and grading frequencies.

The rate of weight increase was very similar for the three sets of oysters, stocked at a medium density, for the first six weeks of the experiment. Growth rates were observed to gradually taper off after the April 10 sampling. The growth rates of the oysters graded at both the low frequency and medium frequency were similar giving a final weight increase of 89%, whilst the growth rate of oysters graded at high frequency decreased slightly, attaining a final weight increase of 82%.

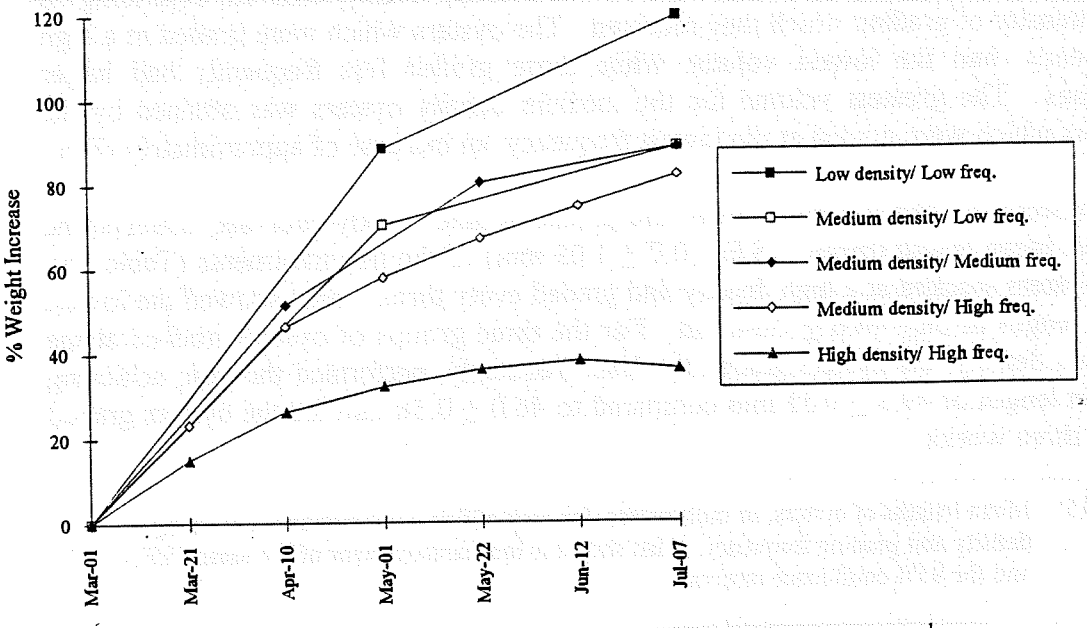

Figure 6. The effect of density and grading frequency on the percentage weight increase of oysters.

Oyster volumes showed similar trends to oyster weights when the oysters were subjected to the different treatments (Fig. 7). The oysters held at the low stocking density and graded less frequently achieved the greatest increase in volume of 80%. In contrast, oysters held at a high stocking density and graded frequently, showed the least growth, with a final volume increase of only 13%. Unlike weights, oyster volumes appeared to be more affected by grading. From April onwards, all the treatments except the low density/low frequency one showed a decrease in volume with each successive grading.

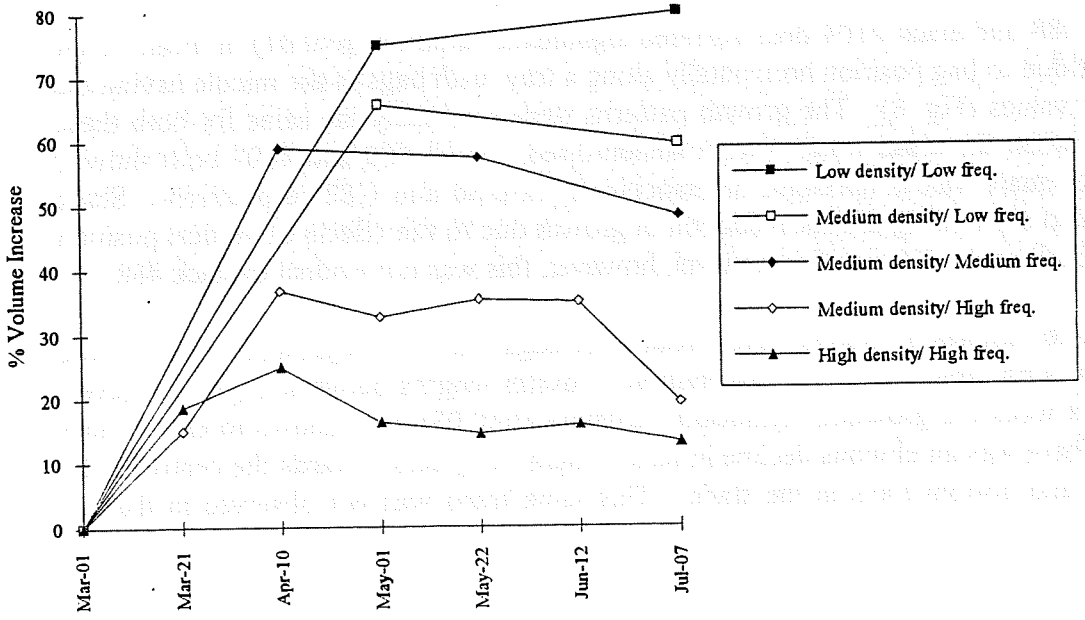

Figure 7. The effect of density and grading frequency on the percentage volume increase of oysters.

The final volumes of the oysters stocked at the medium density differed, depending on the intensity of grading which they received. The oysters which were graded at a high frequency, had the lowest volume while those graded less frequently had larger volumes. The greatest volume for the medium density oysters was attained by the oysters which were graded at the lowest frequency, an increase of approximately 60%.

The oysters stocked at a low density and graded at nine weekly intervals, achieved the highest mean length (mean $\pm$ S.E; 50.7 $\pm$ 1.03 mm) of the five treatments (Table 15). The oysters stocked at a high density and graded every three weeks showed the lowest mean length of only 44.6 $\pm$ 0.34 mm. For the three groups of oysters stocked at the medium density, the oysters graded the least frequently, performed the best, achieving a mean length of 49.3 $\pm$ 0.55 mm compared to 46.0 $\pm$ 0.58 mm for the oysters graded every three weeks.

Table 15. Mean lengths of oysters, in millimetres, for each of five combinations of stocking density and grading frequency. Also shown is the standard error of the mean (S.E.) and the 95% confidence interval.

Treatment	Mean length (mm)	S.E.	95% C.I.
High density/High freq.	44.6	0.34	43.9 to 45.3
Medium density/High freq.	46.0	0.58	45.4 to 46.6
Medium density/Medium freq.	48.2	0.53	47.7 to 48.7
Medium density/Low freq.	49.3	0.55	48.8 to 49.9
Low density/Low freq.	50.7	1.03	49.7 to 51.7

Variation in oyster growth throughout a commercial growing stack.

Stack #88 and stack #104 demonstrated significant variation ($p<0.01$) in mean oyster weight due to bag position horizontally along a tray, with bags in the middle having the lowest values (Fig. 8). The growth patterns were essentially the same for both these stacks when the mean weights were standardised. Stack #88 and #104 both showed high R-square values (strength of association) of 0.86 and 0.82 respectively. Stack #104 also showed significant reduction in growth due to the effects of vertical position (tray level) at the 5% significance level, however, this was not evident in stack #88.

Initial sub samples of oysters, taken from three bags prior to the growout trial, showed there was no difference in the distribution of oyster lengths between bags. However, after six weeks of growout, significant variations ($p<0.05$) were shown to exist (Table 16). There was an obvious decline in mean length of oysters towards the centre of the middle and bottom trays in the stack. This same trend was not observed in the top tray.

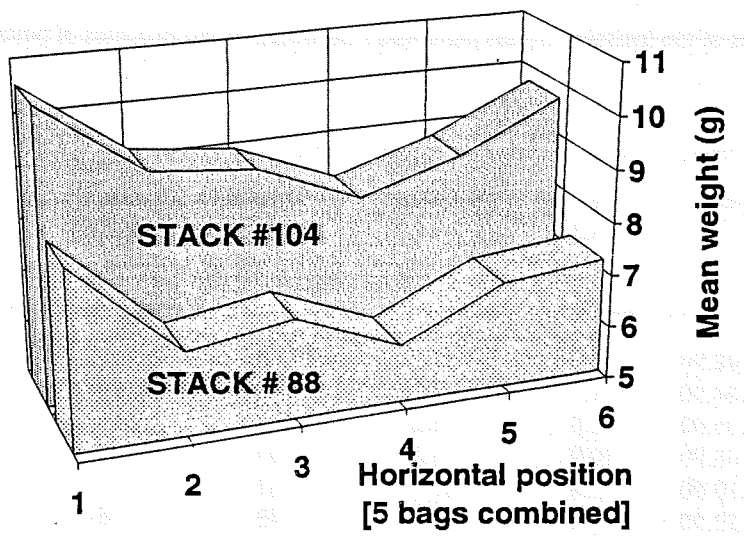

Figure 8. The effect of horizontal position in the growing stack on oyster growth rate after a four week growing period.

Table 16. Mean lengths of oysters sampled from various growing positions within a commercial growing stack. Lengths are in millimetres and include the standard error of the mean.

Tray position	Position within each tray		
	North	Middle	South
Top	53.7 ± 0.55^{a}	53.1 ± 0.62^{a}	50.4 ± 0.64^{b}
Middle	55.2 ± 0.59^{a}	45.9 ± 0.58^{b}	48.5 ± 0.65^{c}
Bottom	54.0 ± 0.67^{a}	46.4 ± 0.64^{b}	54.6 ± 0.68^{a}

N.B. Values within the same row, having different superscripts, are significantly different at the 5 % level of significance.

Tray culture of oysters at two sites of potential culture in Victoria.

There were no large differences in the hydro-biological parameters at both sites, although Grassy Point appeared to have slightly higher temperatures and lower salinities (Table 17).

Table 17. Values of the hydrobiological parameters measured at the two sites of potential cultivation.

Sites	Date	Temp (°C)	Salinity (p.p.t.)	Particulate Nitrogen (ug-at.L^{-1})	Suspended solids (mg.L^{-1})	Chlorophyll a (ug.L^{-1})
Grassy Point	15.02.90	22.1	34.9	1.74	1.38	0.56
	11.04.90	19.7	35.3	1.39	0.50	1.29
	14.06.90	12.6	35.2	1.64	0.80	n.a.
	09.08.90	10.9	35.0	2.07	1.35	1.40
	08.10.90	13.8	34.7	1.31	n.a.	0.44
	12.12.90	18.6	34.6	1.43	1.45	n.a.
	18.02.91	20.9	35.1	2.08	1.35	n.a.
	04.04.91	18.4	35.5	1.45	1.00	0.60
Port Albert	07.02.90	19.5	36.2	3.48	n.a.	1.46
	03.04.90	17.9	36.9	1.76	n.a.	1.30
	06.06.90	12.0	35.7	1.25	0.10	n.a.
	14.08.90	11.4	35.4	1.39	2.20	0.39
	02.10.90	14.6	35.0	1.56	0.05	0.57
	05.12.90	19.7	35.7	1.13	1.55	n.a.
	06.02.91	19.9	36.5	2.29	1.35	n.a.
	17.04.91	16.4	36.3	2.46	2.90	0.69

Weight increases at both sites were very similar, showing steady increases for the first nine months of growout (Fig. 9). During the period from December to February, the weight of oysters at Grassy Point decreased quite markedly, whilst the weight of oysters at Port Albert continued to increase, but at a slower rate. From February until the conclusion of the experiment in April, the weight of oysters at both sites declined dramatically. The final weight of oysters at Port Albert was 28.3 kg compared with 17.2 kg at Grassy Point (Table 18). In fact, the weight of oysters at each site was less at the final sampling than in October, after the initial seven months of growout.

Table 18. The total weight and volume of oysters held in commercial, lined trays and graded bimonthly. (N.B. Weights are given in kilograms; volumes are given in litres).

	Port Albert		Grassy Point	
Month	Weight (g)	Volume (ml)	Weight (g)	Volume (ml)
Mar-90	5.3	10.1	5.3	10.3
Jun-90	19.5	34.1	19.4	34.2
Aug-90	24.4	37.9	23.6	35.2
Oct-90	28.5	42.2	29.3	41.0
Dec-90	38.6	56.7	38.6	61.3
Feb-91	41.0	61.6	33.1	50.0
Apr-91	28.3	39.4	17.2	25.0

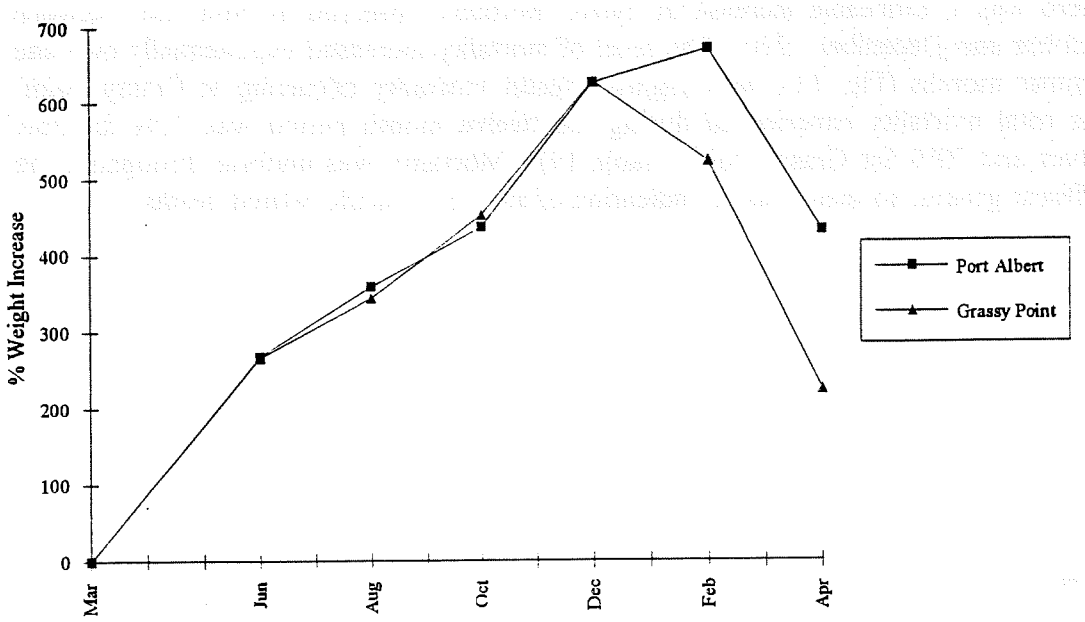

Figure 9. Total weight of oysters (kg), graded every two months and grown in static trays at Port Albert and Grassy Point.

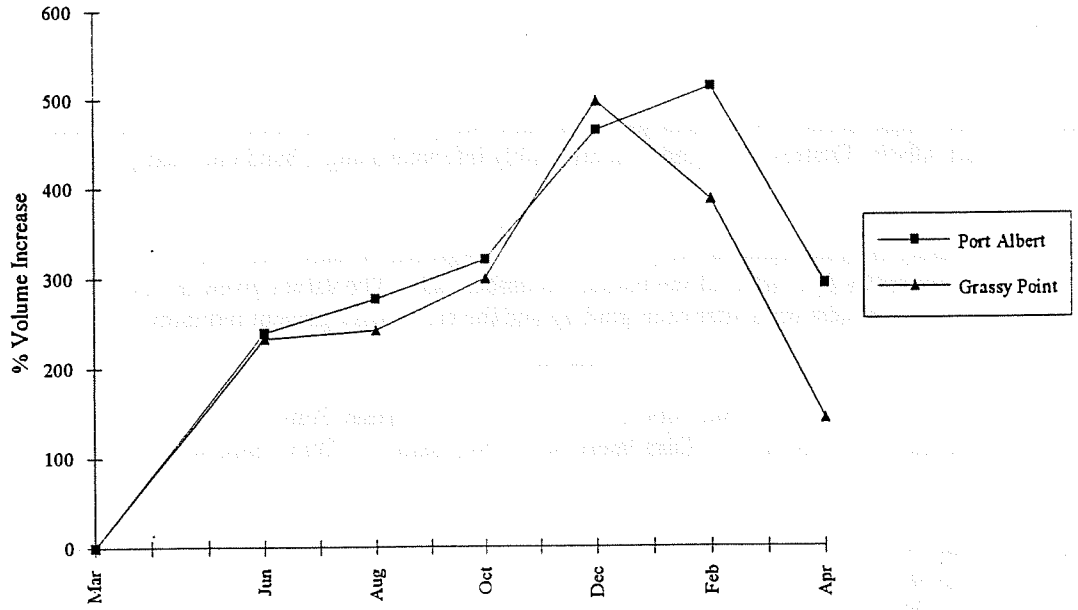

Figure 10. Total volume of oysters (litres), graded every two months and grown in static trays at Port Albert and Grassy Point.

Changes in total volume of oysters at the two sites showed similar trends to the weight increases described above (Fig. 10). Similarly, the volume of oysters at the two sites parallelled one another until December. The volume of oysters at Port Albert continued to increase whilst the volume at Grassy Point showed a negative trend. By February, the volume of oysters at Port Albert, like those at Grassy Point, was in a state of rapid decline.

There was a noticeable increase in oyster mortality observed at both sites between October and December 1990. The level of mortality increased exponentially over the summer months (Fig. 11), with slightly greater mortality occurring at Grassy Point. The total mortality experienced during the twelve month period was 72% for Port Albert and 79% for Grassy Point (Table 19). Mortality was uniform throughout the different grades, so there was no indication of any size specific related deaths.

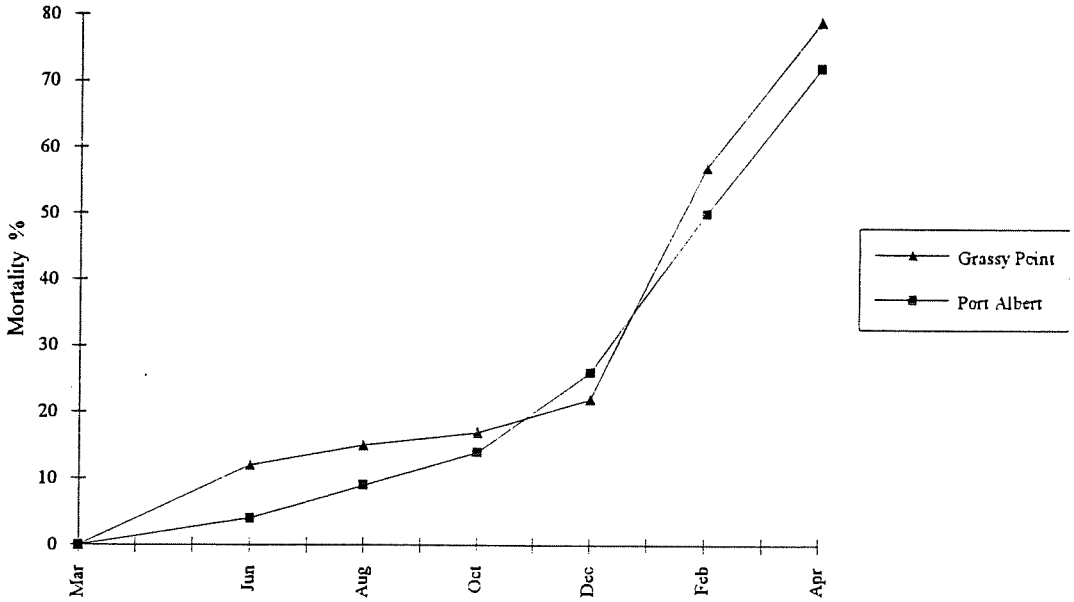

Figure 11. Percentage mortality of oysters grown in static lined trays at two sites, Grassy Point and Port Albert. Oysters were graded at bimonthly intervals using a hand operated grader.

Table 19. Mortality of oysters graded every two months and grown in static lined trays, supported approximately one metre off the bottom on timber rails. The values given are the number of oysters dead after each grading and the cumulative percent mortality.

	Port Albert		Grassy Point	
Month	No. dead	Cum. mort.%	No. dead	Cum. mort.%
Mar-90	0	0	0	0
Jun-90	192	5	274	7
Aug-90	187	9	159	10
Oct-90	93	11	166	14
Dec-90	302	18	332	22
Feb-91	1068	44	1228	51
Apr-91	1197	72	1176	79

Grading often resulted in large amounts of shell being knocked from the edges of the oysters, particularly when growth was rapid and the oysters' margins were thin and not yet consolidated with additional layers. At the October grading of the Port Albert oysters for example, approximately one kilogram of shell was lost as a result of the

grading process (average of 0.3 g.oyster^{-1}). This, at first, did not seem significant, however, oyster shell is not very dense and the loss of 1 kg of shell was equivalent to a loss in volume of 4.8 L. Heavy grading removed most of the new growth, leaving the oyster with a thick, rounded margin.

2.2.4 Discussion

The effects of stocking density and grading frequency on the growth of oysters.

The growth rate of oysters was inversely proportional to density and grading frequency. However, stocking densities did have a greater effect on growth rates than grading frequency. Elevated stocking densities, combined with frequent grading, caused an obvious reduction in oyster growth.

The weight of oysters increased throughout the eighteen weeks of the experiment, with the exception of oysters stocked at a density of 2.0 g.cm^{-2} and graded on a three weekly cycle. These oysters showed 'negative' growth towards the end of the experiment which was due to shell loss as a result of mechanical abrasion caused by the frequent grading.

The volume of oysters decreased after the April sampling for all but the low density/low frequency treatment. This was attributed to lower temperatures slowing growth plus the impact of shell loss due to grading. The loss in volume without a loss in oyster weight was caused by the loss of the oyster 'frill' which contributed greatly to the measured volume of the oysters, but little to their weight.

The mortality was greatest in the oysters graded at frequent intervals of once every three weeks, reaching approximately 6% during the eighteen week period. Low frequency grading of the oysters at the medium density produced the lowest levels of mortality. A higher than expected mortality was observed for the oysters stocked at the low density and graded at a low frequency. This was attributable to a number of oysters which were lost from this treatment during the course of the experiment and were classified as having died. The handling of oysters during grading can cause damage to the margins of the shell which are important in preventing water loss when exposed to air (Mantzaris, 1991). Therefore, oysters which have been stressed by high stocking density and frequent grading are likely to suffer higher mortalities than those which are in good condition.

Oyster production can be increased by reducing density and grading less frequently in winter. In Swan Bay, a grading every nine weeks would be the maximum requirement accompanied by light cleaning to remove fouling organisms. Although reduced density will produce superior growth rates, the gain in growth is accompanied by an increase in capital and labour costs. A reduction in density by 50% automatically produces a 100% increase in capital outlay as twice the number of bags and trays are required. Furthermore, this also increases the surface areas exposed to fouling organisms which will require extra cleaning effort thus increasing labour costs.

The economics of production will dictate the density used for growout. However it was demonstrated that even a density of 0.6-0.7 g.cm^{-2} can be inhibiting to growth.

The low density used in the experiment of 0.2 $g.cm^{-2}$ is likely to be impractical in a commercial operation; however, it may have important implications for the final stages of growout for the fattening of oysters prior to sale.

These problems of capital and labour costs associated with multiple tray culture led to the development of long-line culture in order to take full advantage of the extra dimension of depth. (See following section 2.3 Suspended culture of *O. angasi*.).

Recommendations:

1. Reduce density as much as capital costs and the physical constraints of the farm will allow (i.e. area farm,boat size,cleaning area).

2. Separate grading from the cleaning operation. Repeated gradings, particularly over winter (period of least growth), serve no purpose and may result in a retardation of growth. Quick cleaning to remove fouling organisms and a shortened exposure time can greatly reduce the stress on the oysters.

3. Grade selectively
- frequent light grading of nursery seed over summer.
- grade prior to growout
- grade prior to sale

Variation in oyster growth throughout a commercial growing stack.

The slower growth of oysters towards the middle of the trays was probably attributable to lower food availability as a result of reduced water exchange rates throughout the stack. The oysters in the uppermost trays did not exhibit the same reduced growth rates towards the centre of the tray as did the oysters in the lower trays, probably due to the top trays receiving a less inhibited water flow. The high cross-sectional density of the trays and bag meshes would create a substantial resistance to water flow which would be greater towards the middle of the stack. Growth becomes food limited in regions of low water exchange (Heral, 1985) which would explain the growth trends described above.

Greater spacing between stacks would be likely to reduce the variability of growth between bags by allowing a greater flow of water through the stack, particularly from the sides. In a commercial situation, adjacent stacks are often packed very tightly to economise on space. This practice creates an almost solid wall of growing trays which can greatly reduce the flow rate of water past the oysters.

As a result of the findings of the above experiment, a new tray was designed which was slightly shorter in length and which had higher sides. It was hoped that by increasing the height of the sides, a greater flow rate would pass through the stacks thus maximising the growth of the oysters in the middle of the trays. The new trays also incorporated an innovative interlocking system which allowed trays to be clipped together quickly and easily to form a growing stack, thus removing the need to tie the stacks together with packaging tape. A set of four hooks per tray, formed by bending

the ends of rod during tray manufacture, securely attach each tray to the one below (Appendix 3).

The reduced growth rates in the centre of growing stacks over a very short time would have a compounding detrimental effect over a longer time period. This means that optimising area usage by stacking trays in layers will adversely effect oyster production. The allocation of small areas for oyster farming in Victoria will not allow farmers to grow oysters in one layer as is practised in New South Wales and Tasmania.

In making the following recommendations to improve oyster growth, it is recognised that they will all increase oyster farming costs. The most optimum use of depth in a growing area is described in the following section on suspended culture.

Recommendations:

1. Increase the height of the trays to improve water flow characteristics.

2. Increase the spacing of adjacent stacks in an attempt to improve water flow through the sides of the trays.

3. Reduce oyster stocking densities.

Tray culture of oysters at two sites of potential culture in Victoria.

Oysters contained in lined, static trays and graded every two months, experienced extremely high mortality rates and poor growth at both growout sites. While the hydro-biological parameters, apart from salinity, were not shown to be significantly different between sites, it could be expected that the higher currents experienced at the Port Albert site may have increased the food available to the oysters and thus promoted growth. Growth trials have shown that increased water flow can increase food uptake in oysters leading to superior growth. However, growth of oysters at Port Albert was not found to be superior to that at Grassy Point. The high silt and drift weed content in the waters of Port Albert blocked the meshes of the trays, thus negating the benefits of increased water flow.

The growth rate of oysters at both sites slowed slightly between June and October. This was probably due to a decrease in water temperature, since oysters tend to stop producing new shell growth when water temperatures approach 10°C (Korringa, 1976a). The dramatic decrease in total oyster weight and volume which occurred over the summer was largely a result of the high mortality and the removal of dead oysters at the subsequent gradings. Oyster losses increased from 20% to almost 80% during this period. The remaining oysters showed little or no growth.

The massive summer oyster mortality reported here led to the discovery of the deadly oyster pathogen *Bonamia* in Victoria, which is a B-notifiable disease. The disease was subsequently found at all growing sites from Port Phillip Bay to Port Albert, and has since been discovered in Tasmania and Western Australia, thus causing Australia to lose its disease free status for Bonamiasis.

Evidence suggests that oysters exposed to two summers have an increased susceptibility to a disease such as Bonamiasis (Anon., 1991b). Oysters used in this trial were entering their third summer when the high mortalities were observed. The stress of the grading process could also have made the oysters more susceptible to Bonamiasis which finally lead to the extreme mortalities.

Although it is impossible to determine just how significant the effect of frequent grading was on the low survival rate of the oysters in this experiment, due to the confounding effects of *Bonamia*, the results tend to suggest that Flat Oysters are not as resilient to the grading process as the Pacific Oyster. While it has been shown that it is important to grade oysters and reduce densities to maximise growth, the Flat Oyster may require modifications to the method and practices of grading. Less frequent grading, lighter grading and occasional cleaning, without grading is likely to reduce stress induced losses.

It was clearly shown that commercial growth performance could not be achieved by manipulating labour costs (grading frequency), or capital costs (changing density).

Commercial production of Flat Oysters would require a minimum of three years' grow-out if bottom mounted racks were used.

The disease Bonamiasis would make Flat Oyster culture in bottom-mounted racks unviable in Victoria.

2.3 Suspended culture of *O. angasi.*

2.3.1 Introduction

The Japanese technique of three-dimensional culture is used to attach shellfish to ropes or wires and suspend these from floating surface rafts. This greatly increases shellfish yields for each unit area of ocean being farmed. Furthermore, the shellfish have access to the food available throughout the entire water column which presents opportunities to further improve shellfish productivity (Bardach et. al., 1972).

A new suspension technique suitable for growing *O. angasi* in open waters in Victoria was developed. The technique involved attaching individual oysters to 5 m. long tapes, which were suspended from mussel farming longlines. The growth performance of oysters subjected to the new growing method is described and factors affecting growth, were investigated.

2.3.2 Materials and Methods

The site selected for the growout trial was located at Grassy Point in Port Phillip Bay (Appendix 1). The water at this site was 9 to 10 metres in depth and therefore well suited to suspended culture. Experimental oysters, with a mean length of 36.9 $\pm$ 0.12 mm, were obtained from the Australian Flat Oyster Company. The oysters were approximately eight months old, having been produced in the Victorian Fisheries Research Institute's hatchery in November of the previous year and held in a field nursery in Swan Bay (Appendix 1). The oysters were obtained from the hatchery at about 3-5 mm in length and held in fine plastic mesh bags (2 mm mesh size), supported in lined trays. The oysters were cleaned and graded using hand sieves at four weekly intervals during the period of rapid growth over the summer months (December to February). At each grading, the oysters were separated into different size classes and placed back into bags of varying mesh widths according to size.

Experiment 1.

Oysters were randomly assigned to different treatments described below and were located at Grassy Point from 25 July 1989 until 14 June 1990, a period of approximately eleven months.

A total of four hundred oysters were placed into two, 20 mm plastic mesh bags at a density of two hundred oysters per bag. The bags were formed by folding and cutting commercially available Nylex oyster mesh to form bags of dimensions, 800 x 360 x 110 mm. The oysters were held in a 5000 L tank with flow through seawater whilst the remaining oysters were prepared for attachment to drop lines. Once deployed at the growout site, the two bags of oysters were placed in a galvanised tray (1.8 m x 0.8 m) which was supported approximately one metre above the sea floor on steel pickets. It was necessary to reduce the density of oysters in the bags in March due to overcrowding. Both bags of oysters were divided equally into two new bags.

A batch of 600 oysters was prepared for attachment to lengths of polyester tape. A small area on the cupped valve, proximal to the hinge end of each oyster, was cleaned

using a nylon scrubbing brush under running water. It was important to remove any silt or algal growth from the shell to provide a clean surface for an adhesive to bond. Each shell was quickly blotted dry with paper towel and the oysters were placed, cupped valve uppermost, in trays where they were allowed to further air dry for 10-15 minutes prior to the gluing operation.

A small plastic tag (10 mm x 30 mm), cut from 2 mm oyster mesh, was glued to the prepared surface of each oyster using an epoxy resin (Epiglass Epoxy Resin Glue-Epiglass Australia Pty. Ltd.). Approximately one gram of glue was required to securely attach a tag to each oyster. The adhesive did not stick to the plastic itself but instead, the glue formed beads up through the mesh which held it firmly in place. The oysters were left in the trays for 18 to 20 hours to allow the glue to achieve full strength. Damp hessian bags were draped over the oysters to keep them cool and help reduce water loss.

The oysters were attached to 13 mm polyester packaging tape using commercial plastic tag pins. A tag pin was inserted through the mesh tag attached to the oyster and through the tape itself with a tag applicator gun (Fig. 12).

Two droppers, each containing two hundred oysters, were prepared by the procedure outlined above. On one dropper, the oysters were spaced at a density of one hundred per metre while on the other dropper, the oysters were spaced at a density of fifty per metre. Each metre interval was marked on the tapes so that any differences in growth due to depth could be measured. Both of these droppers were suspended from a subsurface longline which was set approximately 2.5 metres below the surface. A third dropper of two hundred oysters was prepared and suspended from a surface longline which was subjected to strong wave action.

As a variation to the vertical dropper system, a timber frame (approximately 1m x 2m) with horizontal lengths of braided nylon twine stretched across it at 20 cm intervals, was used to hang oysters in a vertical plane by suspending it from a subsurface longline (Fig.12). It was envisaged that the frame may have had an application in areas of shallow water or in areas subject to high wave energy. The oysters were attached with tag pins in a similar way to those attached to the tapes. There were ten horizontal positions on the frame to which oysters were attached. Oysters were attached at densities of 50 and 100 per metre to compare differences in growth patterns which may have been a result of the stocking density. Only the top six positions, which consisted of two rows of oysters at 100 per metre and four rows at 50 per metre, were measured during the experiment.

A sample of fifteen similar sized oysters were collected from both a dropper (density 100 oysters/m) and a bag on 14 June 1990, after approximately eleven months of growout in order to compare condition and meat yields.

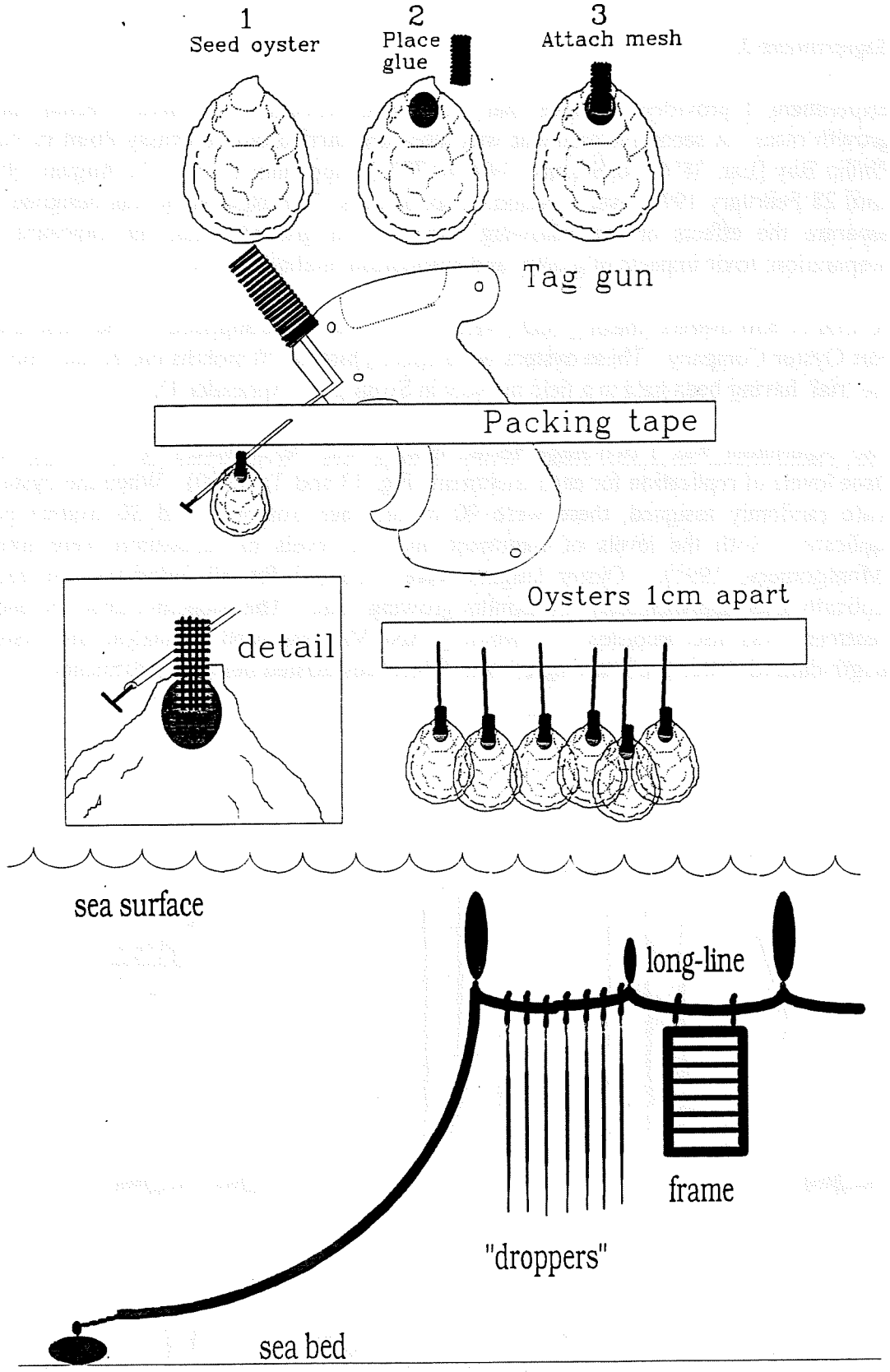

Figure 12. Method of gluing mesh to individual seed oysters, and attaching them to polypropylene packing tape with plastic tag pins. Tapes are suspended from longlines as vertically hanging 'droppers'.

Experiment 2.

Experiment 1 provided evidence that the gluing process could have affected early growth rates. A second experiment was therefore carried out at Grassy Point in Port Phillip Bay [Lat. 38° 06.43'S Long. 144° 40.77'E] (Appendix 1) from 31 August 1990 until 28 February 1991, over a period of six months. The experiment was designed to separate the effects of the following variables on growth rates: air exposure in preparation; toxic impacts of gluing; and suspension methods.

A total of 630 oysters (mean ± S.D.; 41.8 ± 2.99 mm) were supplied by the Australian Flat Oyster Company. These oysters were approximately 20 months old at the time of the trial, having been held in a field nursery in Swan Bay (Appendix 1).

The experiment was a two-stage nested design, with seven levels of treatment and three levels of replication for each treatment (Fig. 13 and Table 20). When the oysters were randomly assigned, there were 90 oysters per treatment and 30 oysters per replicate. Both the levels of treatment and the levels of replication were fixed (Montgomery, 1991). Oyster lengths were recorded for all individuals in each replicate after approximately six months growing time. The total mortality for each treatment was also recorded. A two-way ANOVA was used to analyse the oyster length data to determine if any significant differences existed between treatments.

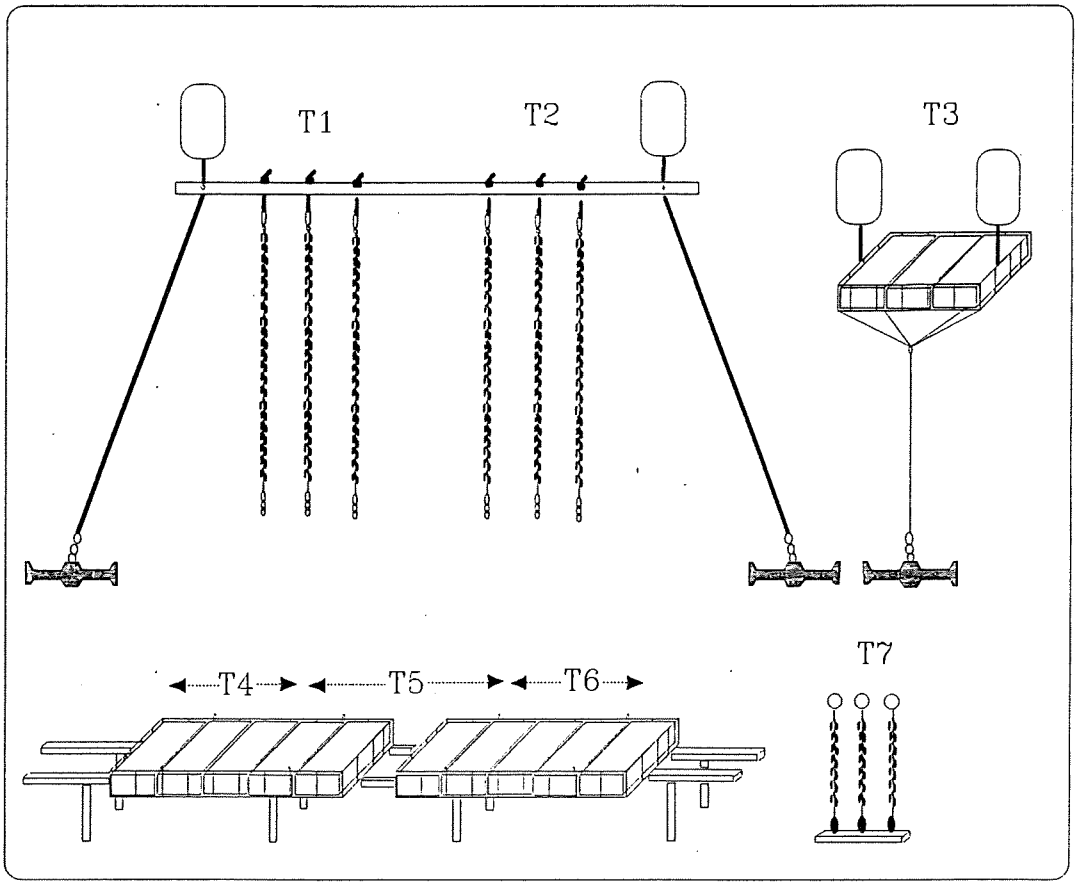

Figure 13. Seven experimental oyster growing treatments [T1= suspended tapes, 2hr exposure, glued; T2= suspended tapes, 18hr exposure, glued; T3= suspended bags, 18hrs exposure,glued; T4= control bottom bags, no exposure, no glue; T5= bottom bags, 18hrs exposure, no glue; T6= bottom bags, 18hrs exposure, glued;T7=bottom tapes, 18hrs exposure, glued.]

Table 20. Seven different treatments to which the oysters were exposed. Variables included the presence or absence of epoxy resin, exposure time to air, culture method and position of the oysters in the water column.

Treatment	Epoxy resin	Exposure time	Method	Position in water
T1	yes	minimum (2 hrs.)	tapes	upper
T2	yes	maximum (18 hrs)	tapes	upper
T3	yes	maximum (18 hrs)	bags	upper
T4	no	none (< 2hrs)	bags	bottom
T5	no	maximum (18 hrs)	bags	bottom
T6	yes	maximum (18 hrs)	bags	bottom
T7	yes	maximum (18 hrs)	tapes	bottom

The control (Treatment T4) was three, 20 mm plastic mesh bags (30 oysters per bag) placed in a bottom mounted tray at the growout site. There was no exposure to air or to gluing and the oysters were not suspended.

To minimise any stress due to cleaning, the oysters for the six remaining treatments were cleaned with a high pressure water jet. Approximately one third of the cupped valve of each oyster was held in the jet for five seconds. This removed the microalgal layer on the shell which was very important to enable a strong bond between the shell and the adhesive. Care was taken to avoid damage to the frill of the oyster. Oysters were quickly dried with a piece of absorbent towelling and placed in trays, cupped shell uppermost, to air dry for a further fifteen minutes prior to gluing.

To determine the effect of exposure only, a second batch of untagged oysters (similar to the the control treatment) was exposed for 18 hours. These oysters were also divided randomly amongst three, 20 mm mesh bags which were placed in a bottom mounted tray (Treatment T5).

For the remaining five treatments, a small plastic tag was attached to the prepared surface of all oysters, using an epoxy resin (previously described in Experiment 1, section 2.3.2). The oysters were then held in the air for the adhesive to cure. One batch of oysters with newly attached tags was placed in a flow through tank after only 2 hours drying time (Treatment T1). These oysters were later attached to three, one metre lengths of polypropylene tape using plastic tag pins as previously described. Oysters were attached at a density of 30 oysters per tape. A second batch of oysters which was glued and exposed to air, this time for approximately 18 hours, was similarly attached to tapes (Treatment T2). The oysters in both these treatments were then suspended in mid-water from a subsurface beam which was set at approximately three metres below the surface.

Another batch of tagged oysters, which had been exposed for 18hrs was placed into mesh bags and positioned in a bottom mounted tray (Treatment T6).

A further batch of oysters was attached to tapes which were tethered to the bottom and buoyed with styrene floats to a similar height as the oysters in bags on the bottom tray (Treatment T7).

The final batch of oysters was divided evenly into three, 20 mm plastic mesh bags and placed in a subsurface tray which was buoyed to the same height as the oysters hanging from the sub surface beam (Treatment T3).

2.3.3 Results

Experiment 1.

Oysters grown on subsurface droppers suspended from a longline showed exceptional annual growth (Fig. 14). Almost the whole population of oysters grown on droppers were larger than the small number of large oysters in the control bags (Fig. 15). Furthermore, the suspended oysters were much less variable in size than the oysters grown in bags (also Fig. 15). This enhanced growth performance was achieved despite the fact that the oysters in the control bags were larger for the first five months (Fig. 16 and Table 21). Most of the spectacular growth of 'dropper oysters' occurred over only four Summer months from December to April (Fig. 16). In the same period the growth of 'bag oysters' almost ceased.

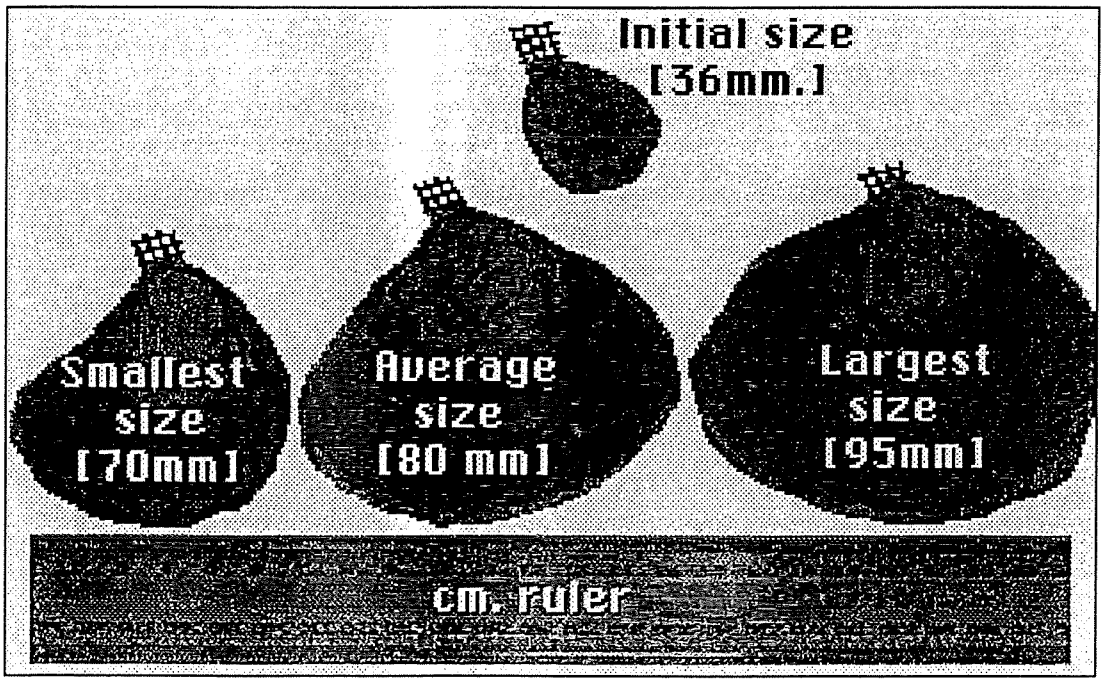

Figure 14. Exceptional annual growth of the whole population of *O. angasi* grown by suspended culture.

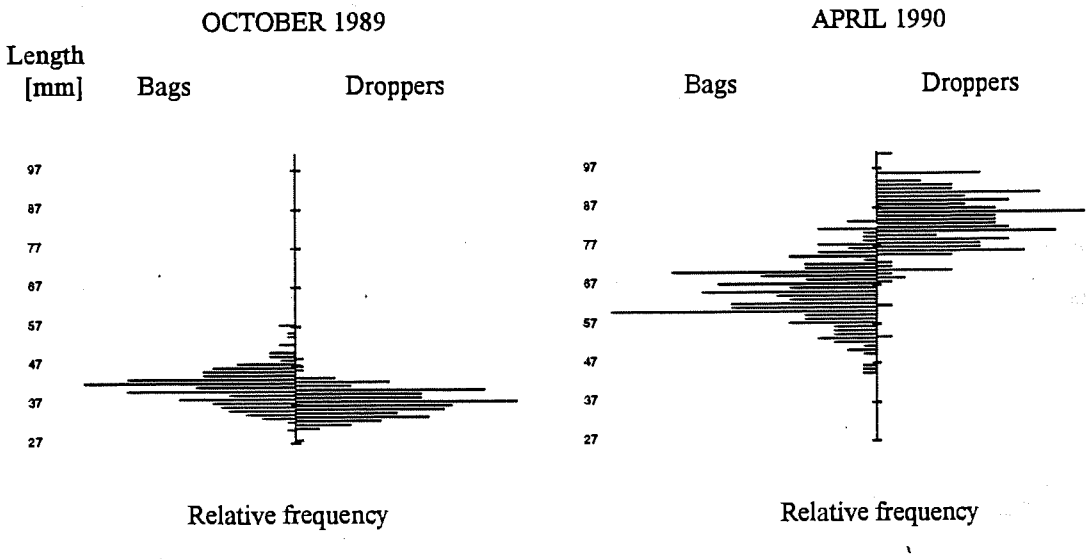

Figure. 15. The growth of *O. angasi* on longline droppers for six months shows that the whole population attain commercial size (> 70 mm), in marked contrast to oysters grown in bags.

Despite using the same grade of oysters, holding the control 'bag oysters' in flow through seawater for the period of 10 days which it took to prepare the other treatments, resulted in the control 'bag oysters' being larger at the time of deployment to sea (Fig. 16).

Table 21. Mean length (millimetres) and standard error of oysters grown in bottom bags and on subsurface droppers. Significance levels are given for the two treatments.

Date	Bag		Dropper		Significance
	Mean	S.E.	Mean	S.E.	
Jul 89	38.0	0.24	35.6	0.26	Bag > Dropper $p<0.001$
Oct 89	41.4	0.34	36.9	0.24	Bag > Dropper $p<0.001$
Dec 89	52.7	0.46	45.9	0.36	Bag > Dropper $p<0.001$
Jan 90	61.5	0.50	56.8	0.45	Bag > Dropper $p<0.001$
Feb 90	63.6	0.54	65.6	0.49	Dropper > Bag $p<0.01$
Mar 90	64.2	0.53	76.2	0.52	Dropper > Bag $p<0.001$
Apr 90	64.6	0.57	82.5	0.54	Dropper > Bag $p<0.001$
May 90	71.8	0.56	81.8	0.58	Dropper > Bag $p<0.001$

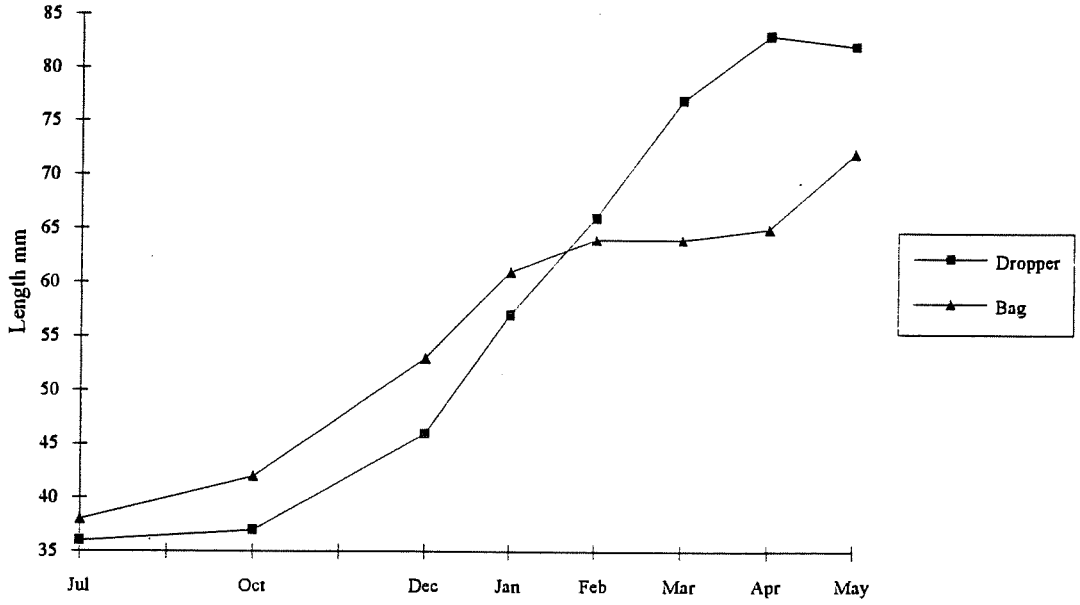

Figure 16. Mean length in millimetres for oysters grown in bottom bags (200 oysters/bag) and on droppers at a density of 100 oysters per metre.

The growth rate of oysters suspended on tapes from a subsurface longline was superior ($p<0.001$) to the growth achieved by oysters on a surface longline (Fig. 17). The mean length of oysters on the subsurface longline increased from 45.9 $\pm$ 0.36 mm to 82.5 $\pm$ 0.54 mm in just four months (7 December - 2 April), compared to the mean length of oysters on the surface longline which increased from 44.9 $\pm$ 0.59 mm to 67.3 $\pm$ 0.72 mm during the same period.

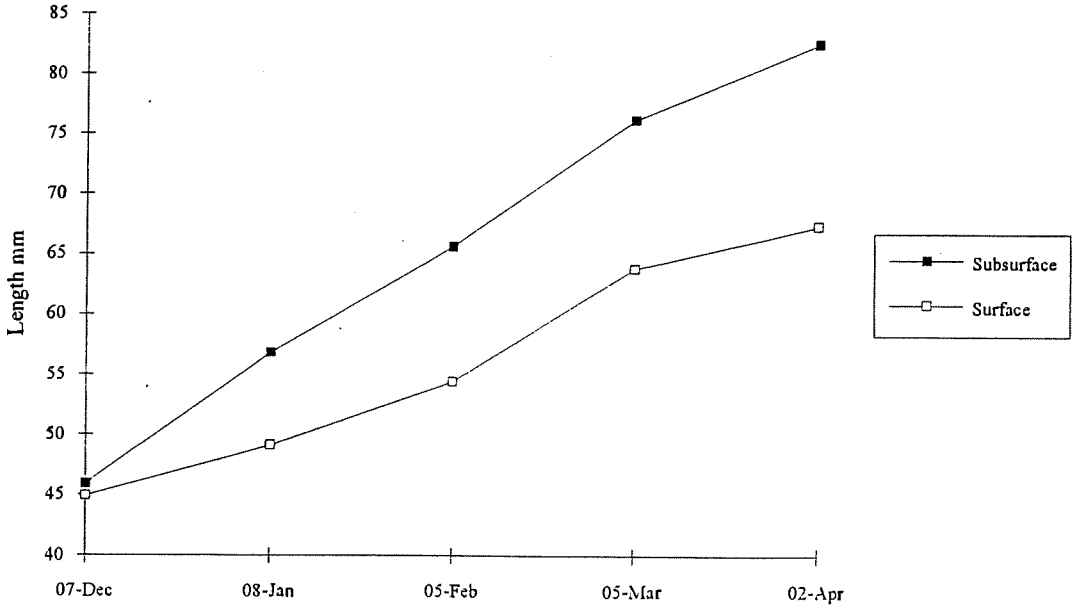

Figure 17. Growth of oysters attached to tapes suspended from a subsurface longline, compared with the growth of oysters on a surface longline.

During the period from April to May, windy weather caused the loss of almost all the oysters from the surface longline. Most of the oysters became detached at the adhesive-shell surface interface. Conversely, less than ten percent of the oysters were lost from the sub surface dropper and the majority of this loss was caused by the frequent handling they received during the experiment.

There was no significant difference ($p>0.05$) between the mean length of oysters grown on tapes at a density of 50 oysters per metre and the mean length of oysters grown on tapes at a density of 100 oysters per metre, after approximately ten months' growout. In contrast, oysters suspended horizontally on the frame showed differences in growth rates due to density. Oysters attached to the frame at a density of 100 per metre grew at a greater rate than oysters stocked at a density of 50 per metre. At the final sampling in May, the mean length of oysters stocked at a density of 100 oysters per metre was significantly greater ($p<0.01$) than the mean length of oysters stocked at the lower density (Table 22). Observations revealed that the oysters grown at a density of 100 per metre were cleaner than the oysters held at a density of only 50 per metre.

There was no strong relationship ($r=-0.49$) between the length of oysters and their position on the dropper at the final sampling on the 8th May.

Table 22. Mean length (millimetres) and standard error for oysters grown at two densities; 50 oysters/m and 100 oysters/m on droppers and on a frame. ($^{a}P>0.05$; $^{b}P<0.01$)

Date	Dropper		Frame	
	50/m	100/m	50/m	100/m
Jul 89	38.4 + 0.27	35.6 ± 0.26	36.0 ± 0.26	36.3 ± 0.29
Oct 89	38.1 + 0.26	36.9 ± 0.24	35.9 ± 0.26	36.1 ± 0.25
Dec 89	46.3 + 0.33	45.9 ± 0.36	42.2 ± 0.23	43.0 ± 0.35
Jan 90	54.7 + 0.43	56.8 ± 0.45	51.9 ± 0.44	54.4 ± 0.43
Feb 90	63.1 + 0.50	65.6 ± 0.48	57.3 ± 0.51	59.2 ± 0.55
Mar 90	73.2 + 0.53	76.2 ± 0.52	69.2 ± 0.57	76.1 ± 0.59
Apr 90	79.3 + 0.54	82.5 ± 0.54	73.4 ± 0.55	76.1 ± 0.61
May 90	81.7 + 0.60	81.8 ± 0.58[a]	75.9 ± 0.51	77.4 ± 0.56[b]

The oysters grown on the frame (density 100/m) and suspended from the subsurface line were significantly smaller (p,0.05) than the oysters attached to single droppers at the same density (Table 23). The growth of oysters on the dropper remained superior ($p<0.001$) to the growth of oysters on the frame with the final mean lengths of 81.8 ± 0.58 mm and 77.4 ± 0.56 mm for the dropper and frame respectively. The level of fouling on the oysters grown on the frame appeared to be greater than the fouling which occurred on the droppers.

Table 23. Mean length and standard error for oysters attached horizontally to a frame and vertically to a dropper, suspended from a subsurface longline. Growth rates were superior on the dropper ($p<0.001$).

Date	Frame		Dropper		Significance
	Mean	S.E.	Mean	S.E.	
Jul 89	36.3	0.29	35.6	0.26	$p>0.05$
Oct 89	36.1	0.25	36.9	0.24	$p<0.05$
Dec 89	43.0	0.35	45.9	0.36	$p<0.001$
Jan 90	54.4	0.43	56.8	0.45	$p<0.001$
Feb 90	59.2	0.55	65.6	0.48	$p<0.001$
Mar 90	71.6	0.59	76.2	0.52	$p<0.001$
Apr 90	76.1	0.61	82.5	0.54	$p<0.001$
May 90	77.4	0.56	81.8	0.58	$p<0.001$

Calculation of condition index (Lawrence and Scott, 1982) showed that oysters from the dropper had a mean index of 109 compared to 116 for oysters from the bag. However, this was misleading in that the oysters sampled from the bag (79.3 $\pm$ 0.92 mm) were the largest in that treatment while the oysters sampled from the dropper (80.7 $\pm$ 0.58 mm) were the smallest of the population. Consequently, the meat yield from each treatment probably gives a more meaningful assessment of growth performance than does condition index. The mean wet meat weight of oysters grown on the tape was significantly greater ($p<0.0001$) than the wet meat weight of oysters in the bag (Table 24).

Table 24. Comparison of mean wet meat weights of oysters (n=15) sampled from the dropper and the bag on 14 June 1990, after approximately eleven months growout. The results are mean values $\pm$ SEM. ($^{a}P<0.0001$).

Variable	Treatment	
	Dropper (n=15)	Bag (n=15)
Length (mm)	80.7 $\pm$ 0.58	79.3 $\pm$ 0.92
Wet meat wt. (g)	9.3 $\pm$ 0.35[a]	7.2 $\pm$ 0.30

Experiment 2.

A short adhesive curing time significantly ($p<0.05$) reduced the oyster growth rate (cf. T1 and T2 in Table 25). There was no significant difference due to: exposure alone (T4 cf. T5); gluing alone (T5 cf. T6); and suspension (T2 cf. T3 cf. T7) - see Table 25 and Fig. 13.

Oysters suspended on bottom tapes (T7) were significantly larger ($p<0.01$) than similarly glued oysters held in bags at the same level (T6).

Table 25. Mean and median oyster lengths for oysters grown in seven treatments, after approximately seven months growout. All lengths are given in millimetres.

Treatment No	Description	Mean	Median	Std.	Stderr.
T1	Suspended tape 2 hr exposure Glued	66.6	67	5.60	0.72
T2	Suspended tape 18 hrs exposure Glued	70.8	71	6.18	0.84
T3	Suspended bag 18 hrs exposure Glued	70.3	71	7.48	1.00
T4	Control. Bottom bag No exposure No glue	66.1	66	7.29	0.91
T5	Bottom bag 18 hrs exposure No glue	66.3	66.5	6.72	0.83
T6	Bottom bag 18 hrs exposure Glued	64.6	63	6.31	0.83
T7	Bottom tape 18 hrs exposure Glued	69.1	68	6.38	0.84

2.3.4 Discussion

It was shown that oysters could be effectively grown on a longline from a post-nursery stage, through to harvest in approximately nine months, with low mortality and high meat yields. The greatest significance of this result is that this husbandry method has great potential to minimise losses due to the deadly disease Bonamiasis which has devastated flat oysters throughout the world. The disease has often been reported to kill 100% of oysters which are older than two years (Bonnet and Troadec, 1985; Fisher, 1988). By optimising nursery production in year 1, this suspended growing method has the potential to grow the whole population to maturity before the disease attacks sexually mature animals.

This exceptional mid-water growth can be attributed to two features of suspended culture:

i) Suspension culture is distinct from bottom and off-bottom culture techniques in that it utilizes depth as a third growing dimension. This has been recognised as important in the culture of many species of molluscs in that it increases the availability of planktonic food for growth and alleviates many of the problems of overcrowding associated with other methods.

ii) Observations showed that the flexibility of the tag pins, attaching the oysters to the tapes, allowed the oysters to move freely over one another. This movement had a self-cleaning action by limiting the colonisation of fouling

organisms. (The decline in growth rates noted for the oysters held in the control bags from January to April was due to overcrowding and increased summer fouling severely restricting water flow).

Although the final size of the 'dropper oysters' was superior to the control 'bag oysters' the growth performance in the bags was better for the first five months of the trial. Abrasion caused by increased handling was responsible for the smaller mean size of oysters suspended on tapes, prior to the commencement of the growout. Other factors inherent to the processes involved in suspending oysters from a longline (such as desiccation or toxic effects of gluing) were thought to have been responsible for the initial lag in growth of the oysters on the tapes. It was discovered that the suspension method and desiccation were not responsible for slowing initial growth rates but chemicals within the glue could reduce growth if oysters were placed back in a restriced water flow before the glue was properly cured.

The main reason for the initial difference in growth rates between suspended and bag grown oysters was the initial size difference brought about by holding the control oysters in seawater (where they grew slightly) when the experimental oysters were being subjected to the gluing process. This means that if oysters of a larger size than 36 mm were to be used, the annual growth potential may be improved to an even greater extent.

The positioning of the longline in the water column was critical to oyster growth. Growth on a surface longline was slower than on the subsurface line and losses were higher due to the increased movement caused by surface wave action. The oysters on the surface longline showed a marked stunting of the shell which was particularly noticeable on the oysters in the upper half of the dropper. Windy weather was shown to cause almost 100% loss of oysters from the surface longline, whereas only 10% of the oysters were lost from the subsurface longline. At two metres below the surface, the oysters on the submerged line still showed some signs of abrasion; however, this was not detrimental to growth. In fact, it was believed that the flexible nature of the tag pins holding the oysters to the tapes may have been important in helping to control the settlement of fouling organisms. Further evidence to support this was provided by growth results on the frame which showed that oysters stocked at a density of 100 per metre grew better than those stocked at only 50 per metre. The greater overlap of oysters at the higher density, in conjunction with the abrasive action of neighbouring oysters' shells gently knocking one another, could have resulted in the better control of fouling organisms and thus the improved growth.

When considering different sites, the wave action and fouling organisms at each growing site will dictate the best depth to suspend the longline. A balance will need to be made between the depth required so that wave action can cause moderate abrasion to keep the oysters clean, and not cause losses due to storm damage. Mussel farmers in Port Phillip Bay have gained a great deal of experience in this area in recent years and can now set longlines at any specified depth.

The growth potential of oysters suspended from a longline was very encouraging and certainly worthy of further experimentation. The attachment of individual oysters to tapes as carried out in this experiment was very labour intensive, however, the

technology exists to mechanise this operation since a Dutch firm has recently developed a machine capable of attaching 2000 scallops an hour to rope droppers (Anon., 1991a). A further advantage of this system was the production of perfectly shaped oysters with extremely low incidence of mudworm infestation. This is particularly important since oysters to be eaten raw on the halfshell must have uniformly shaped shells if they are to bring the best prices (Bardach et. al., 1972).

In areas susceptible to the oyster disease Bonamiasis, the development of suspended culture offers some hope that husbandry practice may still allow flat oysters to be grown commercially. The growth rates achieved by growing in bags or containers would not permit this. Furthermore, if the adhesive and attachment process can be automated, there are significant economic gains to be made in reducing labour and capital costs associated with bottom growing methods.

Conclusions for Section 2 - Grow-out of *O angasi.*

1. Traditional bottom growing and bottom rack methods would not produce oysters quickly enough to minimise losses due to Bonamiasis which is a disease which kills mature oysters.

2. Development of a new suspended culture method produced exceptionally fast growth rates with low mortalities.

3. The use of husbandry techniques to grow flat oysters quickly is proposed as a management tool to control the disease Bonamiasis which has devastated flat oyster production throughout the world.

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APPENDICES.

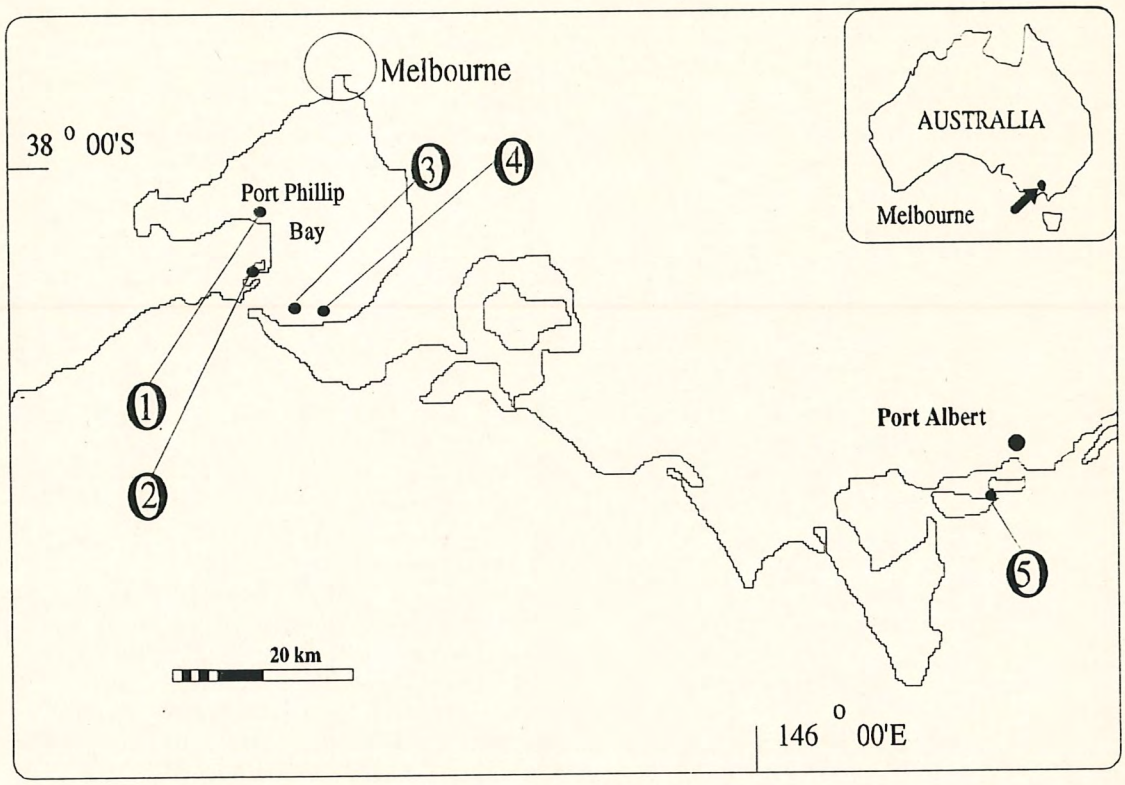
1] Location of Study Areas.

2] Tumbler Design and Operation.

3] Design of Inter-locking Growing Stack and Nursery "Corf".

APPENDIX 1

LOCATION OF STUDY AREAS



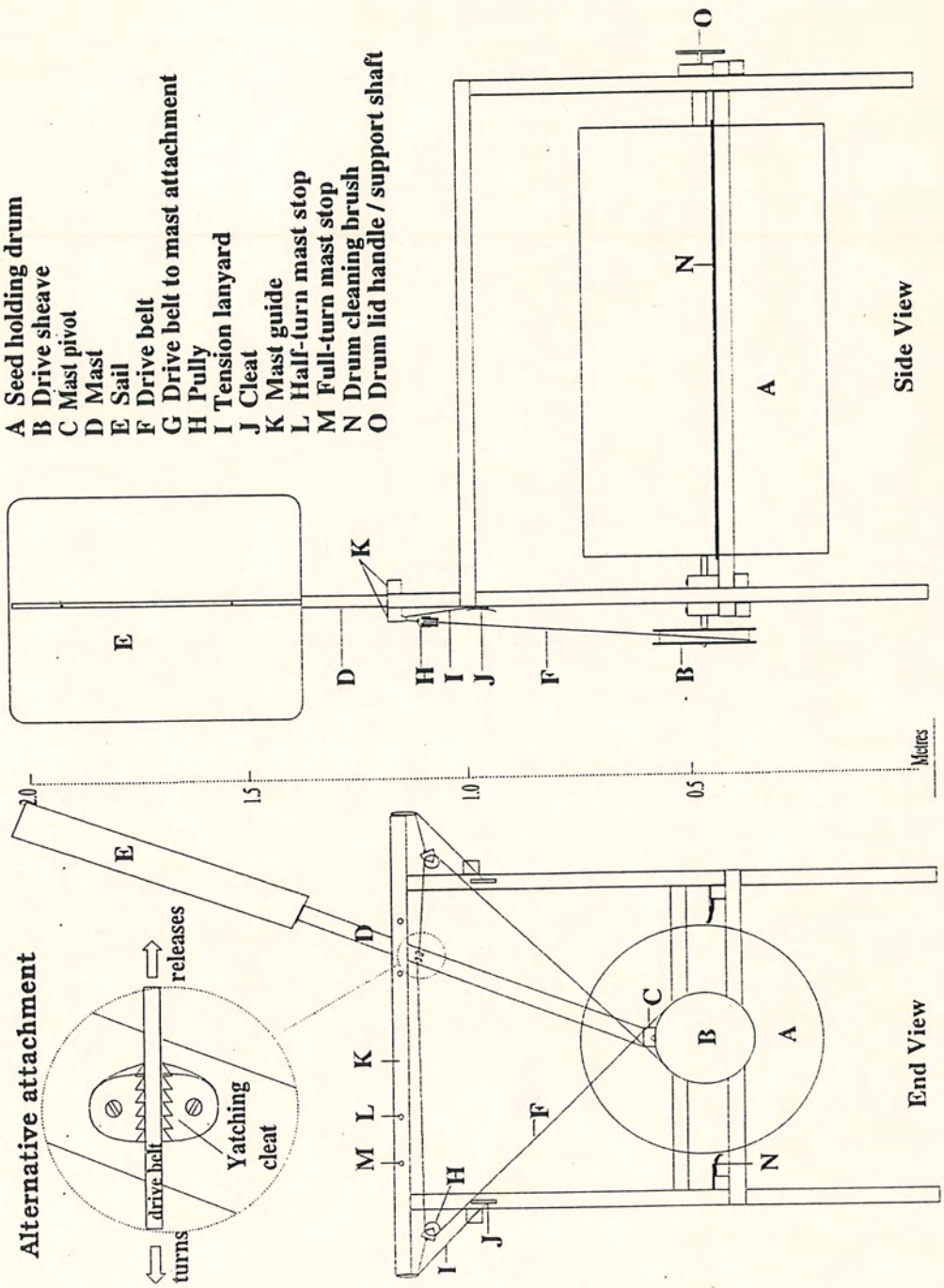
Location of Victorian study sites for all experiments and growth trials.

Site number	Site name	Latitude and longitude
1	Grassy Point	Lat. 38° 06.43'S Long. 144° 40.77'E
2	Swan Bay	Lat. 38° 13.30'S Long. 144° 40.20'E
3	Blairgowrie	Lat. 38° 21.43'S Long. 144° 47.20'E
4	Capel Sound	Lat. 38° 20.50'S Long. 144° 49.50'E
5	Port Albert	Lat. 38° 44.50'S Long. 146° 37.50'E

Report Section code	Title of section	Location of exps. [site nos.].
1.1	Nursery - deep water rotating systems	3
1.2	Nursery - shallow water static systems	2 & 3
2.1	Grow-out. Bottom culture	4
2.2	Grow-out. Off-bottom culture	1,2.4,&5
2.3	Grow-out. Suspended culture	1

APPENDIX 2

TUMBLER DESIGN AND OPERATION



System design

A mesh cylinder, measuring 510 d x 900 h mm, was designed to hold appproximately 250 thousand oysters of 3 mm shell length. The internal frame of the cylinder was constructed from 6 mm diam. stainless steel rod (316 marine grade). This framework consisted of seven hoops which were held together at 150 mm spacings by sixteen horizontal sections of rod, welded at 100 mm intervals. The ends of the horizontal sections were cut so that they protruded 25 mm beyond the ends of the cylinder and were threaded to hold the end caps in place. The end caps were cut from 6 mm P.V.C. sheet and were fastened to the cylinder by a series of wing nuts. A gasket of high density foam rubber was used to form a tight seal between the outer rim of the cylinder and the end caps. The cylinder was covered by a fine stainless steel mesh (1.5 mm diam.) in order to contain the oyster seed.

A drive shaft was fitted centrally to the two lids on the cylinder and this enabled it to be supported horizontally in an outer framework which contained the drive mechanism. The supporting framework was manufactured from square section steel tubing (25 x 25 mm) which was hot-dip galvanised to prevent corrosion.

A sail connected to a mast utilised the power produced by the current to turn the cylinder. A drive belt attached to the mast, passed through a set of tensioning pulleys and around a drive sheave which was connected to the driving shaft on the cylinder. As the direction of water flow reversed (ie. tide change) and reached sufficient velocity, the sail and mast were forced to move in the direction of tidal flow and as a result, the cylinder revolved. By altering the size of the drive sheave or the distance of mast travel, the degree of cylinder rotation could be controlled. An innovative part of the design were the rows of brushes attached to the frame which cleaned the meshes of the cylinder as it revolved.

The nursery tumbler, consisting of the mesh cylinder holding oyster seed and the outer supporting framework with associated drive mechanism, was completely submerged and moored on the seabed. The bidirectional nature of the sail and mast necessitated that the tumbler be positioned across the current. This also ensured that the greatest surface area of the cylinder was exposed to the current to maximise water flow past the oysters.

Operation

The cylinder and drive mechanism of the tumbler remained fully serviceable for an eighteen week period without requiring any maintenance. The base and supporting frame were uncorroded and relatively free of any marine fouling organisms. The seals on the P.V.C. cylinder ends had collapsed from compression, however, were still intact and had not permitted the loss of any oyster seed. Corrosion was evident on the stainless steel mesh where it was in contact with the welds of the internal cylinder frame. The corrosion, although slight, could have become a problem with time (in a subsequent experiment, severe corrosion was encountered in the stainless mesh after only six weeks, probably due to electrolysis).

The brushes kept the meshes of the cylinder clean throughout the eighteen week period with only minor fouling occurring on the inside of the mesh, where the brushes could not reach. In contrast, fine mesh bags positioned in a tray alongside the tumbler to act as a control, became heavily fouled with hydroid, bryozoans, silt and algae.

The movement of water through the cylinder was observed using a fluorescene dye released from a 50 ml. syringe at varying distances upstream from the tumbler. Dye released proximal to the mesh, at the top and the bottom of the cylinder, tended to follow the contour of its surface rather than enter through the mesh. Dye released along the centre of the cylinder passed rapidly through the mesh where its movement slowed and it became dispersed. A constant stream of dye was observed leaving the cylinder, with some dye diffusing through the oyster mass, which was concentrated in the lower quarter of the cylinder. Flow rate was obviously impeded by the fine mesh, however, it was thought that a deflector plate may improve the flow by directing water up through the cylinder.

Modifications

In light of the corrosion problems encountered with stainless steel in seawater, a cylinder was constructed using a polyester mesh. The internal frame of the cylinder was made from mild steel which was later galvanised to prevent corrosion. The polyester mesh was stretched over the frame and joined using an epoxy resin. When trialled under field conditions, the polyester mesh was found to stand up well to the abrasive action of the oysters tumbling around inside and showed no evidence of sagging or tearing. The inner framework of the cylinder showed no sign of corrosion after nine weeks' operation at sea.

As previously described, the rotation of the cylinder can be controlled by the size of the drive sheave and by adjusting the length of travel of the mast along the mast guide. A further development was the use of a one way cleat on the drive mechanism which turned the drum on a twelve hourly cycle, rather than every six hours with each tidal change. The issue of the optimum tumbling intensity for maximum oyster growth was addressed in an experiment (**Effects of rotation on seed growth**) by comparing the resultant growth performance of oysters in two tumblers, one which turned four complete revolutions per day and the other which turned just one revolution per day. The one revolution was achieved using the cleat system and adjusting the mast travel so that the cylinder would complete a half revolution every twelve hours.

A further innovation involved the use of a drogue instead of a sail, to power the mechanism to turn the cylinder. The drogue was made from dacron and had an opening of one metre in diameter. It was attached to the lever arm on the tumbler by a five metre length of rope. A small buoy (10 cm) was attached to the tail end of the drogue so that it would not sink and foul the tumbler during slack water. It was found that the drogue would operate in low current areas (< 0.8 km/hr.) which previously lacked the power to move the sail arm. By utilising either the sail or the drogue and by adjusting the length of the lever arm, the tumbler can be used in a wide range of areas with differing current strengths.

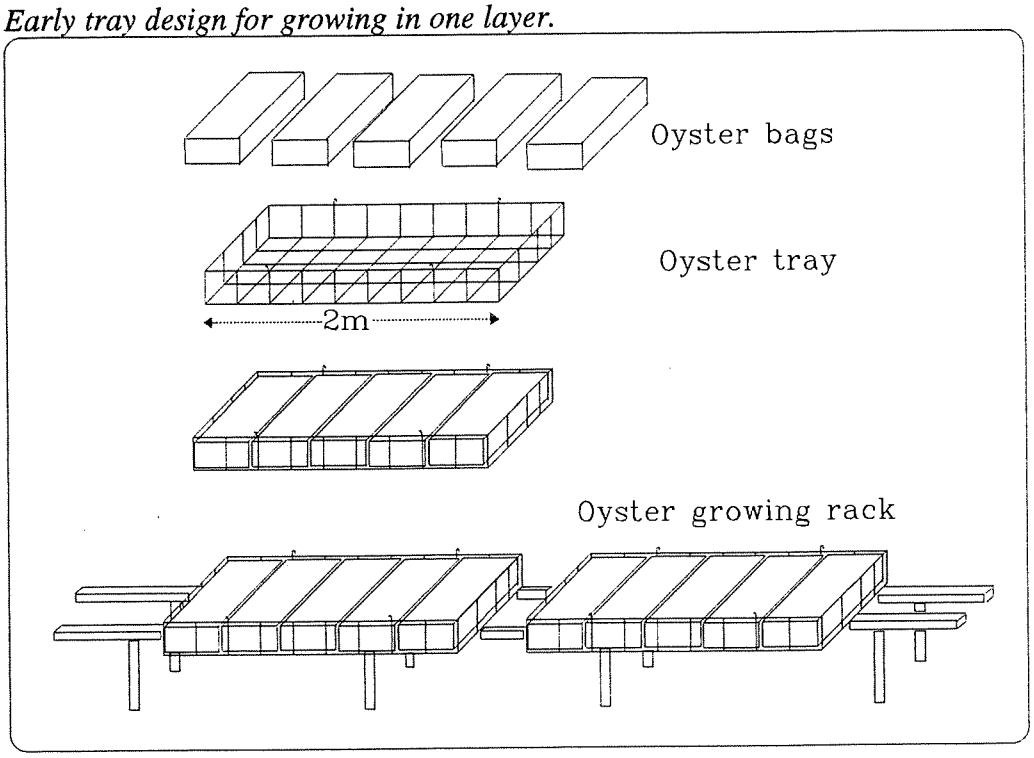
Summary

The tumbler operated continuously for a period of eighteen weeks, during which time the fine meshes of the revolving drum were kept free of fouling by the cleaning brushes. Problems of corrosion encountered with the use of stainless steel were alleviated when the internal frame was replaced with galvanised mild steel and a polyester outer mesh was used to replace the existing stainless steel one. The tumbler was shown to be adaptable in that it could be used in a wide range of areas with differing current strengths by simply making adjustments to the drive mechanism. The tumbler has the potential to provide a low maintenance way of handling large numbers of post-hatchery oyster seed. Due to the high costs of feeding oysters in a land based nursery, this system offers oyster growers a significant economic gain in producing 10-15 mm seed oysters.

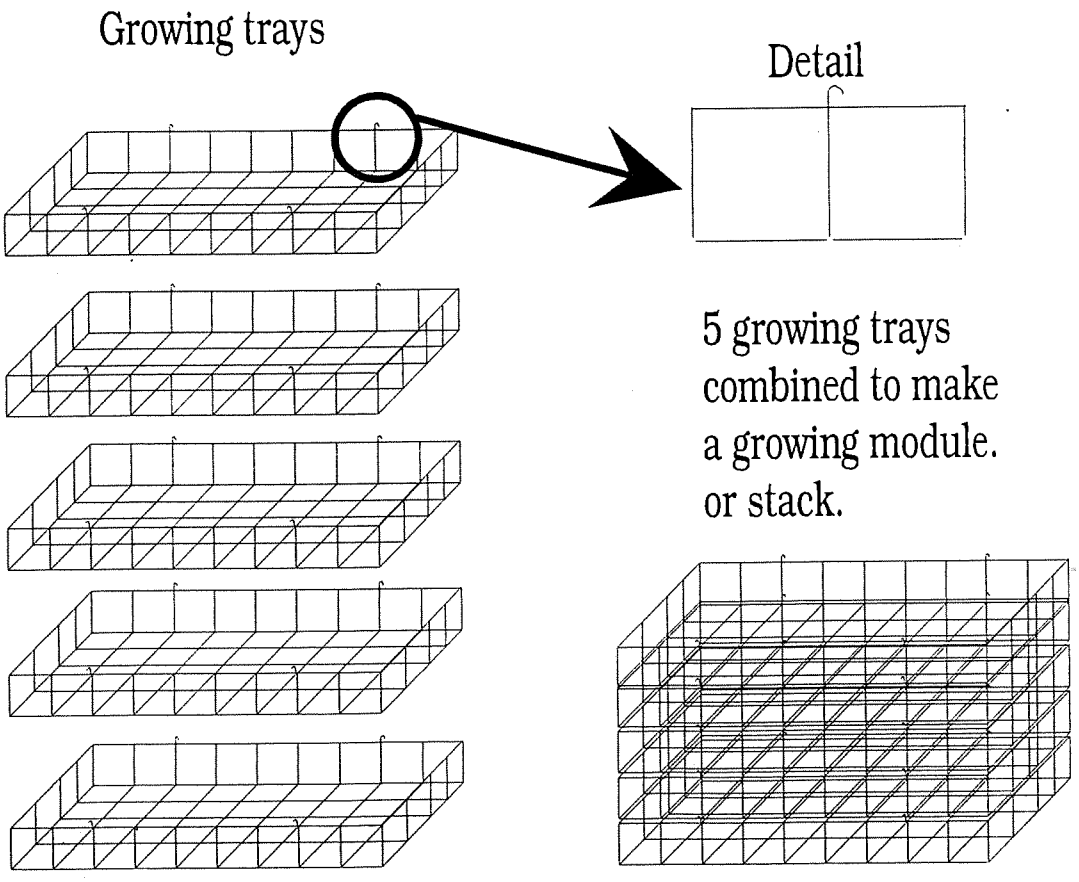
APPENDIX 3

DESIGN OF INTER-LOCKING GROWING STACK AND NURSERY CORF

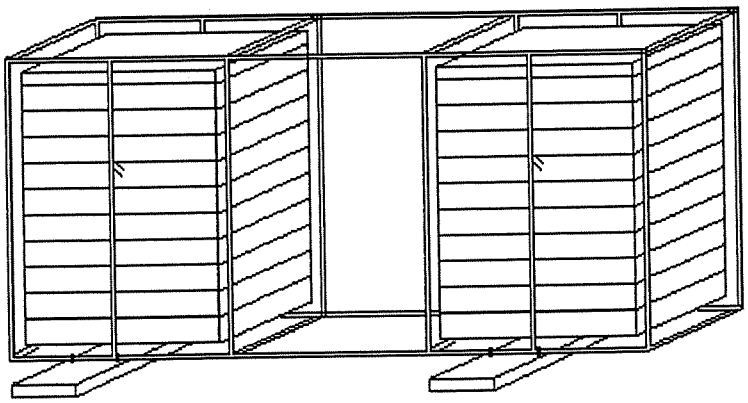
Early tray design for growing in one layer.



Re-designed trays with simple inter-locking mechanism.



NURSERY "CORF"



System design

In an attempt to streamline the culture of small oyster seed, AFOC developed the Nursery Corf, which consisted of a rectangular, galvanised frame (1.5 m x 0.5 m x 1.0 m) capable of holding two columns of ten nursery boxes. Each nursery box was made from a square sheet of rigid, plastic mesh, folded into a box (490 x 490 x 90 mm) and stapled to four wooden corner pegs for support. The boxes stacked, one on top of the other, the upper box forming the lid of the box beneath it. The interchangeable nature of the boxes allowed different mesh sizes to be used as the oysters grew.

The system was designed so that oysters could be easily loaded and unloaded from the boxes. The capacity of the boxes meant that a greater volume of seed could be handled at a time compared to the use of bag culture. The corf was also a free standing structure which could be positioned directly on the bottom, unlike the trays which required supporting trestles to raise them off the bottom.

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