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NURSERY CULTURE OF THE SYDNEY ROCK OYSTER *SACCOSTREA COMMERCIALIS* AND THE PACIFIC OYSTER *CRASSOSTREA GIGAS*

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FINAL REPORT

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CONTENTS

SECTION 1

INTRODUCTION

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All objectives proposed in the original and extended grants have been achieved, however, several experiments were altered or terminated prematurely. Experiments related to cultivation of Pacific oysters were altered after a change in NSW Government policy, which declared the Pacific oyster a noxious fish, making its cultivation and presence on a lease an offence. Several cursory experiments were conducted, firstly to determine the optimum settlement zone for Sydney rock oysters in the tidal range and secondly to determine the effects of stocking a uniform grade of Sydney rock oysters in sectionalised nursery trays has on growth and survival. The results of the trials were presented at the Brackish Water Fish Culture Annual Open Days (Appendix). Further experiments to determine zone of settlement were not undertaken as there was no significant difference in settlement between treatments tested and as there was an experiment on this topic proposed in Mr McOrries' FIRDC grant (No. 84/04). Follow-up experiments were not conducted to determine the effects of stocking uniform grades of spat as it was felt that additional time should be allocated to expanding the more relevant areas of nursery culture.

The major objective of the grant was to develop settlement and nursery techniques for Sydney rock (*Saccostrea commercialis*) and Pacific oysters (*Crassostrea gigas*) with specific aims as follows:

1 Compare hatchery and natural settlement of Sydney rock and Pacific oysters and retention of single seed and market grade oysters on various commercially-used collectors.

2 Determine optimum stocking densities of juvenile Sydney rock oysters in sectionalised timber trays and PVC cylinders.

3 Evaluate performance of juvenile Sydney rock oysters in the major nursery units used in Australia. These units included:
   - a Passive upwellers & trays
   - b Baskets, sectionalised trays & cylinders
   - c Cylinders, trays, discs & upwellers
   - d Tarred & PVC sticks

4 Evaluate potential nursery sites and performance of juvenile Sydney rock oysters using the various nursery units described above.

5 Determine the effects of cold storage on pediveliger Sydney rock and Pacific oyster larvae for remote setting on PVC and slurried coated collectors.

The project with annual gross total cost of $33 376, commenced on July 1, 1987 and was completed on June 30, 1990.

The report is composed of separate manuscripts using the format required for 'Aquaculture'. Currently, two of the four manuscripts submitted to "Aquaculture" have been published (Appendix). A paper was accepted for presentation at the First Australian Aquaculture Conference held in Perth, 1988 and another published as a Fisheries Bulletin. Several manuscripts have also been prepared for future publication as part of a Fisheries Bulletin on oyster culture (Appendix).

Progress reports were presented to farmers at the Brackish Water Fish Culture Research Station annual 'Open Days' in 1987, 88, 89 and 90 and an article on using PVC growing sticks as an alternative to traditional tarred hardwood sticks was published in the oyster farmers magazine 'The Australian Oyster' (Appendix).

SECTION 2

BACKGROUND AND RELEVANCE TO INDUSTRY

Alternative cultivation methods for the Sydney rock oyster, *Saccostrea commercialis*

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ABSTRACT

The development of the conventional stick and tray farming methods used for Sydney rock oysters *Saccostrea commercialis* in New South Wales is briefly described. The industry based on these methods flourished for several decades but in recent years it has experienced a decline in production and poor returns on investment. Research on alternative cultivation methods for this species and further developmental work by commercial farmers have provided a range of farming options. The advantages and problems associated with commercial use of these alternative methods are discussed. The New South Wales oyster farming is facing a range of economic and biological challenges and it is argued that the alternative methods eg subtidal and single seed culture, can help meet these challenges. Some of the likely future trends in farming methods for this species are also indicated.

1. INTRODUCTION

Aquacultural industries can progress through the combined efforts of research workers and practical farmers, and their relative contributions can vary between industries and between different phases in the development of an industry. One popular field of applied aquacultural research is the development of novel farming methods. The various approaches to oyster farming can be categorised into:

(a) bottom culture in which oysters and perhaps hard settlement surfaces (cultch) are scattered on the bottom of estuaries and bays;

(b) off-bottom culture in which supporting frames fixed in the bottom sediment are used for growing oysters above the sediment layer either subtidally or intertidally, and

(c) hanging culture in which the oysters are suspended below some form of flotation (Wisely, *et al.* 1979a).

Oyster farmers in New South Wales developed Sydney rock oyster *Saccostrea commercialis* farming methods which progressed from bottom culture to a highly regarded form of off-bottom culture (Korringa, 1976). Research workers subsequently helped to adapt and develop alternative cultivation systems for this species, including both off-bottom and hanging culture methods, and these systems have been further developed by farmers. This paper deals with a variety of alternative farming methods for Sydney rock oysters and relates these to some of the major biological and economic problems faced by the industry.

2. HISTORICAL DEVELOPMENT OF CONVENTIONAL FARMING METHODS

Early attempts at farming oysters in New South Wales during the last century involved little more than collecting oysters from rocks and mangroves. Some of the oyster laden rocks were transferred within and between estuaries to improve growth rates. A notable exception to this primitive approach was the construction in the early 1870's of land based oyster channels similar to the French "claires". High water temperatures and siltation were thought to have caused the failure of this ambitious project in the Georges River area (Map 1) (Roughley 1922). Excessive harvesting of intertidal and subtidal oysters, for human consumption and for the production of lime for mortar, necessitated the introduction of legislation in the 1870's restricting harvesting practices which threatened major oyster populations (Roughley 1922; Croft 1962a,b).

A century ago the oyster growing areas in New South Wales were very seriously affected by mudworm. These shell-boring spionid polychaetes, predominantly *Polydora websteri* and *Boccardia chilensis*, thrive if oyster are partially covered by silt (Skeel 1979). The mudworm problem, the shortage of juvenile oysters (spat) and government regulations forced farmers to adopt more innovative farming practices. In particular, a wide variety of cultch materials were positioned on elevated leases and the height of the leases was progressively raised as sand, shell or other materials were placed on top of the mudflats (Roughley, 1922; Croft 1962a,b).

One innovation was to insert stakes, usually cut from *Casuarina* or mangrove trees, vertically into the sediment for larvae to settle on. Before World War II this method was progressively refined so that bundles of sticks which had caught spat were separated and arranged horizontally on intertidal, timber post and rail leases (Malcolm 1987). The spat were farmed on these sticks until they approached market size. Oysters removed from the sticks could be placed on tarred hardwood and wire mesh trays on similar leases. The use of these trays for oyster fattening had been pioneered early in the industry's development (Roughley 1922). These off-botttom methods reduced labour costs, allowed oysters to be farmed well above the sediment layer and reduced silt buildup on the oysters, thus minimising mudworm problems. The drying out of oysters on intertidal leases at low tide also helps control mudworm (Skeel 1979).

Two other traditional approaches to oyster farming should also be noted. Dredge bed culture, a form of bottom culture, was practised widely in the early part of the century for Sydney rock oysters in Queensland (Smith 1982) and New South Wales and for flat oysters *Ostrea angasi* in several Australian states (Croft 1962b; Sumner 1972; Coleman 1986). In this farming system oyster larvae settle on old oyster shell deposited on the estuary bottom and marketable oysters are subsequently harvested with dredges. This type of culture declined because of increased siltation of the estuaries, mudworm infection and "QX disease" which is caused by the ascetosporan parasite *Marteilia sydneyi*, (Smith 1982). However, a few dredge bed leases are still used for oyster farming in New South Wales (Holliday and Wisely 1988). The other traditional approach is rock culture in which slabs of rock with attached oysters are supported on horizontal timber bearers or on tripods made of vertical timber stakes. Once the mainstay of the industry, this intertidal method is now only used by a few farmers (Malcolm 1987).

3. THE MODERN STICK AND TRAY INDUSTRY

Although the farming of *Saccostrea commercialis* was once a major industry in Queensland (Smith 1985), production there is now relatively minor compared to that in New South Wales. Consequently, the following discussion of modern commercial farming methods for this species has been restricted to the New South Wales industry. The major size grades used in the industry are spat, seconds and plate oysters which roughly correspond to oysters in the following size ranges: from settlement to <30 g; 30-40 g, and >40 g in that order.

In postwar years the industry progressively replaced mangrove sticks with tarred, hardwood sticks (1.8 m x 25 mm x 25 mm). The intertidal stick and tray production system for post and rail leases has been described in detail by Korringa

(1976), Malcolm (1987) and Maguire *et al.* (1988). About 100 sticks are nailed together to form a five layer unit known as a block and are placed on post and rail catching leases in high spatfall areas (Holliday and Goard 1986). Around six months after settlement, the blocks are relocated upstream on depot leases to avoid overcatch of spat and are then moved to growing leases. At this stage the sticks are rearranged into a single horizontal layer. About 3 years after settlement the oysters are dislodged from the sticks by firmly striking each stick. Clumps of oysters are separated (culled) and the individual oysters are either marketed or ongrown on tarred wooden trays (1 m x 1.8 or 2.7 m) to plate size.

Compared with many other aquacultural industries, oyster farming methods can be seen as often being primitive in that there may be little control of stocking density. This applies to conventional stick farming methods, however, farmers can easily manipulate oyster densities on trays. Oyster densities on sticks vary greatly as spatfall varies between years and between catching sites (Holliday and Goard 1986; McOrrie 1987). Subsequent losses caused by mortality on the sticks or by oysters falling off sticks are also variable. McOrrie (unpublished data) estimated that the average number of spat on sticks in Salamander Bay (Port Stephens), just prior to the sticks being moved to depot leases at the end of the 1986 catching season, was 178.6 ± 21.6 spat/stick ($\bar{x} \pm$ S.E., n=10 for groups of 25 sticks). While individual sticks could yield up to 100 plate oysters/stick, average yields are in the range 30 - 50 oysters/stick.

Little information is available on production of oysters per unit area for stick leases and thus an estimate has had to be calculated. About every two years a stick lease could produce 5.0 - 8.0 kg/m^2 of whole oysters per unit of area directly enclosed by a line of sticks. This estimate is for 1.8 m sticks, spaced at 6.5 sticks/m, yielding 30 - 50 oysters per stick at 45 g/oyster. Although this is not a high yielding system, stick culture has been a particularly attractive system for farming oysters. One reason is that from the time sticks are nailed out on growing leases, through to the time they are harvested, very little management is usually required. Production rates from tray leases are also poorly documented but oyster farmers estimate that three 1.8 x 1.0 m trays will hold one bag of oysters (ca. 54 kg/bag). This is equivalent to 10 kg/m^2 of plate oysters per unit tray area.

The stick and tray system of farming has sustained a remarkably successful industry with production in New South Wales rising steadily after World War II until the early 1970's when annual production was about 130,000 bags (Maguire *et al.* 1988). Bags of oysters vary considerably in total weight and in number of oysters per bag depending on shrinkage of standard hessian bags, oyster sizes and packing methods employed by farmers (Holliday, unpublished data). However, a bag of oysters usually contains about 1200 plate grade oysters.

Since the late 1970's, production has declined to 103,000 bags in 1986/87. Maguire *et al.* (1988) noted some of the biological, marketing, economic and regulatory problems which could have contributed to this decline in production. Oyster diseases still periodically cause heavy losses (Nell and Smith 1988) and the industry is facing increased competition from Tasmanian and New Zealand producers. In a study based largely on conventional stick and tray farms, Marshall and Espinas (1987) and Espinas *et al.* (1988) concluded that commercial oyster farming in New South Wales did not represent an attractive investment in the years surveyed (1981/82 to 1983/84). Labour costs, largely associated with culling, accounted for a high proportion of the total costs incurred by oyster farmers. Since 1983/84 oyster production has fallen even further and many farmers consider that economic returns have also declined (Maguire *et al.* 1988). Farmers have also had to contend with a very rapid increase in the number of Pacific oysters *Crassostrea gigas* in New South Wales estuaries. This problem has been particularly serious in Port Stephens, the major estuary for collection of Sydney rock oyster spat (Nell 1988). Regulations imposed to control the spread of the Pacific oysters within New South Wales are restricting the operations of many farmers (Maguire *et al.* 1988).

4. RESEARCH ON ALTERNATIVE METHODS

Research on alternative methods for oyster cultivation has been carried out by staff at the Brackish Water Fish Culture Research Station over the past fifteen years. This research included the development of methods for: subtidal oyster culture; single seed spat production from a hatchery and from natural spatfall, and nursery culture of single seed spat.

Other oyster research topics pursued at the Research Station include: nutritional requirements of larvae (Numaguchi and Nell 1988) and adults (Nell and Wisely 1984); diseases (Nell and Smith 1988); environmental requirements (Nell and Holliday 1988); depuration (Capps 1987); genetics (Mason 1986); larval monitoring (McOrrie 1987), and Pacific oyster biology (Nell 1987).

(A) *SUBTIDAL CULTURE*

The chief aim of this research was to use potential growing areas where water depths exceed those encountered on conventional leases. In these deeper areas the cost of posts for leases makes conventional stick and tray farming methods unprofitable. Another factor favouring subtidal culture was the possibility of obtaining faster growth rates as oyster feeding behaviour need not be disrupted by tidal exposure.

The first recorded attempt at subtidal farming (other than dredge bed culture) was in Port Stephens in the late 1960's (Wolf 1969). The farmer achieved good growth rates, but serious mortality and fouling problems were experienced. From 1973 to 1980 many subtidal experiments were conducted by Research Station staff using a variety of methods in numerous estuaries along the New South Wales coastline.

(i) **The Japanese "ren" farming system (longlines).**
Spat were caught on scallop shells which were then spaced evenly over a length of 1.8 m on vertical wires suspended from polystyrene floats. The spat were then grown on these shells for up to two years (Wisely *et al.* 1979a). This system proved to be useful for identifying appropriate subtidal culture sites but was too labour intensive and hence too costly for New South Wales oyster farmers.

(ii) **Pontoon cultivation.**
PVC stormwater grade pipes (90mm diameter) were used in relatively sheltered areas as flotation for fully submerged conventional oyster trays and sticks (Wisely *et al.* 1979b and unpublished data). The average growth rate of oysters in the subtidal trays was about twice that of oysters in conventional intertidal trays. While the pontoons were successful in sheltered areas, they tended to break up if moored in more exposed areas. Thus there was a need to develop more robust flotation units i.e. rafts. An additional factor favouring rafts over pontoons was that oyster weight gains, on longlines and in tray units used in initial raft trials, were not obviously affected by depth (Wisely *et al.* 1979c). This suggested that three dimensional grow-out systems could be developed to maximise production per unit water surface area. Pontoons did not have sufficient flotation to support several layers of trays.

(iii) **Pilot and commercial-scale rafts with wooden trays.**
Small rafts which had only two 164 l drums for flotation also proved to be unstable in rough conditions (Wisely *et al.* 1979d) and subsequently commercial-scale rafts (6.4 x 4.3 m) which had twelve 200 l drums for flotation were used. These rafts were much more stable and held 20 tarred, wooden trays (2.7 x 0.9m). However, these trays became heavily fouled with barnacles, polyzoans and ascidians (Wisely *et al.* 1979d,e) and were subsequently replaced with cages.

(iv) **Commercial-scale rafts with cages.**
The cages (Plate 1) consisted of galvanised steel mesh which was were cut and joined into a rectangular frame containing five shelves (2.2 x 0.8 m) which held the oysters. Each cage was enclosed with wire mesh to prevent spillage and predation by fish (Wisely *et al.* 1983). A total of 4 - 6 cages were suspended below each commercial-scale raft. Six cage rafts were considerably larger (7.5 x 3.9 m) and could hold 900 kg of oysters per raft. Cages were cumbersome to handle and were not adaptable in that they could not be used for intertidal culture. They have generally been replaced with modules.

(v) **Commercial scale rafts with modules.**
The steel trays (modules) developed by Research Station staff are hot-dipped, galvanised trays (1.8 x 0.9 x 0.1 m) constructed from steel reinforcement mesh

with PVC mesh inserts attached to the trays floor and walls to retain the oysters (Plate 2). These trays can be stacked and suspended under a raft (Wisely *et al.* 1983 and unpublished data) or placed individually on intertidal leases. In contrast to wooden trays which have solid vertical sides, cages and modules have mesh sides which allow better water flow. This characteristic largely eliminated the need for open spaces between trays.

Most of these subtidal trials involved the farming of large spat or second grade oysters e.g. 22 - 40 g, for 2 - 3 months. Variable but encouraging oyster growth rates i.e. 2.4 - 6.5 g/month/oyster, usually resulted in the production of plate grade oysters e.g. 38 - 53 g (Wisely *et al.* 1979e, 1983). Essentially these trials can be seen as an evaluation of subtidal systems to replace intertidal trays for the final phase of production in which undersized oysters culled from sticks are grown to plate oyster size. To allow comparisons with other grow-out systems, data obtained from these publications on subtidal culture were recalculated as weight of oyster per m^2 at harvest. The subtidal cages held 17.0 kg/m^2, of oysters per unit area of cage shelf (Wisely *et al.* 1983) although it should be noted that further work is needed on the optimum stocking density for larger spat or seconds in subtidal systems.

Subtidal production systems have also proved useful for grow-out of small, unattached spat (Wisely 1980) and in this sense can be seen as a form of single seed culture (Section 5.B.iii). By using subtidal systems for both nursery and grow-out phases, research workers produced plate grade oysters from very small spat in 18 months (Holliday, unpublished data).

(B) *POND CULTURE*

Artificial ponds are of interest for oyster production because food levels can be enhanced through the stimulation of algal blooms. While oysters in ponds are usually grown in the equivalent of a subtidal situation, partial drainage of ponds can be used to simulate intertidal exposure for killing fouling organisms. Marketing of Sydney rock oysters is affected by seasonal variation in meat condition, especially in winter when oysters are usually in poor condition. The value of fertilised ponds as fattening sites for Sydney rock oysters was investigated by Maguire *et al.* (1981) and Nell and Wisely (1984). They found that oyster condition did improve rapidly in ponds but that labour requirements, overspatting (spat settlement on larger oysters) and mudworm could pose major problems.

An approach that may warrant further investigation as a fattening system is the use of land based oyster tanks which draw water from fertilised ponds (Mason 1988). This approach has much in common with a nursery system, previously used by Research Station staff and some commercial hatcheries in Australia and overseas (Holliday 1985a), in which water from artificial ponds is supplied to upweller units (Section

5.B.iii). Although ponds have been constructed by a few farmers, considerable developmental work remains on pond based fattening and nursery systems. Similarly, artificial diets for fattening adult oysters require further development (Nell and Wisely 1984).

(C) *SINGLE SEED CULTURE*

In this type of farming system oyster larvae settle on minute scallop shell chips or on collectors from which the spat can be detached prior to being stocked into nursery or grow-out units. These oysters develop a relatively uniform shape that is highly acceptable to consumers. The availability of single seed spat also allows diversification of grow-out systems.

(i) **Hatcheries.**

Breeding techniques for Sydney rock oysters were developed at the Research Station's pilot-scale hatchery in 1981 (Holliday 1983, 1985a). Large numbers of flat oysters were also produced in the hatchery for grow-out trials in several New South Wales estuaries (Holliday 1985b).

As a result of this research and the demand for single seed spat within the industry, a commercial-scale hatchery was constructed at the Research Station. It was commissioned in 1988 and includes four, 20 000 l capacity, larval rearing tanks. In this building the upper floor area is used for algal production so that algae can be transferred by gravity flow to the larval and nursery production units below. As production expands in private hatcheries the research station's hatchery staff will increasingly be involved with research e.g. oyster genetics.

(ii) **Natural spatfall.**

Farmers in New South Wales are able to obtain most of their spat from natural spatfall. In contrast, farmers in the other major oyster farming industry in Australia, the Tasmanian Pacific oyster industry, have to rely on hatcheries for most of their spat. Sixteen of the estuaries along the New South Wales coastline receive commercially useful annual spatfall of Sydney rock oysters. Port Stephens has the most reliable spatfall; 36% of farms obtain their spat from this estuary (Espinas *et al.* 1988) and Malcolm (1987) estimated that two-thirds of all the sticks on catching leases in New South Wales were located in Port Stephens. However, the heavy settlement of Pacific oysters in Port Stephens could adversely affect its role as a Sydney rock oyster spat collecting area in the future.

Early attempts by one commercial farmer and Research Station staff, to use conventional spat collection methods for obtaining a source of single seed oysters, merely involved collecting spat inadvertently dislodged from sticks when moved to or from depot leases (J. Ryall, personal communication, 1988 and Wisely 1980). Subsequently a scraping technique was developed to forcibly remove spat from sticks (Holliday and Goard 1986). This method is much more successful when very dense spat settlement occurs as the spat are then more easily detached thereby reducing mortality. A variety of synthetic, spat collecting devices are used overseas (Plate 3) (Holliday 1985a) and some local oyster farmers have also been developing other collectors. Fortunately it is relatively easy to remove spat from some of these synthetic collectors. Holliday (1985b) demonstrated that a collector imported from France caught more Sydney rock oyster spat per unit area than conventional tarred sticks. More recently, a comparative study undertaken to assess settlement and subsequent spat loss rates on nine types of synthetic spat collectors, showed that all of these produced higher settlement rates (1.9 - 5.3 spat/cm^2) than the tarred sticks (1.3 spat/cm^2) (Holliday 1988).

These collectors are also being evaluated as substrates for larval settlement in hatchery tanks. After the larvae have settled, the collectors are positioned on estuarine leases. The aim is to develop an alternative early nursery system to the labour intensive methods currently used by many hatcheries (Holliday 1988).

(iii) **Nursery culture.**

Nursery trials were conducted to complement the research and development of single seed spat production methods. Farmers initially experienced considerable problems with using very small spat detached from spat collectors or obtained from hatcheries (Holliday *et al.* 1988).

Commercial hatcheries often use upwellers for the initial growth phase after larvae have settled on minute chips of scallop shell. The upwellers used by research station staff are plastic cylinders which receive a vertical flow of algal rich seawater either by passive or forced flow (Wisely 1983; Holliday 1985a; Frankish 1987). A series of trials was conducted at the Vales Point Power Station, Lake Macquarie, to investigate the potential of using heated effluent to accelerate growth rates of Sydney rock oysters in nursery systems. Although high mortalities and poor shell growth were recorded in very warm water at the Power Station's outlet channel, the relatively warm inlet water sustained good winter growth rates with exceptionally high survival rates (Holliday *et al.* 1988). A pilot-scale, passive upweller nursery system has since been established at this inlet site and is being used to complement the Research Station's commercial-scale hatchery.

A sectionalised nursery tray (Plate 4) was developed in conjunction with commercial farmers and consists of a 1.8 x 0.9 m hardwood tray divided equally into six sections and covered top and bottom with a rigid 3 mm mesh. Using this type of tray, optimum stocking densities have been determined for various size grades of spat i.e. 88 mg - 1.6 g/spat (Holliday *et al.* 1988).

(D) *OVERVIEW OF RESEARCH ON ALTERNATIVE METHODS*

While Research Station staff have helped pioneer the use, within Australia, of many of these alternative methods, it should not be inferred that these were completely original developments. For example, two versions of the steel trays used as commercial raft modules (Section 4.A.v) were also developed concurrently by farmers (Wisely 1980). Similarly, many of the hatchery and nursery methods devised for producing Sydney rock oysters were in part adapted from overseas methods. Some of the overseas methods evaluated by Research Station staff have not proved to be appropriate for farming Sydney rock oysters in this state e.g. Japanese longlines (Wisely *et al.* 1979a) as a grow-out system and seed boxes and plastic netting mesh bags as nursery systems (Holliday 1985b). The true significance of the research is that whereas the conventional farming methods were developed almost totally by farmers, research workers have been able to help adapt or develop alternative methods for farmers. By actively involving commercial farmers in the research projects, both the applicability of the research and the efficiency of information transfer were improved. Moreover, it is both inevitable and desirable that practical farmers have subsequently modified these alternative systems to meet the not inconsiderable economic challenges they face.

5. COMMERCIAL USE OF ALTERNATIVE METHODS

(A) *SUBTIDAL CULTURE*

(i) **Advantages.**

The advantage of this approach over conventional methods include:

- quicker growth rates (Wisely *et al.* 1979b);
- utilisation of deep water areas;
- increased production through expansion of growing areas and higher yields per unit water surface area;
- reduced production costs (Green, unpublished report, 1983);
- reduced risk from heat kill during intertidal exposure (Potter and Hill 1982);
- the ability to work the crop regardless of tidal influences, and

- in the case of pontoons, more cost-effective lease construction than for post and rail leases.

This list clearly indicates why research workers and farmers would contemplate using subtidal culture methods. However, there are also some disadvantages and limitations to the use of subtidal and single seed methods and these are discussed in later sections of this paper.

(ii) **Rafts.**

Rafts and pontoons are the main flotation units adopted by oyster farmers for subtidal culture in this state. Raft culture is used commercially in the Clarence, Wooli, Nambucca, Maclean, Kalang, Bellinger, Crookhaven and Clyde Rivers (Map 1). Interviews conducted by the authors with oyster farmers indicate that rafts are used in the production of 4,000 bags (4.8 million plate oysters) in New South Wales in 1986/87. A similar quantity was produced using pontoons.

Commercial rafts vary in design but the most commonly used rafts are similar to the larger rafts used by Wisely *et al.* (1983) i.e. 7.5 x 3.9 m. One major design modification adopted by some farmers is the use of large sealed concrete floats to replace plastic drums. This increases raft capacity from 18 to 50 bags per raft when compared to the above rafts.

Stackable steel trays (modules) are the most popular production units used below commercial rafts and a 7.5 x 3.9 m raft could hold six stacks of 6-8 modules. Espinas *et al.* (1988) estimated that modules account for 47% of the trays used in estuaries in the North Coast region of New South Wales (Tweed River to Manning River, Map 1). They are also widely used in other estuaries on conventional intertidal leases.

Rafts have a variety of roles in commercial production. Several farmers use rafts for the short term roles of fattening plate oysters and finishing shell growth of "all-ins" (ungraded oysters harvested from sticks). Some farmers use their rafts for the nursery phase, to promote rapid initial shell growth for single seed spat, while others use rafts for the complete grow-out operation.

The management strategy for raft culture is far more complex than for intertidal culture. In a subtidal situation many undesirable species of bivalves and other marine fouling organisms settle and grow rapidly on the crop. As a result subtidal oyster units require regular maintainence i.e. washing and drying of oysters every 6 to 8 weeks in areas which experience serious fouling problems. In many estuaries farmers avoid using their rafts at times when heavy fouling occurs i.e. summer, and often stock them with grades of oysters which will reach market size before fouling problems become excessive. Subtidal oysters also have to be examined regularly for the buildup of silt which may increase the incidence of mudworm.

(iii) **Pontoons.**

Most of the oysters produced using pontoon culture are grown in Wallis Lake although this type of farming is also used in the Wooli, Manning, and Clyde Rivers (Map 1).

Commercial pontoons are constructed using PVC pipes (6 m x 100 mm diameter) glued together and capped at the ends to form long floats (18 - 24 m). Single layers of caught sticks obtained from depot leases are wired underneath two parallel pipes which are moored between posts. Additional pipes can be used to supplement the existing flotation as the weight of the crop increases. Information provided by a commercial farmer indicates that an 18m pontoon will support 150 single layer caught sticks (Plate 5) containing 18,000 to 23,000 oysters (120-150 oysters/stick at about 20 g/oyster). This is equivalent to ca. 11.0-14.0 kg/m^2 of oysters per unit area enclosed by a line of sticks. These high yields result in part from the rapid growth rates that are obtained and also from high oyster retention rates on the sticks. The oysters remain on sticks for a shorter period than in the conventional system and thus cumulative oyster losses are reduced. Oysters are also less likely to be affected by wave action and predation by fish can be easily restricted by enclosing sticks within netting (Holliday and Wisely 1988). After 8 - 12 months the sticks are removed from the pontoons and after being dislodged from the sticks the oysters are stocked onto trays.

As oysters are more easily dislodged from sticks during handling than from trays, maintenance of pontoon units involving trays cannot be as frequent as for tray units. Thus it is important to select growing areas which do not suffer from heavy settlement of barnacles, polyzoans or ascidians if stick units are used. When excessive marine fouling does occur, oysters are knocked off the sticks and placed in trays on intertidal growing leases where fouling organisms are destroyed by intertidal exposure.

(iv) **Off-bottom cage culture.**

In this system, which was developed by farmers in conjunction with Research Station staff (Wisely 1980, Holliday and Wisely 1988), stacks of modules or cages are positioned on the estuary bottom, to increase shell growth and to fatten oysters. This approach should be considered as off-bottom culture (Wisely *et al.* 1979a) as the bottom tray is unstocked and helps keep the oysters clear of the bottom sediment. As with other forms of subtidal culture, these units are positioned with a punt and a winch or hydraulically operated lifting equipment (Plate 1). Although the need for flotation equipment is eliminated and navigational hazzard problems are reduced, off-bottom cage culture is only practised in two estuaries. It is only appropriate for areas with a sandy substrate as mudworm infection is a serious risk.

(B) *SINGLE SEED CULTURE*

(i) **Advantages.**

The main advantage single seed culture has over conventional methods is the virtual elimination of the laborious task of culling oysters. The single seed spat are also more uniform in shape and this allows the use of grading and packaging machines which are widely used overseas to reduce production costs. Other advantages include:
- increased seed production by early removal of spat
  from the collectors (Holliday 1988);
- lower mortalities due to the elimination of culling;
- a higher meat to shell ratio (Nell 1988);
- future genetic improvements through hatchery production of selected, faster growing or triploid oysters. These oysters have three sets of genetic material, do not spawn and thus maintain optimum meat condition for extended periods (Mason 1986; Griffiths *et al.* 1988);
- faster growth rates by controlling oyster densities (Holliday *et al.* 1988);
- easier removal during grading operations of oysters with attached Pacific oyster spat, and

- reduced oyster losses during relocation of grow-out units as oysters are less likely to be dislodged from trays than from sticks.

Single seed culture techniques are currently the most widely adopted type of alternative production strategy, despite representing a major change from the long established, farming methods. An increasing number of farmers are now attempting to use these novel methods on a pilot or commercial scale. Two Port Stephens farmers expect to double their combined annual production to 14,000 bags by using single seed methods.

(ii) **Spat supply.**

Although most farmers have relied on natural spatfall, there is increasing demand for single seed hatchery spat. This has been produced in the Research Station's pilot and commercial-scale hatcheries and in three private hatcheries in the Clarence River, South West Rocks and Brisbane Waters areas. Hatchery produced spat are sold in various grades at prices ranging from 1.4c/spat for 3-4 mm spat to 2.0c/spat per 6 to 8 mm spat. Larger hatchery produced spat are also likely to become available. In addition there are also five spat merchants, operating in various estuaries in the state, who obtain single seed spat (4 to 15 mm) from natural spatfall for sale to the industry. An increasing number of farmers are also catching their own spat using single seed methods. For example, one Port Stephens farmer collects an estimated 4 million spat annually on spat collection discs imported from France and Spain (Plate 3) (Bailey 1988). Many farmers prefer natural spat over hatchery spat as they are cheaper to produce (His 1978). However, provided hatcheries are appropriately located, the supply of spat from hatcheries can be more reliable.

(iii) **Nursery systems.**

The intertidal, sectionalised trays used by Holliday *et al.* (1988) are now being used by many of the larger farmers for nursery culture of single seed spat. Another intertidal system that is used commercially involves a seed cylinder known as the Stanway cylinder (Plate 6). This was developed by a New South Wales oyster farmer, for the initial nursery phase particularly in estuaries with a heavy silt load. The cylinders which are constructed from aluminium or PVC mesh are set on an intertidal rack and revolve with the changing tide thereby helping to remove silt from around the spat (Moxham 1985).

Subtidal culture units are also used commercially for nursery culture of single seed spat. One type is a modified floating cylinder which revolves with the changing tide. Subtidal steel modules with small mesh plastic inserts are also used by some farmers.

(C) ***COMBINATION OF METHODS***

The majority of farmers who stock single seed spat use a combination of methods for spat collection and grow-out. This is evident in the following example of an oyster farming operation in the Clyde River. The farmer purchases his spat from both spat merchants and hatcheries. The spat are grown for 3-6 months on intertidal leases in either sectionalised nursery trays or cylinders, depending on lease conditions. They are then transferred to modules on commercial rafts for the winter-spring period when fouling problems are not usually serious. After being graded the oysters are transferred to conventional trays on intertidal leases, for final grow-out. Plate size oysters are marketed 18-24 months after purchase of spat.

6. FUTURE TRENDS

In future years the relative importance of the various farming methods for Sydney rock oysters in this state is likely to be closely linked to the economic performance of the industry. A deterioration in returns from conventional methods will encourage many farmers to adopt new methods to improve profitability. If these methods are successfully adopted the potential exists for considerable improvement in the performance of the industry. A major factor will be competition from Pacific oysters both in terms of biological effects e.g. overcatch of faster growing Pacific oysters (Holliday and Nell 1985, Nell 1988), and marketing factors e.g. increases in production of less expensive Pacific oysters in New Zealand and Tasmania (Maguire *et al.* 1988). For farmers to alter growing methods, considerable reinvestment may be required particularly for subtidal culture and this may be a major problem for small-scale farmers who numerically comprise the great majority of New South Wales farmers. However, Marshall and Espinas (1987) concluded that the larger-scale farms provide most of the production. Specifically, they estimated that of the 485 farms which had actually produced oysters in 1983-84, some 58.9% of production was provided from just 10.1% of farms.

Regardless of these economic uncertainties, projections have been made for the various forms of oyster farming in the state. It is not anticipated that many individual farmers will completely replace their conventional production units with alternative systems in a short period of time. They are more likely to progressively evaluate and adopt alternative methods over a number of years.

(A) *CONVENTIONAL METHODS*

Tray culture has become increasingly popular in New South Wales over the past decade. This trend which is likely to continue has been at the expense of stick culture. Oysters grown on trays have a better shape than those from sticks, culling is minimised and stock losses during transfers between leases are reduced. An additional problem with stick cultivation is that hardwood turpentine sticks of adequate quality are expensive to purchase and are becoming harder to acquire. Tray culture has much in common with single seed culture in that unattached oysters are stocked into trays albeit at a large size. It is likely that trays will increasingly be stocked with much smaller oysters. However, trays fixed to post and rail leases are not as appropriate as sticks in very exposed estuarine sites as tray leases are more prone to physical damage during rough weather because of their greater resistance to water flow.

In areas where farmers persist with stick culture, the use of light plastic netting to reduce predation by fish is likely to increase. The development of this management procedure is a good example of how research workers, farmers and manufacturers have interacted to help overcome a serious problem. The future prospects for stick culture could be improved if oyster settlement and retention rates can be increased through the use of synthetic sticks (Holliday 1988), thereby enhancing the yield of plate oysters. At present too many sticks on commercial leases have only a poor coverage of plate oysters. However, when the same substrate is used for both catching spat and for subsequent grow-out, as in stick culture, it is difficult to achieve an optimum coverage of oysters. Very dense settlement of spat is ideal if the spat are to be scraped off the sticks but farmers consider that high oyster densities on sticks during the grow-out phase depress growth rates.

B *SUBTIDAL CULTURE*

The potential for expansion of raft culture in New South Wales is limited by the availability of suitable areas and competition for those areas from the general public, particularly for recreational boating. Also the majority of estuaries in New South Wales are now closed to the granting of new leases. Many areas are simply unsuitable for subtidal culture as they are either prone to equipment or oyster losses through flooding or suffer from excessive marine fouling and mudworm infection. These problems were also experienced to various degrees during experimental raft trials (Wisely 1979e and 1983). However, raft culture is currently expanding rapidly in the Nambucca River where existing but unusually deep leases are being used for subtidal culture. It should be noted that raft culture of *Saccostrea commercialis* has commenced in Moreton Bay, Queensland.

In some areas e.g. Wallis Lake, pontoon culture is replacing the post and rail system used to support intertidal crops grown on sticks and trays. This form of subtidal culture requires less depth of water than raft culture and is a promising alternative cultivation method for existing intertidal leases. In less exposed areas its use is likely to increase considerably.

Several areas in New South Wales which are currently not used extensively for oyster farming e.g. Lake Macquarie and Jervis Bay, may well be suitable for subtidal cultivation particularly for flat oysters. Grow-out trials conducted in conjunction with commercial farmers in several estuaries produced some promising results with this species (Holliday, unpublished data).

(C) *SINGLE SEED CULTURE*

The general industry trend is towards single seed spat cultivation. Increasing numbers of farmers are acquiring their single spat from natural spatfall by scraping tarred sticks or flexing PVC collectors. New types of collectors are being evaluated by research workers both for natural spatfall and hatchery spat (Holliday 1988). The feasibility of farmers setting pediveliger oyster larvae from hatcheries onto synthetic collectors at their own farms (Jones and Jones 1983; Gunn 1984) will also be assessed. Hatchery technology and capacity has increased to a level where potential production of single spat for sale to the industry may well be more than adequate in the future. Further research may lead to the production of triploid oysters (Griffiths *et al.* 1988) and perhaps a faster growing strain of oyster and this could increase the demand for spat from hatcheries.

Hatchery production, although not as cost effective as harvesting natural spatfall, has the capacity for more reliable production, particulary for some species of bivalves which have an unpredictable spatfall e.g. flat oysters and scallops (including *Pecten alba*). Apart from stick culture and primitive rock culture methods, any of the grow-out methods discussed in this paper can be used or adapted for single seed spat.

7. <u>RELEVANCE TO INDUSTRY PROBLEMS</u>

Alternative cultivation strategies could help the Sydney rock oyster farming industry overcome many of its problems. The farmers have indicated the areas of major concern during joint industry - NSW Agriculture & Fisheries meetings. Overall the general decline in production (Maguire *et al.* 1988) and inadequate profits, as indicated by poor "returns to capital and management" (Marshall and Espinas 1987), are the major problems. Maguire *et al.* (1988) noted a range of possible causes for the industry's decline but it is difficult to determine which have been the most influential.

Farmers are concerned about slow growth rates and generally ascribe these to pollution or overstocking of estuaries. Compared to the Pacific oyster, the Sydney rock oyster is a relatively slow growing species but subtidal methods can be used to substantially increase growth rates of both species (Wisely *et al.* 1979b, Nell 1987). Alternative cultivation methods may not have an impact on pollution problems but they do offer the possibility of manipulating the density of oysters within grow-out systems. This is not easily done using intertidal stick culture methods and it could be useful for at least responding to any seasonal changes in carrying capacities of leases. Holliday *et al.*(1988) attributed the decline in oyster growth rates, as stocking density was increased on sectionalised trays, to competition for food.

Competition from Pacific oyster farming industries is having an increasing impact on the marketing of Sydney rock oysters. Improving the quality of the Sydney rock oysters that are marketed would be of considerable economic benefit. Faster growth rates would allow the sale of larger oysters, while single seed cultivation methods greatly improve shell shape. There is also some evidence that subtidal methods can lead to an improvement in meat condition in cooler months (Nell 1988).

Although farmers have been able to regularly increase wholesale oyster prices in response to increases in production costs, labour costs are a major problem. The most likely way that the industry could reduce labour costs would be by adopting single seed culture methods thereby virtually eliminating labour input for culling. It should be emphasized that while culling costs are minimised there are additional labour costs incurred if oysters are graded or periodic reductions in oyster densities are made in nursery or grow-out units to improve growth rates. Regardless the nett effect, on labour costs relative to crop value, of moving to single seed culture is likely to be beneficial if siting and management is appropriate.

In single seed systems not only are clumps of oysters rare but those that do occur are usually the result of overspatting. Grading procedures for these more uniformly shaped spat allow easy separation of oysters with attached spat and this is particularly helpful for estuaries were overspatting can occur from both Sydney rock oysters and Pacific oysters. As a subsidiary effect this makes it easier for farmers to conform with regulations requiring the removal of Pacific oysters from leases.

A major factor affecting economic returns is oyster production per unit area. In this paper production estimates have been provided which indicate that subtidal systems can be much more productive than conventional methods. These estimates have been presented as per unit shelf or tray area or per unit area occupied by a line of sticks. For raft culture when up to eight layers of subtidal trays may be used, estimated production is very high if expressed per unit area of water surface occupied by a raft. A 29.25 m^2 (7.5 x 3.9 m) raft supporting eight layers of trays (6 trays/layer) with each tray (1.8 x 0.9 m) containing 17 kg/m^2 of oysters per unit tray area would yield 1322 kg of oysters per raft. When expressed as weight of oysters per unit of water surface area occupied by the raft, this production estimate is equivalent to ca. 45.0 kg/m^2. However, other variables can influence the production per unit lease area e.g. relative spacing required between rafts, and this variable has not necessarily been optimised. Regardless, it is clear that subtidal systems do offer great potential for increasing production per unit lease area. As growth rates are much faster in subtidal systems, this advantage is enhanced when considered on the basis of production per unit lease area per unit time. It should be emphasized that more data should be collected to thoroughly evaluate the effectiveness of the alternative methods when used commercially. Hopefully this will occur as they become more widely used by farmers.

Disease problems are still of major concern to oyster farmers. Oysters in subtidal systems can be quite prone to mudworm infections particularly if inappropriate sites are chosen or if maintenance is inadequate. Similarly, fouling problems can be worse in subtidal systems. One method of controlling another serious disease, winter mortality is to raise the intertidal growing height (Nell and Smith 1988). This is not possible for subtidal systems and winter mortality risks could be greater in these systems (Wolf, 1969). However, as this disease is thought to mostly affect older oysters there may be potential for reducing mortality by enhancing growth rates and harvesting at an earlier age.

The use of durable, synthetic materials for spat collectors and flotation units, to replace hardwood sticks, posts and rails could allow less regular replacement of lease materials and hence reduce costs.

The development of hatchery techniques for Sydney rock oysters may well lead to greater consistency in the supply of spat and hence lessen the impact of poor catching years (Maguire *et al.* 1988). It would also lessen the industry's dependance on key catching areas which in time could be affected by urban development. While spatfall is usually more than adequate, single seed methods do allow for much higher survival rates in nursery systems and this could be quite important if spat availability or prices are unfavourable for farmers.

The New South Wales oyster farming industry is undergoing a period of rapid change and considerable uncertainty remains about the future structure of the industry and the types of growing methods which will be adopted. However, continued liaison between research workers and farmers should lead to the refining of the more appropriate farming systems in the future. Although the research discussed in this paper mostly involved Sydney rock oysters, it may also be useful in other areas where Pacific oysters are farmed.

8. **ACKNOWLEDGEMENTS**

The authors wish to emphasize the enormous contribution that Dr. Baughan Wisely has made to the field of oyster cultivation systems. Without his pioneering work, subsequent research and the adoption of new farming methods by the industry would be considerably less advanced. The cooperation of commercial oyster farmers who provided technical information and helped develop these methods is gratefully acknowledged. The suggestions made by Mr. G. Allan, Ms. C. Mason and Mr. S. McOrrie in relation to this manuscript were most helpful. Much of the research discussed in this paper was supported financially by the Fishing Industry Research Trust Account.

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PLATE 1 Cumbersome steel mesh oyster growing cages were initially used for commercial-scale raft trials experiments and are presently used for subtidal off-bottom culture of Sydney rock oysters in New South Wales. Hydraulically operated lifting equipment is often required.

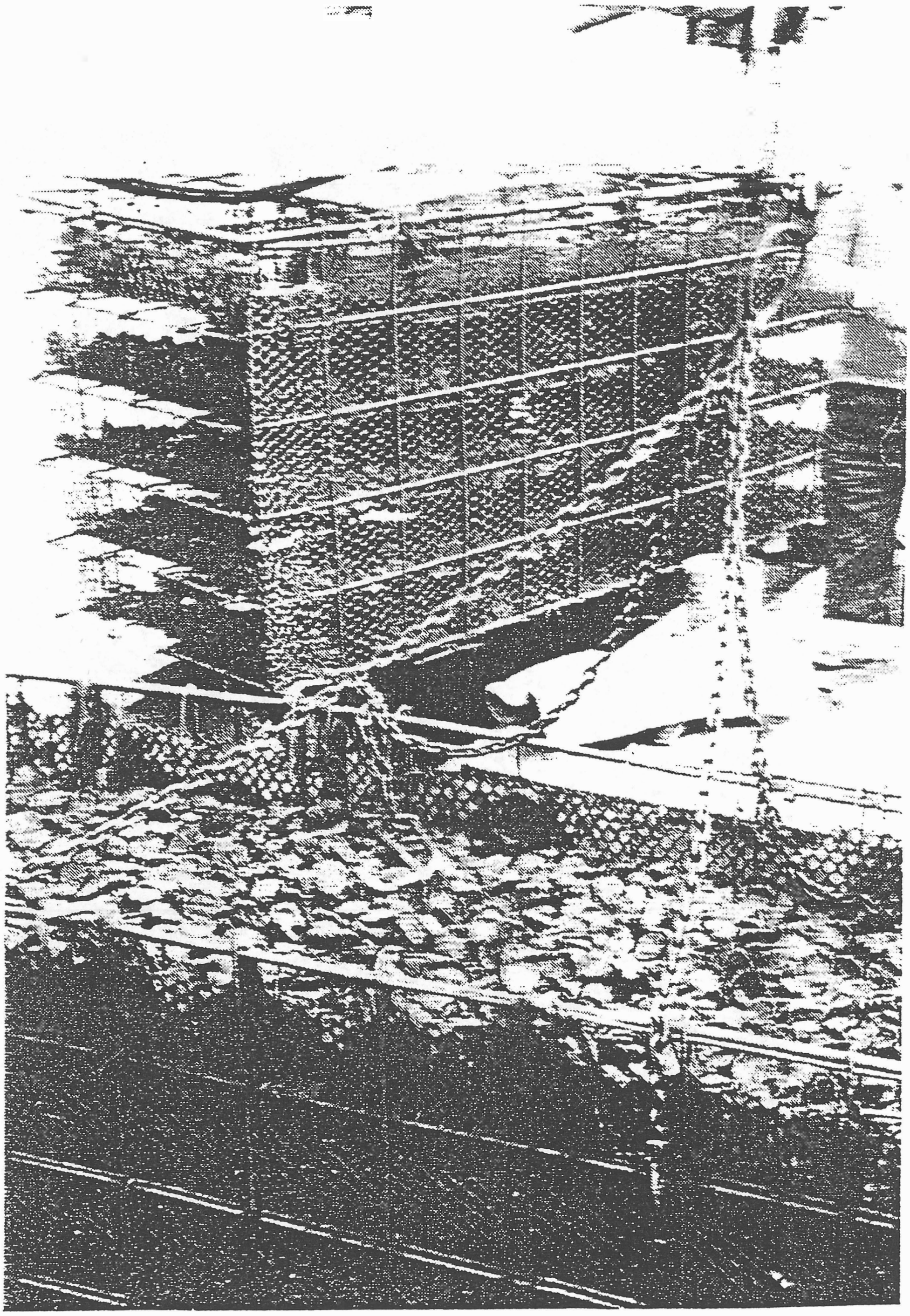


PLATE 2 Steel trays (modules) can be stacked and suspended below rafts or used on intertidal leases. Plastic mesh inserts are used with mesh size varying depending on initial oyster size.

PLATE 3 These discs which were imported from Spain have been successfully used for the collection of natural spatfall for Sydney rock oysters. The discs are flexed to remove the oysters as single seed spat.

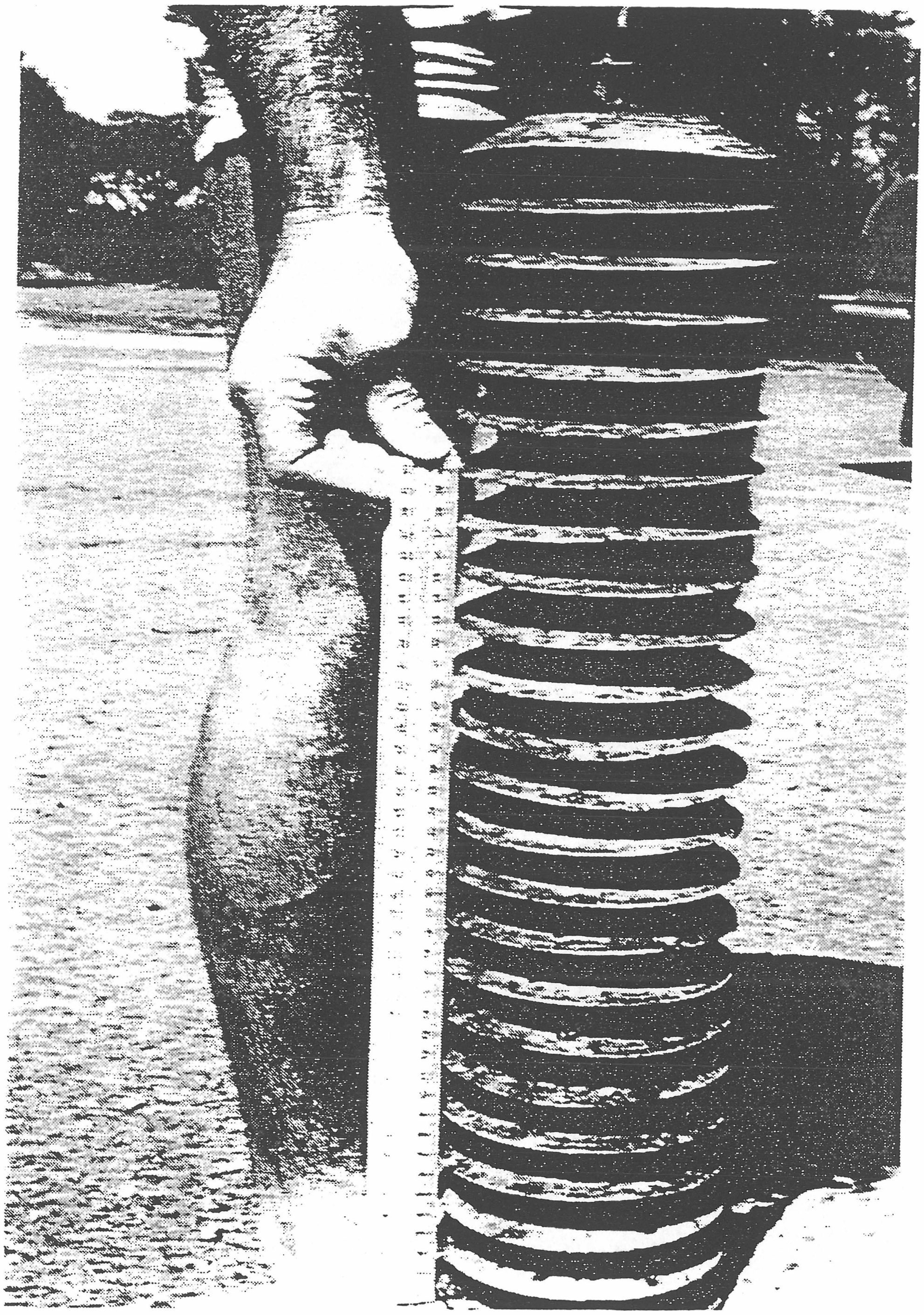


PLATE 4 Sectionalised trays are the most widely used nursery system for single seed spat in New South Wales. Both upper and lower tray surfaces are covered with 3mm PVC mesh.

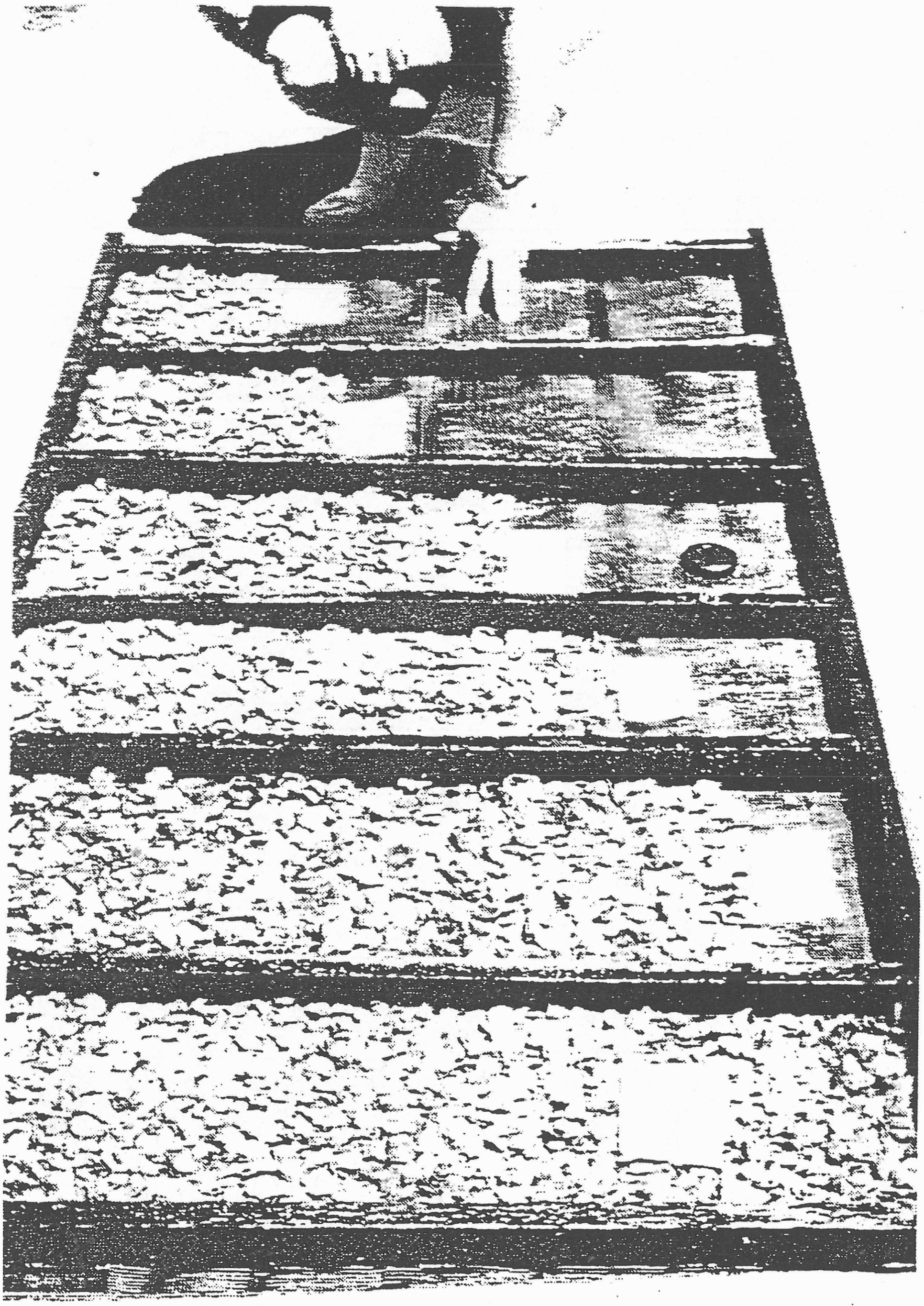


PLATE 5 PVC pontoons consisting of 6m lengths of 100mm UV stabilised pipe are joined together to form 18-24m floats which support a single layer of oyster sticks or trays arranged subtidally.

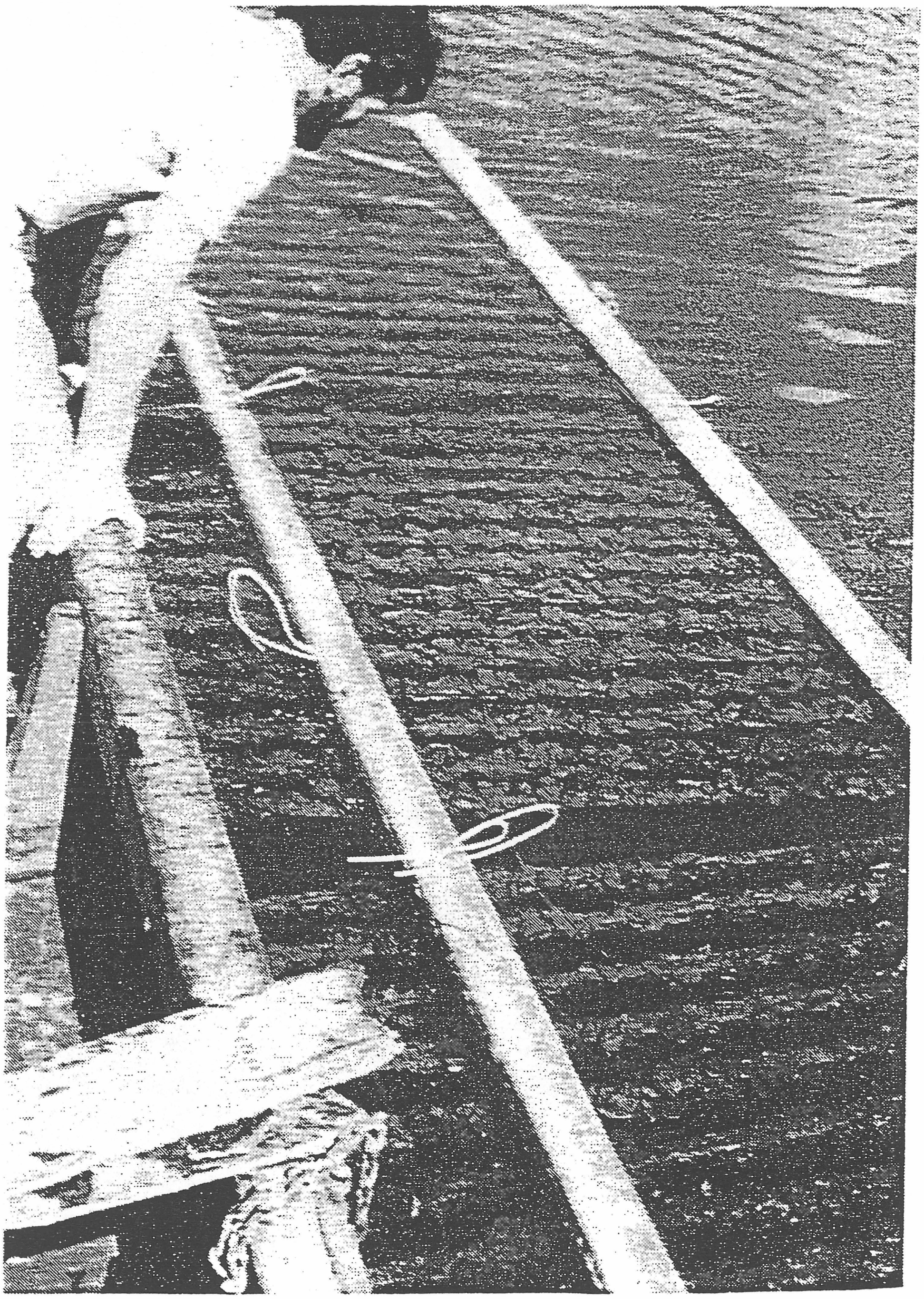
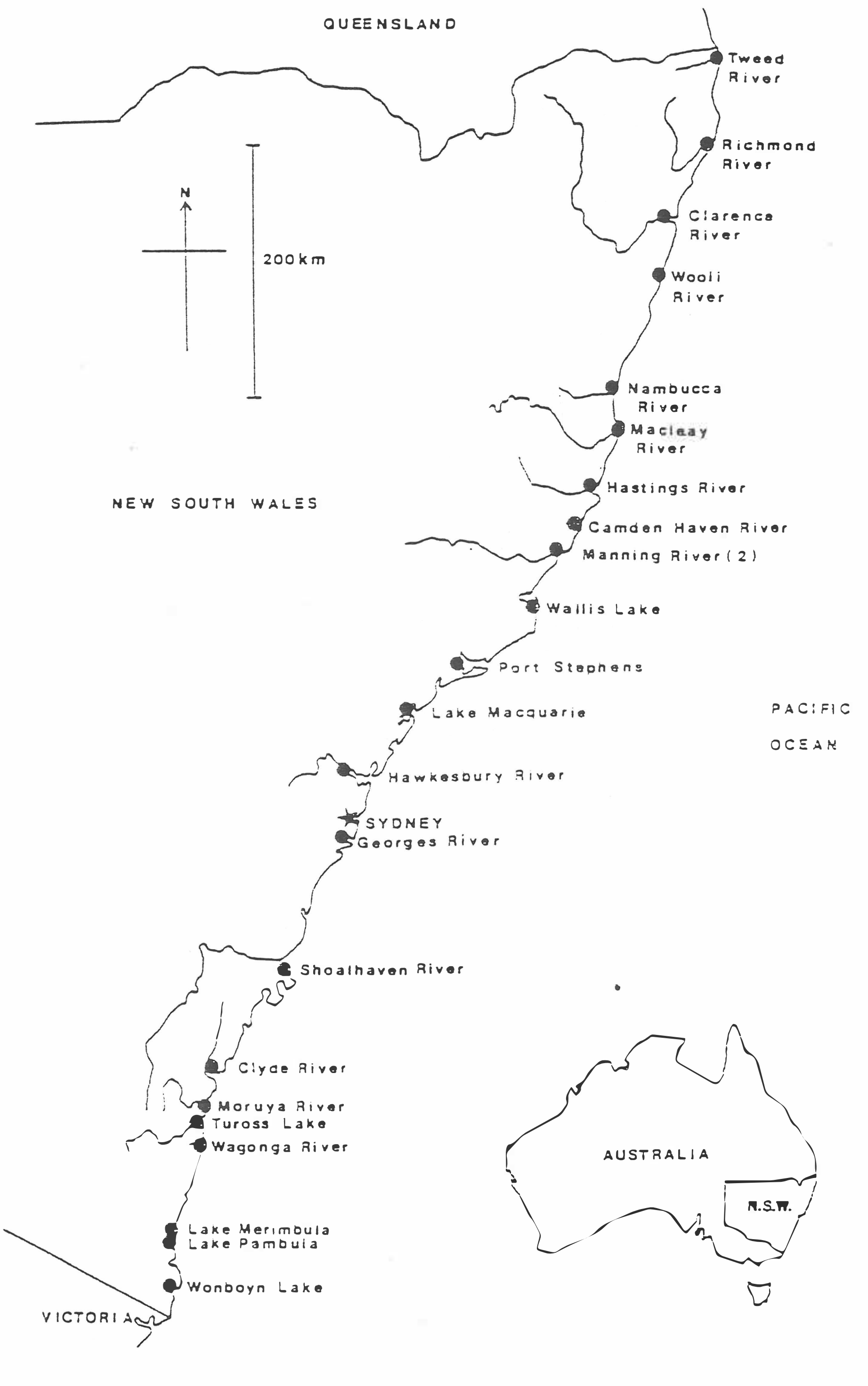


PLATE 6 The Stanway spat cylinder is widely used for initial nursery cultivation in estuaries with a high silt load. It is designed to revolve with the changing tides so that silt is removed from around the spat.



Map 1. Major oyster farming estuaries of New South Wales (after Wisely *et al.* 1979a).

SECTION 3

SETTLEMENT AND RECRUITMENT

Hatchery settlement of Sydney rock oyster larvae, *Saccostrea commercialis*, on various commercially used collectors

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ABSTRACT

Holliday, J. E., Nell, J. A., Goard, L. J. and Diver, L. P. Hatchery settlement of Sydney rock oyster larvae, *Saccostrea commercialis*, on various commercially used collectors.

Three experiments were conducted to assess hatchery settlement of Sydney rock oysters (*Saccostrea commercialis*) on various commercially used collectors. Maximum settlement of Sydney rock oyster larvae was recorded from slurry-coated PVC discs, 72 h after deployment in aquaria ($7.6 \pm 1.3 \times 10^3$ spat/disc) and in a commercial-scale experiment ($3.9 \pm 1.3 \times 10^3$ spat/disc). Eight commercial collector types had minimal settlement and may require additional conditioning prior to settlement.

Settlement on horizontally deployed PVC slats was significantly higher ($P < 0.001$) than slurry-coated slats and PVC slats deployed vertically (7130 ± 281, 5601 ± 326 and 67 ± 25 spat/slat in that order) as was the number of larvae which settled (76.6%, 60.2% and 0.7% in that order).

INTRODUCTION

Historically, oysters have been harvested from numerous types of substrata including scallop shells, old oyster shells, bamboo, roofing tiles, stones and dry mangrove branches (Quayle, 1988). Australian and New Zealand farmers gradually moved to asbestos-cement (fibro) and hardwood sticks, which were tarred to protect them from marine borers (Korringa, 1976; Curtin, 1985; Malcolm, 1972; Holliday et al., 1988). Today, many hatcheries settle oyster spat on chips of scallop shell using downweller systems (O'Sullivan and Wilson, 1976; Holliday 1985; Jones and Jones, 1988). Once settled, the spat are transferred to on-shore nurseries (Bayes, 1981), which can have variable operating costs and a low margin of profit (Claus, 1981).

Subsequent to the comparative nursery study by Holliday et al. (unpublished data), which recorded the highest survival of post-settled Sydney rock oysters from spat settled on chips of scallop shell and on-grown in upwellers, high mortalities have been consistently experienced from upwellers in commercial nurseries in NSW. However, natural settlement and recruitment of single seed oysters on PVC slats and slurry-coated slats has been high (Holliday et al., submitted). Generally the industry has moved towards PVC and other synthetic collectors, to increase oyster settlement and recruitment, and reduce nursery operating costs (His, 1978; Gunn, 1984). Various materials have been examined over the years both in the hatchery and the wild, in an attempt to find a more productive substratum. Dupuy and Rivkin (1970 and 1972), described the use of finely ground oyster shell particles to obtain "cultch-free spat" and used plastic trays and mylar sheet when setting *Crassostrea virginica* in a hatchery. Hidu et al., (1975) showed that polished marble was also a suitable hatchery substratum for *Ostrea edulis*. Other materials, including asbestos cement, coconut shell, and cement-coated nylon and plywood were also found to be suitable as collectors for wild spat of *C. belcheri* and *S. cucullata* (Kong and Luh, 1976). His (1978) demonstrated the effectiveness of cement and lime coated discs as an alternative cultch to roofing tiles for the intertidal collection of Pacific oyster (*C. gigas*) spat in Arcachon, France. Studies by Gunn (1984) and Curtin (1985) also produced encouraging and commercially acceptable sets on round hollow PVC sticks.

Since the early 1970's the technique of transporting and setting eyed and pediveliger oyster larvae at locations remote from the hatchery, "remote setting", has developed in North America (Chew et al., 1986; Jones and Jones, 1988). Presently a variety of cultch is used for remote setting, including hollow PVC pipes, cement coated discs and vexar bags filled with oyster shell (Jones and Jones, 1988). However, a comparative assessment of settlement on the various types of commercially used substrates has not been conducted.

The objectives of this study were to determine which collector type would catch the maximum number of hatchery reared Sydney rock oysters and to evaluate the effect of orientation of collectors on settlement.

METHODS

Broodstock for experiments were collected from an intertidal lease in Port Stephens, NSW. The larvae were reared to pediveliger stage at 26.1±1.0°C and 35.0±0.1‰ using an established technique (Loosanoff and Davis, 1963; Walne, 1966; Holliday, 1985). For Experiments 1 and 2, the nine types of collectors described in Table 1 were conditioned to leach toxic substances from the new collectors and allow the growth of a bacterial film necessary for settlement (Jones and Jones, 1988; Weiner et al., 1989). Thus, collectors were immersed in fresh water for 72 h, then sea water for a further 72 h prior to deployment.

Light was excluded from the experiments to eliminate phototropic responses with settlement (Shaw, 1967; Ritchie and Menzel, 1969; Jones and Jones, 1988). For Experiments 1 and 2, algae and water were circulated with light aeration and larval densities for each replicate estimated at stocking by counting larvae in a subsample (n=4) on a Sedgewick-Rafter. Sea water was prefiltered with a 1 μm cartridge (to exclude other larvae) and stored prior to the experiment. Throughout the text data is presented as mean±SE ($\bar{x}$±SE).

Experiment 1

In Experiment 1, nine collector types (described in Table 1) were cut to provide a similar surface area (5769±100 cm^2) for settlement. Collector types were: flat spiky PVC sticks, round spiky PVC sticks with lug, round grooved PVC sticks, round spiky PVC sticks, PVC discs, slurry-coated PVC discs, bioresin slats, PVC slats and slurry-coated PVC slats. Collectors were bound in a commercial format described in Table 1, and deployed in polypropylene tanks (n=4; 50 l). Pediveliger larvae were stocked at 63.8±4.3 x 10^3/tank and an equal mix of *Nannochloris atomis,* Tahitian *Isochrysis* aff. *galbana* and *Dunaliella tertiolecta* was fed at a daily rate of 15.7±0.2 x 10^4 cells/ml. Water temperature was maintained at 26.1±0.9°C in an air conditioned room. Preheated sea water (34.0±0.1‰) was exchanged in the larval tanks every 48 h.

Total set was recorded from all collector types at the completion of the experiment with the exception of the slurry-coated discs, where settlement was estimated by counting the number of spat settled in a rectangular grid (15 cm^2), randomly placed across both upper and lower surfaces of each disc. The experiment ran for seven days.

Experiment 2

This experiment was conducted to determine which of the nine collector types used in Experiment 1 would obtain maximum larval settlement when bound in full commercial format described in Table 1 (His, 1978; Gunn, 1984; Jones and Jones, 1988) and deployed in large fibreglass tanks, similar to the commercial remote settling operations (Jones and Jones, 1988). Two stacks of each of the nine collector types were randomly allocated a position in a 2700 l fibreglass tank (n=2; 160 x 240 x 70 cm depth). Tanks were stocked with pediveliger larvae (61.0±3.8 x 10^4/ tank) and fed *Pavlova lutheri* at a daily rate of 20.0±2.0 x 10^3 cells/ml. Water temperature was maintained at 26.1±1.0°C with a 2 kW silicon quartz immersion heater and thermostat. Sea water (35.4±0.1‰) was preheated and exchanged in the tanks every 48 h.

At the completion of the experiment total settlement was recorded from all collectors and adjusted for surface area with the exception of the slurry-coated PVC discs, where set was estimated by counting total spat in a rectangular shaped grid (10 cm^2) randomly placed across both upper and lower surfaces of each disc. The experiment ran for five days.

Experiment 3

Experiment 3 was conducted to compare settlement on PVC slats with slurry-coated PVC slats, and secondly to assess settlement on PVC slats deployed horizontally and vertically. PVC slats (250 x 60 mm), cut from 90 mm diam stormwater grade pipe and aged for two years and slurry-coated PVC slats (coated with a mixture of 100 g cement: 100 g fireclay: 500 g lime, mixed to a smooth paste with 180 mls of PVC bonder added to 4 l of tap water) were used for the experiment. Collectors were submerged 48 h prior to the experiment in a 1 megalitre estuarine pond, to allow the growth of a bacterial film on the collectors as Bonar et al. (1985) showed that the bacterial film which covers conditioned collectors is important for successful settlement.

Slats (3/aquaria) were deployed in 10 l perspex aquaria (n=4), which were randomly immersed in a temperature control bath, maintained at 25.6±0.3°C. PVC slats and slurry-coated slats were deployed horizontally on the base of the tanks, and PVC slats (joined by a strip of 4 mm PVC), vertically (90° angle). Larval densities were estimated at stocking by counting larvae in subsamples (3/replicate aquaria) on a Sedgewick-Rafter. Aquaria were stocked with pediveliger larvae at 27.9±1.0 x 10^3 (n=36). Larvae were fed an equal mix of Tahitian *Isochrysis* aff. *galbana* and *Pavlova lutheri* at a daily rate of 25.0±2.0 x 10^3 cells/ml. Water in aquaria was exchanged every 24 h.

Total settlement was recorded from the upper surfaces of all collectors and the lower surfaces of slats deployed vertically. For slats and slurry-coated slats, settlement on the lower surfaces of each replicate was estimated by counting spat in a rectangular shaped grid, randomly placed on the collector. The experiment ran for six days.

RESULTS

Experiment 1

The highest settlement was recorded from slurry-coated discs which had an average catch of 7.6 ±1.3 x 10^3 spat/disc and 22.8±3.9 x 10^3 spat/replicate). Few larvae were observed swimming 72 h after deployment. The remaining eight treatments had poorer settlement ranging from 4±2 to 376±64 spat/replicate (Table 2).

Experiment 2

Slurry-coated discs had the highest settlement with 3.9±1.3 x 10^3 spat/disc and 47.0±15.5 x 10^3 spat/stack. The majority of larvae settled within 72 h of deployment. The other eight treatments had poor settlements ranging from 8±2 to 600±106 spat/stack (Table 2).

Experiment 3

Settlement was observed on horizontally deployed slats on day two and slurry-coated slats on day four. For combined surfaces, average spat settlement was higher (P<0.001) on horizontally deployed slats (76.6% of larvae settled; 7130±281 spat/slat) than slurry-coated slats (60.2% of larvae settled; 5601±326 spat/slat) and vertically deployed slats (0.71% of larvae settled; 67±25 spat/slat; Table 3).

Settlement was significantly higher ($P<0.001$) on the lower surfaces of the horizontally deployed treatments and similar ($P>0.05$) for both surfaces of the vertically deployed collectors. For horizontally deployed slats and slurried-coated slats, average settlements on the upper and lower surfaces were 174±36 and 6924±238 spat/slat respectively and 366±35 and 5235±292 spat/slat respectively. For vertically deployed slats settlements on upper and lower surfaces were 43±17 and 24±9 spat/slat respectively (Table 3).

Statistical Analysis

For Experiment 3, differences between treatments were assessed using one-way ANOVA. Homogeneity of variance was evaluated using Cochran's Test (Winer, 1971) and means were compared using Tukey's *w* (Winer, 1971). T-test (Winer, 1971) were used to compare settlement on upper and lower surfaces.

DISCUSSION

In both the aquaria and commercial-scale experiments, Sydney rock oyster larvae showed a preference for the slurry-coated discs, although the results in Experiment 2 should be interpreted with caution as the treatments in the commercial-sized tanks were not independent of one another. The poor settlement on eight of the nine collector types used in Experiments 1 and 2 may have been attributed to the period of conditioning. Bonar et al. (1985) showed that bacterial film on substrates is important for successful settlement. Gunn (1984) and Jones and Jones (1988) suggested that leaching PVC pipe intertidally at 3 m for seven days increased spat settlement from nil to 5-10% and to 25% after leaching it for 12 months.

For Experiments 1 and 2, lower settlement was recorded for the slurry-coated PVC slats. Previous experiments with natural settlement of Sydney rock oysters using both types of collectors showed no significant difference between collector types (Holliday et al., submitted). However, a strict comparison of these results is not possible as the composition of the slurry-coating was different.

A literature review and research by Shaw (1967) showed there were numerous variables which influenced the distribution of set on collectors including: distance between layers, orientation of surfaces, siltation, fouling, light, currents, species, gregariousness, type and colour of substratum and swimming position of larvae.

It is possible that with the exclusion of light from the experiments (to eliminate phototropic responses of setting larvae), a factor was introduced which in combination with other variables, such as orientation and current, may have affected settlement. The collector shape (ie. conical shape of the disc, the flat or round hollow surfaces of the sticks), may also have acted in combination with other variables to influence settlement. In Experiment 3, where light and current generated by aeration, were excluded from aquaria, the orientation of collectors appears to have affected settlement, with significantly lower settlement on collectors deployed vertically (90°).

The highest settlements of hatchery reared Sydney rock oyster spat were on slurry-coated PVC discs, aged PVC slats and slurry-coated PVC slats.

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TABLE 1

Summary of specification for collector types used in Experiments 1 & 2

Type	Dimensions of collectors (mm)	Layers	Collectors/ layer	Surface area per collector (cm²)	Surface area per replicate (cm²)
EXPERIMENT 1					
PVC sticks					
Flat spiky	50 width 10 cavity 1.5 wall thickness 309 length	4	4.25	340	5776
Round spiky with lug	22 diameter 16 width lug 452 length	4	4.25	448	5824
Round grooved	22 diameter 452 length	4	4.75	313	5781
Round spiky	22 diameter 452 length	4	4.75	313	5781
Discs					
PVC	140 diameter	9	3.0	275	7013
Slurry-coated	355 diameter 3 wall thickness	3	1.0	1790	5370
Slats					
Bioresin	100 width 370 length	3	3.0	505	5808
PVC	104 width 2 wall thickness 374 length	3	2.6	777	5831
Slurry-coated PVC	104 width 3 wall thickness 374 length	3	2.6	777	5831
EXPERIMENT 2					
PVC sticks					
Flat spiky	50 width 10 cavity 1.5 wall thickness 1235 length	5	4.0	1359	27180
Round spiky with lug	22 diameter 16 width lug 1808 length	5	4.0	1792	35840
Round grooved	22 diameter 1808 length	5	4.0	1250	25000
Round spiky	22 diameter 1808 length	5	4.0	1250	25000
Discs					
PVC	140 diameter 1 wall thickness	20	1.0	275	5500
Slurry-coated PVC	355 diameter	12	1.0	1790	21480
Slats					
Bioresin	100 width 2 wall thickness 1495 length	5	3.0	2020	30300
PVC	104 width 2 wall thickness 1495 length	5	3.0	3110	46650
Slurry-coated PVC	104 width 3 wall thickness 1495 length	5	3.0	3110	46650

TABLE 2

Hatchery settlement of Sydney rock oyster larvae, *Saccostrea commercialis*, on various types of collectors (Experiments 1 & 2)[1]

	Total settlement per replicate	Total settlement per stack
Collector type	Experiment 1	Experiment 2
Slurry-coated disc	22837±3863	46991±15534
Slurry-coated slat	376±64	79+8
Flat stick	291±104	101±18
Disc	122±19	38±17
Slat	56±9	62±16
Bioresin slat	36±19	600±106
Spiky stick+lug	20±8	52±14
Spiky stick	5±2	8±2
Smooth stick	4±2	7±5

[1] Values are $\bar{x}$±SE of adjusted surface areas.

TABLE 3

Hatchery settlement of Sydney rock oyster larvae, *Saccostrea commercialis*, on PVC slats horizontally and vertically deployed (Experiment 3)[1]

Collector Type	Spat Settlement per surface Upper	Lower	Combined	Larval Settlement (%)
Horizontal deployment				
PVC slats	174±36[a]	6924±238[a]	7130±281[a]	76.6
Slurry-coated PVC slats	366±35[b]	5235±292[b]	5601±326[b]	60.2
Vertical deployment				
PVC slats	43±17[c]	24±9[c]	67±25[c]	0.7

[1] Values are $\bar{x}$±SE. Within columns, means with a common superscript do not differ significantly ($P<0.001$).

Evaluation of commercially-used collectors for the settlement or growth of Sydney rock oysters, *Saccostrea commercialis* and Pacific oysters, *Crassostrea gigas*.

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ABSTRACT

Holliday, J. E., Allan, G. L., Frances, J. and Diver, L. P. Evaluation of commercially-used-collectors for the settlement or growth of Sydney rock oysters, *Saccostrea commercialis* and Pacific oysters, *Crassostrea gigas*.

Ten types of commercially-available collectors were evaluated for natural settlement and retention of juvenile Sydney rock oysters (*Saccostrea commercialis*) and barnacles (*Balanus* spp.), in Port Stephens, NSW, Australia. Juvenile Sydney rock oysters (spat) from six collector types were then removed and on-grown for 14 days to assess whether collector type affected post-harvest survival. Retention and growth of Sydney rock oysters to market size were also assessed on five types of collectors used for on-growing. Nine of the collector types were also evaluated as substrates for settlement of Pacific oysters (*Crassostrea gigas*) in Port Stephens.

Density of Sydney rock oyster spat, 172 days after deployment of the collectors in Port Stephens, was higher ($P<0.05$) on five types of PVC collectors, and the bioresin slats, than on traditionally-used tarred hardwood sticks. Retention of spat on four types of PVC collectors between 172 and 271 days was also higher ($P<0.05$) than on tarred sticks. Oyster density at day 127 affected spat losses ($P<0.001$) at day 271. For Sydney rock oysters, vertical position within the stack of collectors had no effect ($P>0.05$) on spat density after 172 days. Differences in spat density on upper and lower surfaces varied among collector types. Tarred sticks at day 172 had the highest density of barnacles ($P<0.05$). With the exception of round, grooved PVC sticks, there was no significant difference ($P>0.05$) in losses of Sydney rock oyster spat between collector types at day 271. Post-harvest survival of single Sydney rock oyster spat 14 days after removal from collectors was high (89-94 %) and similar ($P>0.05$) except for bioresin slats where post-harvest survival was lower (66.8 %) ($P<0.05$).

At harvest, the highest ($P<0.05$) number of market size Sydney rock oysters were retained on four types of PVC sticks and the lowest number on tarred sticks. With the exception of flat spiky PVC sticks, which had a higher percentage loss than round spiky PVC sticks ($P<0.01$), oyster losses between day 172 and harvest for all five types of on-growing collectors were uniformly high (range 92.6-96.5%;

P>0.05). The highest (P<0.01) average oyster shell length at harvest was recorded from tarred sticks, with no difference (P>0.05) for oysters from the PVC sticks tested.

Spat density of Pacific oysters was much lower on all types of collectors than Sydney rock oysters, although it was higher (P<0.001) on three types of PVC collectors than on tarred sticks, PVC slats and bioresin slats. Spat density of Pacific oysters on upper an lower surfaces also varied between collector types.

INTRODUCTION

Oyster industries may obtain juvenile oysters (spat) from hatcheries, or through natural spatfall where a wide variety of substrates may be used (Quayle, 1988). The majority of Sydney rock oyster (*Saccostrea commercialis*) marketed in Australia are produced in New South Wales (NSW; Reid, 1990). Farmers have traditionally relied on hardwood sticks, coated with tar (to deter marine borers), as the major substrate for spat collection and grow-out of attached oysters to market size (Malcolm, 1987; Koringa, 1976). Of the 16 NSW estuaries used for the commercial collection of Sydney rock oysters, the majority of juvenile oysters are collected from Port Stephens (Espinas et al., 1988). Since 1984, the Pacific oyster (*Crassostrea gigas*) has become well established in Port Stephens (Holliday and Nell, 1990; Chew, 1990) and it is now commercially grown in this estuary (Bird et al., 1991).

Many NSW farmers also remove spat from tarred hardwood sticks and PVC collectors and on-grow these oysters using single seed culture techniques (Holliday et al., 1988; Holliday et al., 1991a). A decline in production from 140,000 bags in 1975 to 100,000 bags (approximately 1200 oysters/bag) in 1987 (Malcolm, 1987; Maguire et al., 1987) and inadequate returns on investment (Espinas et al., 1988) have encouraged many farmers to seek alternative substrates for the collection and grow-out of oysters.

Various materials have been evaluated in estuaries or hatcheries as surfaces for settlement of a number of species of oysters including *C. belcheri; C. gasar; C. gigas; C. virginica; Ostrea edulis; S. commercialis;* and *S. cucullata* (Dupuy and Rivkin, 1970 and 1972; O'Sullivan and Wilson, 1976; Ajana, 1979; Curtin, 1985a; Holliday, 1985a; Jones and Jones, 1988; Hidu et al., 1975; Ling, 1970; Kong and Luh, 1976). In Europe and North America there has been a move to the commercial use of PVC and other synthetic collectors to increase settlement and retention of Pacific oysters (Jones and Jones, 1988; Roland et al., 1988) and to reduce operating costs (His, 1978; Gunn, 1984).

The objectives of this study were; 1) to assess the intensity of settlement and retention of Sydney rock oysters, Pacific oysters and barnacles on different, commercially-available collector types; 2) to determine the post-harvest survival of Sydney rock oyster spat from collector types designed for single spat production and 3) to determine which collector types were most suitable for on-growing Sydney rock oysters to market size.

METHODS

Collectors

The ten types of oyster collectors used for this study had been designed and manufactured for collection and removal of spat (single spat collectors) for single seed culture and/or for collecting and on-growing spat to market size. Types of collectors used for single spat collection included: PVC discs (D), slurry-coated PVC discs (SCD), bioresin slats (BS), PVC slats (S), slurry-coated PVC slats (SCS) and tarred hardwood sticks (TS), (Table 1). The types of on-growing collectors used were; flat spiky PVC sticks (FSS), round spiky PVC sticks with a lug (RSSL), round grooved PVC sticks (RGS), round spiky PVC sticks (RSS) and tarred sticks (TS), (Table 1). It should be noted that tarred sticks (TS) are used to collect spat for single seed culture, or for on-growing on the sticks.

As practiced commercially, all collectors were conditioned by deploying them at least one month prior to the start of settlement (Gunn, 1984; Jones and Jones, 1988; Roland and Broadley, 1990). Conditioning of collectors by immersing them in sea water for a period before settlement is important as it; 1) allows potentially toxic compounds in the collectors to leach out; 2) neutralises the pH on the surface of slurry coated collectors, and; 3) allows a primary fouling community (mainly bacteria) to develop (Morse, 1985; Ronald et al., 1988; Roland and Broadley, 1990). Each collector type was deployed in stacks using a similar format (described in Table 1) to that used by commercial farmers (Korringa, 1976; His, 1978; Gunn, 1984; Malcolm, 1987; Holliday et al., 1988; Jones and Jones, 1988; Roland and Broadley, 1990).

Experiment 1 - Sydney rock oysters

Segment 1 - Settlement and spat retention

Ten types of collectors were deployed in the middle of a commercially-used, intertidal spat catching area in Salamander Bay, leased from the NSW Government (32° 43' S; 152° 5' E). The collectors consisted of four types of PVC sticks (FSS, RSS, RSSL, and RGS), three types of slats (BS, S, SCS), two types of PVC discs (D and SCD), and tarred sticks (TS). Collectors were deployed in January, the beginning of the commercial spat catching season (Wisely et al., 1979; Holliday and Goard, 1986). For each treatment, five replicate stacks of collectors were secured by wire to a timber post and rail rack which was set perpendicular to the shore (Korringa, 1976; Quayle, 1988). The 50 m section of rack used on the lease was about 80-130 m from the Indian Spring High Water (ISHW) mark. Each replicate stack was randomly allocated to a position along the timber rack and the bottom layer of each stack of collectors occupied a similar vertical intertidal position (range 0.7-0.9 m above Indian Spring Low Water [ISLW]; S. McOrrie, unpublished data, 1990) to that traditionally used for natural catch on tarred sticks (Thompson, 1954; Korringa, 1976; Malcolm, 1987).

Spat density and retention were estimated by counting the number of spat contained in a grid (10 cm^2) which was placed in a randomly allocated position on both the upper and lower surfaces of each collector in each replicate stack. A value was obtained for the top and bottom surfaces of each replicate stack, for each collector type. Data for the upper surface of the top layer and the lower surface of the bottom layer of each replicate stack were excluded from analyses as the spat on these surfaces were subject to predation by fish.

Segment 2 - Post-harvest survival of spat

Oysters from Segment 1 were harvested from the six types of single spat collectors (D, SCD, S, BS, SCS and TS), 271 days after deployment. With the exception of tarred sticks (TS), a layer was randomly selected from each of the five replicate stacks of collectors per treatment and all spat were harvested by either flexing and brushing. For tarred sticks (TS), spat from four sticks from each of the five randomly selected layers per replicate were harvested, using a paint scraper. The spat from each replicate group of spat (n=5) for each treatment were randomly allocated to one of six internal sections (each 0.25 m^2) of a nursery tray (1.82 x 0.94 m timber frame with 1.7 mm PVC mesh on upper and lower surfaces). Enough spat to cover 50% of the bottom surface of each internal tray section were used, as recommended by Holliday et al. (1991a). The five trays, each with one replicate section containing spat from each collector type, were randomly allocated a position along the same timber rack used for Segment 1. Post-harvest survival was estimated by counting live and dead spat from each replicate section 14 days after spat were removed from collectors.

Segment 3 - Retention and growth of market size oysters

The stacks of collectors for on-growing (FSS, RSS, RSSL, RGS and TS), on which spat had settled in Segment 1, were broken up into single layers for the grow-out phase, following normal practice by oyster farmers (Korringa, 1976; Malcolm, 1987; Quayle, 1988; Holliday et al., 1988). For each collector type, there was no difference (P>0.05) in the number of spat on sticks from different layers when deployed. The sticks were transferred from Port Stephens to an intertidal growing lease in Empire Bay, Brisbane Waters, NSW (33° 30' S; 151° 20' E), as this estuary was not subject to the common problem of settlement of spat on existing Sydney rock and Pacific oysters (overcatch), as is common in Port Stephens.

As the front of the Empire Bay lease (about 500 m from ISHW mark) was subjected to wave action which may have affected retention of oysters on the collectors, the timber rack (60 m) which was perpendicular to the foreshore, was divided into two zones (inshore and offshore). For this segment, each replicate consisted of 4 sticks (a layer from Segment 1). Ten replicates for each type of on-growing collector were randomly allocated to a position in each zone on the lease. Top and bottom layers from each stack, which may have been affected by predation by fish during Segment 1, were not sampled. Collectors were nailed along the post and rail lease at the growing height (about mid tidal range) used by commercial oyster farmers. PVC slats (S) were randomly allocated to positions along the rail, to observe any overcatch. To avoid losses of spat from heat stress during intertidal exposure (Potter and Hill, 1982) and from predation by fish (Korringa, 1976; Holliday et al., 1991a), all sticks were encased in shade cloth (3 mm PVC mesh) as practised by many farmers.

For the five types of collectors, spat density was estimated three times (approximately every six months) by counting all oysters from both surfaces of sticks from two randomly selected replicates in each zone. Retention on upper and lower surfaces were not separated as oysters tended to grow around the sticks (Fig 1). Because the types of sticks had different surface areas, data are expressed as number of oysters/10 cm^2. To avoid future losses which may have been attributed to handling, collectors were discarded after counting. Size was determined at harvest by randomly selecting six of each type of on-growing collector from each zone, removing all the oysters (with a sharp blow to the sticks) and measuring the shell lengths of 100 oysters/stick, chosen at random from each collector.

Experiment 2 - Pacific oysters

All of the types of collectors used in Experiment 1, with the exception of slurry-coated slats (SCS), were evaluated as substrates for settlement of Pacific oysters. For each collector type, four replicate stacks were randomly allocated a position along a timber rack set perpendicular to, and 50 m from the foreshore (ISHW mark), on a lease in the inner harbour of Port Stephens, Tanilba Bay, NSW (32° 43' S; 152°E). Although this is a traditional growing area for the Sydney rock oyster, consistent settlement of Pacific oysters has been recorded in this area (Holliday and Nell, 1990; Reid 1990). Collectors were deployed in the same format used in Experiment 1 (described in Table 1) and occupied a similar vertical intertidal position (range 0.65-0.85 m above ISLW; S. M^c^Orrie, unpublished data, 1990) to that used for growing Sydney rock oysters (Korringa, 1976; Malcolm, 1987). This zone was found to be optimal for Pacific oyster settlement in Tanilba Bay (Nell, unpublished data, 1988).

As spat density was much lower than in Experiment 1, all spat on the upper and lower surfaces on all collectors were counted, except tarred sticks (TS). For tarred sticks (TS), settlement was determined by counting all spat on four randomly selected sticks from each layer in each replicate stack. The top and bottom layers of each stack of collectors were excluded from analyses as the spat on these layers were subjected to predation by fish.

An assessment of post-harvest survival of spat removed from collectors and further studies on grow-out of Pacific oysters were not possible because of the introduction of a NSW Government policy aimed at the eradication of Pacific oysters from Port Stephens and other NSW estuaries (Chew, 1990; Holliday and Nell, 1990).

Statistical Analyses

For each segment or experiment, differences among collector types were assessed using ANOVA. For Experiment 1 (Segment 1), differences in the number of spat which settled on the upper and lower surfaces of each collector type were compared separately using *t*-tests. Data for both surfaces were then combined and one-way ANOVA was used to assess the effect of collector type on density and retention. Homogeneity of variance was confirmed using Cochran's Test (Winer, 1971) and means were compared using Tukey's ***w*** method (Sokal and Rohlf, 1981). For Experiment 1 (Segment 1), retention data was transformed (arcsine $x^{0.5}$) prior to analyses, and linear regression used to examine the relationship between spat density at day 127 and percentage loss at day 271.

For Experiment 1 (Segment 2), variances for post-harvest survival data were heterogeneous after transformation (arcsine $x^{0.5}$), Cochran's Test Statistic=$C_{.95}$ (5,4)=0.52; P=0.024, therefore ANOVA and multiple range analyses were conducted using a lower level of significance (P<0.01), as recommended by Underwood (1981).

For Experiment 1 (Segment 3), one-way ANOVA was used to determine if the number of spat per collector type was affected by layer. Two-way ANOVA was used to determine if zone, collector type or the interaction between zone and collector type were significant. As zone was not significant and there was no interaction between collector type and zone (P>0.05), data from zones were combined and reanalysed using one-way ANOVA. Throughout this paper data are presented as means ± standard error (x±SE).

RESULTS

Experiment 1 - Sydney rock oysters

Segment 1 - Settlement and spat retention

Settlement was intense from January to July (172 days) and spat density was very high on all collector types (range 1122-19562 spat/collector). PVC collectors generally caught far more oysters than the traditionally used tarred sticks (Table 2). Spat density was higher (P<0.05) on five types of PVC collectors (D, RSS, RGS, RSSL and S; 49.3±3.0 spat/10 cm^2, n=25, replicate stacks, and bioresin slats, (BS, 43.6±4.0 spat/10 cm^2, n=5 replicate stacks) than on tarred sticks (TS, 14.5±3.1 spat/10 cm^2, n=5 replicate stacks), (Table 2).

Spat density varied greatly between the upper and lower surfaces of some of the collector types (Table 2). In general, spat were evenly distributed (P>0.05) across the upper and lower surfaces of collectors which had larger concave (downward facing) surface areas (Table 2). These collectors included PVC discs (D diam 140 mm), slurry-coated PVC discs (SCD, diam 355 mm), PVC slats (S width 104 mm) and slurry-coated PVC slats (SCS width 104 mm). Round spiky PVC sticks with lug (RSSL, diam 38 mm) also had a high settlement (Table 2).

Although having reasonably large surface areas, spat densities were lighter ($P<0.001$) on the flat upper surfaces of bioresin slats (BS, width 100 mm) and flat spiky PVC sticks (FSS, width 50 mm), (Table 2). Other collector types with smaller surface areas (range 20-22 mm width/diam) also had poor spat densities ($P<0.001$) on the upper surfaces (Table 2). By far, the highest density of barnacles ($P<0.05$) was recorded from the lower surfaces of tarred sticks (TS), with no settlement on slurry-coated discs (SCD), (Table 2).

Higher numbers of spat ($P>0.05$) were retained at day 271 on four types of PVC sticks (SCD, D, RSS and S; 22.1±1.4 spat/10 cm^2, n=20 replicate stacks) than on tarred sticks (TS, 8.9±1.5 spat/10 cm^2, n=5 replicate stacks). Oyster density affected spat losses ($P<0.001$). The percentage loss of spat ranged from 31.7±10.6 % from tarred sticks (TS) to 69.1±2.6 % from round grooved sticks (RGS; Table 2).

Segment 2 - Post-harvest survival of spat

Post-harvest survival (at day 14) was high and similar ($P>0.01$) for spat removed from tarred sticks (TS, 89.4±1.4%), slurry-coated discs (SCD, 92.0±1.2%), slurry-coated slats (SCS, 92.2±0.6%), slats (S, 93.4±1.9%) and discs (D, 91.8±1.7%). Post-harvest survival was lower ($P<0.001$) for spat removed from bioresin slats (BS, 66.8±6.2%) as spat were often damaged where they attached to the collector.

Segment 3 - Retention and growth of market size oysters

The pattern of retention was similar at each six monthly interval throughout Segment 3, thus only the initial spat density at day 127 and final retention data are presented (Table 3). At harvest (day 843), tarred sticks (TS) had the lowest density ($P<0.05$) of Sydney rock oysters (0.8±0.03/10 cm^2, n=4 replicate layers) and the three types of round PVC sticks (RSS, RSSL, RGS) had the highest oyster density ($P<0.05$; 2.5±0.1 spat/10 cm^2, n=12 replicate layers), (Table 3). Tarred sticks (TS) were heavily infested with marine borers and fractured when handled. Shell length at harvest was similar ($P>0.05$) from all types of PVC sticks (FSS, RSS, RSSL, RGS; range 46.9-48.5 mm/oyster, n=60 replicate sticks) and smaller ($P<0.05$) than that recorded from tarred sticks (TS, 55.1±0.6 mm/oyster, n=12 replicate sticks; Table 3). Collector type affected percentage loss ($P<0.05$) between days 127 and 843, although, the differences were relatively minor (Table 3). There was no oyster settlement (overcatch) on the PVC slats (S) during Segment 3. With the exception of the round spiky PVC stick with lug (RSSL) all types of sticks were damaged during harvesting when removing oysters.

Experiment 2 - Pacific oysters

The settlement period of Pacific oysters was from November to May (187 days). The density of Pacific oysters on collectors was much lighter than Sydney rock oysters in Experiment 1 (Segment 1; Table 4). For combined upper and lower surfaces, spat density ($P<0.001$) was higher on three types of PVC sticks

(SCD, RSS and D; 2.6±0.3 spat/10 cm^2, n=12 replicate stacks), than on tarred sticks (TS), PVC slats (S) and bioresin slats (BS), (0.5±0.1 spat/10 cm^2, n=12 replicate stacks; Table 4). Density of Pacific oysters was heaviest ($P<0.05$) on the lower surfaces of tarred (TS) and round spiky sticks (RSS) and on the upper surfaces of PVC slats (S) and discs (D). For the rest of the collector types, there were no differences ($P>0.05$) in density between upper and lower surfaces (Table 4). No barnacle settlement was detected.

DISCUSSION

The settlement during this study was particularly heavy and is likely to have been commercially acceptable on all collector types (Holliday et al., 1988). However, as intensity of settlement of Sydney rock (Holliday and Goard, 1986) and Pacific oysters (Dinamani, 1978) can fluctuate between years and in different estuaries (S. R. McOrrie, unpublished data, 1990; Reid, 1990), those collector types on which lower numbers of spat settled in this study may not have had commercially acceptable settlement had spatfall been lighter.

PVC and slurry-coated PVC collectors proved to be very effective collectors for Sydney rock and Pacific oyster settlement and poor collectors for barnacles. Tarred sticks had the lowest spat density after both 127 and 271 days. This may have been due to the coal tar covering the sticks. Coal tar pitch, with its antifouling properties designed to prevent infestation from marine borers, becomes soft and volatile and releases flammable vapours when heated (Pope, 1987). This is particularly important when sticks are exposed to sunlight at low tide. Competition on tarred sticks from barnacles probably also affected spat settlement and accounted for some of the spat losses, as settlement was higher than that of Sydney rock oysters and more intense on this collector (17.8/10 cm^2). Barnacles settle in a similar period to Sydney rock oysters (Holliday 1985b; Holliday and Goard, 1986) and can compete for settlement space (Butler, 1955; Ling, 1970).

Gunn (1984) reported natural catches of Pacific oysters in British Columbia on round grooved PVC sticks deployed intertidally and subtidally, although, his attempt at a comparative assessment of a number of test materials was unsuccessful due to a poor natural spatfall (range 0-1 spat/10 cm^2). Heavy natural catches (42 spat/10 cm^2) of Pacific oysters on PVC, two weeks after deployment in New Zealand were later reported by Curtin (1985b).

Oyster densities at day 127 affected spat losses ($P<0.001$) at day 271. Round grooved sticks caught significantly higher numbers of oysters (51.8 spat/10 cm^2) than tarred sticks (14.5 spat/10 cm^2). However, significantly less spat were lost from tarred sticks (31.7%) in the three month period after settlement, compared to the round grooved sticks (69.1%). As spat grew, competition for surface area was probably a contributing factor in the high losses from all collector types during the nine months after deployment.

Sydney rock oysters were evenly distributed on the upper and lower surfaces of collectors which had large concave (downward facing) surfaces which facilitated shading of the underlying layers without creating conditions conducive to a build up of silt on the upper surfaces. Collectors with flat surfaces, such as tarred sticks, bioresin slats and flat spiky PVC sticks, had poor settlement on their upper surfaces, possibly as a result of the accumulation of silt.

Previous studies have concluded that many factors affect the settlement of bivalves on the upper and lower surfaces of a substratum including siltation, current, gregariousness, light, colour, type of surface and swimming position of the larvae (Galtsoff, 1964). Thompson (1954), who found that settlement of Sydney rock oysters was more intense on the lower surfaces of flat fibro cement slate, concluded that light and siltation on the upper surfaces affected settlement. Dinamani and Lenz (1974), also mention the effects of siltation on flat substrates and found that New Zealand rock oysters (*S. glomerata*), a subspecies of the Sydney rock oyster (Buroker et al., 1979), settled mainly on the lower surfaces, although larvae began to settle on the upper surface when the spat density on the lower surfaces was high.

The collectors for Pacific oysters were deployed in a more estuarine site than that used for Sydney rock oysters (Holliday et al., 1991b), and the accumulation of silt on collectors was more likely to have been a problem than at the latter site. Even so, settlement of Pacific oysters was heavier on the upper surfaces of some flat collectors. This may indicate a difference betweem species in terms of relative settlement preference for upper and lower surfaces. With the exception of a study by Schaefer (1937), previous studies have recorded heavier settlement of Pacific oysters on upper surfaces of collectors (Miyazaki, 1938; Sayce and Larson, 1965; Shaw, 1967; Sayce and Tufts, 1968).

The lower post-harvest survival of spat removed from bioresin slats (66.8%; Experiment 1, Segment 2) demonstrates the importance of the surface composition of collectors for single seed culture. Collectors must not only facilitate settlement and retention of spat, but enable harvesting of spat without damage. It is also advantageous to be able to harvest the spat without damaging the collector. The optimal time to harvest spat from collectors is when the majority have shell diameters large enough to be retained by the mesh covering the nursery growing units. In NSW, the common nominal mesh size used on sectionalised nursery trays (Holliday et al., 1991a) and PVC cylinders is 3.0 mm (Holliday, unpublished data, 1991). The use of smaller mesh sizes may lead to problems caused by inadequate water flow and fouling (Lucas and Gerard, 1981; Holliday, et al., 1991a).

The most effective collector for on-growing Sydney rock oysters (Experiment 1, Segement 3) was the round spiky PVC stick with lug, as this stick retained large numbers of oysters, and these could be harvested without damaging either oysters or sticks. Little quantitative information is available on losses of oysters from tarred sticks or growth rates during the traditional three-year grow-out period, although high losses (95%) have been reported from tarred sticks (Holliday, 1985b; Holliday and Goard, 1986) with average yields of only 30-50 (about 45 g) oysters/stick (Holliday et al., 1988). In this study, the high oyster losses from collectors during grow-out has been attributed to settlement density, intraspecific competition for surface area and surface texture of the stick. However, despite the lighter settlement, tarred sticks exhibited similar loss rates to other collector types.

The highest shell growth was on tarred sticks, which also had the lowest density of settlement. The higher numbers of spat which settled on PVC sticks may have reduced oyster growth, as competition for food probably increased with density. However, flat spiky sticks had a lower oyster density at harvest than other PVC sticks but a similar average shell length (Table 3). Jarayabhand and Newkirk (1989) found that with increasing stocking densities of European oysters (*O. edulis*) on cultch, specific growth rates decreased, particularly for smaller oysters. Food was found to be a growth limiting factor for mussels (*Mercenaria mercenaria*) stocked at a range of densities (Hadley and Manzi, 1984). Holliday et al. (1991b) also suggested that food may have affected growth rates of juvenile Sydney rock spat grown at a range of densities.

In this study, spat densities for both Sydney rock and Pacific oysters were lower on tarred sticks than on PVC sticks. Tarred sticks were so heavily infested with marine borers that they fractured when harvested and were not reusable. Thus, the traditionally used tarred hardwood stick, which are becoming more difficult to acquire, have a lower productivity and functional life than most PVC collectors tested. For PVC sticks, the higher initial costs (approximately double those of tarred sticks at the time of the study) are effectively reduced by the increased life of the sticks. Shape, composition and surface texture of the collectors probably affected oyster and barnacle settlement, retention and growth. PVC collectors were the best for Sydney rock oyster spat production, while round spiky PVC sticks with lug proved to be the best of the PVC collectors for on-growing and harvesting market grade oysters. For Pacific oysters, PVC discs and sticks, with or without a slurry coating, were the best spat collectors.

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TABLE 1

Summary of specifications for collector types used in Experiments 1 and 2

Type	Dimensions/ collector (mm)	Surface area/ collector (cm^2)	Format of stacks No. of layers	Format of stacks No/layer	Total No. collectors/ treatment
PVC sticks[1]					
Flat spiky PVC stick (FSS)	50 width 10 cavity 1235 length 1.5 wall thickness	1359	5	4	100
Round spiky PVC stick with lug (RSSL)	22 diameter 16 width lug 1808 length	1792	5	4	100
Round grooved PVC stick (RGS)	22 diameter 1808 length	1250	5	4	100
Round spiky PVC stick (RSS)	22 diameter 1808 length	1250	5	4	100
PVC discs					
PVC disc (D)[2]	140 diameter 1.0 wall thickness	275	10	3	150
Slurry-coated[2,3] PVC disc (SCD)	355 diameter 5.0 wall thickness	1790	6	1	30
Slats					
Bioresin[2,4] slat (BS)	100 width 1010 length	2020	5	3	75
PVC slat (S)[2,5]	104 width 1495 length 2.0 wall thickness	3110	5	4	100
Slurry-coated[2,3] PVC slat (SCS)	104 width 1495 length 3.0 wall thickness	3110	5	4	100
Tarred hardwood[2,6,7] **stick** (TS)	20 x 20 1800 length	1440	5	12	300

1 Manufactured by Dynex Extrusions Ltd, PO Box 56-122, Auckland, New Zealand.
2 Collectors were designed for single seed culture.
3 Disc and slats were slurry-coated with the following mix: 600 g hydrated lime, 200 g cement, 100 ml PVC bonder and 2.2 l fresh water.
4 Bioresin was impregnated on a woven fibreglass cloth.
5 Slats were 2 years old.
6 Sticks coated in coal tar pitch type and air dried for 2 months prior to deployment. Spatfall was confined to upper and lower surfaces (effective area 720 cm^2).
7 Collectors were designed for spat collection and/or on-growing oysters to market.

TABLE 2

Density of Sydney rock oysters *Saccostrea commercialis*, on 10 commercial spat collector types in Salamander Bay, Port Stephens, NSW, January to October 1988 (Experiment 1, Segment 1).

	Spat density at day 127 (July) ($spat/10\ cm^2$)[1]			Spat density at day 271 (October) ($spat/10\ cm^2$)	Spat losses July-Oct '88 (%)	Barnacle density at day 127 ($spat/10\ cm^2$)
Collector type	Lower	Upper	Combined	Combined	Combined	Combined
Tarred stick (TS)	28.2±5.3	0.4±0.2	14.5±3.1[a]	8.9±1.5[a]	31.7±10.6[a]	17.8±2.8[a]
Flat spiky stick (FSS)	29.5±3.3	7.0±2.0	21.5±3.4[ab]	13.0±1.7[ab]	36.3±7.4[ab]	0.3±0.1[de]
Slurry-coated disc (SCD)*	33.7±2.5	33.5±4.5	33.6±2.9[abc]	21.3±2.9[bc]	37.3±5.1[ab]	0[e]
Slurry-coated slat (SCS)*	33.9±4.2	39.6±5.0	37.5±3.7[abc]	20.0±1.9[abc]	42.5±11.0[ab]	6.1±0.5[b]
Disc (D)*	39.9±2.1	39.1±4.1	40.8±3.2[bc]	26.1±3.2[c]	35.9±5.6[ab]	2.5±1.0[bcd]
Bioresin slat (BS)	56.1±5.5	37.4±4.0	43.6±4.0[bc]	21.5±2.8[abc]	51.7±4.6[ab]	0.2±0.1[de]
Round spiky stick (RSS)	81.3±12.4	7.0±3.0	44.7±5.4[bc]	16.8±2.0[bc]	60.3±6.4[ab]	3.8±1.1[bc]
Round grooved stick (RGS)	90.3±11.5	14.1±5.0	51.8±6.4[c]	16.3±2.9[abc]	69.1±2.6[b]	0.8±0.3[cde]
Round spiky stick with lug (RSSL)*	57.0±5.7	36.9±8.6	53.0±8.7[c]	20.0±3.1[abc]	56.9±9.1[ab]	1.4±0.6[cd]
Slat (S)*	47.4±6.5	62.9±8.9	57.5±7.9[c]	26.0±2.6[c]	52.9±5.5[ab]	0.3±0.2[de]

1 Values are x±SE, n=5. Within each column, means with a common superscript are not significantly different (P>0.05).

* Each collector type with this superscript showed no significant difference (P>0.05) in spat density/10 cm^2 on lower or upper surface.

TABLE 3

Density of Sydney rock oysters *Saccostrea commercialis*, on five collector types in Salamander Bay, Port Stephens and Empire Bay, Brisbane Waters, NSW, July 1988 to May 1990 (Experiment 1; Segment 3)[1].

Collector type	Spat density at day 127 (spat/10 cm^2)	Oyster density at day 843 (oysters/10 cm^2)	Shell length at day 843 (mm)	Nett loss between[2] days 127 and 843 (%)
Tarred Hardwood stick				
Tarred stick (TS)	14.5 ± 3.1^{a}	0.8 ± 0.03^{a}	55.1 ± 0.6^{a}	95.0 ± 1.2^{ab}
PVC sticks				
Flat spiky stick (FSS)	21.5 ± 3.4^{ab}	1.4 ± 0.1^{b}	48.2 ± 1.2^{b}	96.5 ± 0.8^{b}
Round spiky stick (RSS)	44.7 ± 5.4^{c}	2.6 ± 0.2^{c}	48.5 ± 0.8^{b}	92.6 ± 0.9^{a}
Round spiky stick with lug (RSSL)	53.0 ± 8.7^{c}	2.5 ± 0.1^{c}	48.2 ± 0.9^{b}	93.2 ± 0.6^{ab}
Round grooved stick (RGS)	51.8 ± 6.4^{c}	2.3 ± 0.1^{c}	46.9 ± 1.4^{b}	95.2 ± 0.2^{ab}

1 Values are $x \pm SE$, $n=4$. Within each column, means with a common superscript are not significantly different ($P>0.05$).

2 Data were transformed ($arcsine^{0.5}$) prior to ANOVA.

TABLE 4

Density of Pacific oysters *Crassostrea gigas,* on nine types of commercial collectors in Tanilba Bay, Port Stephens, NSW, November 1988 to June 1989 (Experiment 2)[1]

Collector type	Spat density/10 cm^2		
	Lower	Upper	Combined[3]
Tarred stick (TS)	0.4±0.1	0.2±0.1	0.5±0.1[a]
Slat (S)	0.2±0.1	0.4±0.1	0.5±0.1[a]
Bioresin slat (BS)*	0.3±0.1	0.3±0.1	0.6±0.1[a]
Round spiky stick with lug (RSSL)*	0.5±0.1	0.5±0.1	1.1±0.1[ab]
Flat spiky stick (FSS)*	0.8±0.3	0.5±0.2	1.3±0.4[ab]
Round grooved stick (RGS)*	1.4±0.3	0.7±0.1	2.0±0.5[ab]
Slurry-coated disc (SCD)*	1.2±0.1	1.1±0.1	2.4±0.1[b]
Round spiky stick (RSS)	1.9±0.1	0.8±0.1	2.7±0.1[b]
Disc (D)	0.9±0.1	2.0±0.3	2.8±0.7[b]

1 Values are x±SE, n=4. Within each column, means with a common superscript are not significantly different (P>0.05).

2 Each collector type with this superscript showed no significant difference (P>0.05) in numbers of oysters/10 cm^2 settled between upper and lower surface.

Fig 1 Retention of Sydney rock oysters (Experiment 1, Segment 3) on an average traditionally used tarred hardwood stick (left) and an average round spiky PVC stick with lug (right).

SECTION 4

STOCKING DENSITY

Optimum stocking density for nursery culture of Sydney rock oysters (*Saccostrea commercialis*)

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ABSTRACT

Holliday, J.E., Maguire, G.B. and Nell, J.A. Optimum stocking density for nursery culture of Sydney rock oysters (*Saccostrea commercialis*).

Growth rates of juvenile Sydney rock oysters (*Saccostrea commercialis*) declined with increasing stocking density ($P<0.01$) in intertidal sectionalised trays in three 3-5 month experiments. Optimum stocking densities based on maximum biomass gain results (kg/m^2) for oysters with average initial whole weights of 0.09, 1.15 and 1.56 g/oyster were obtained at densities of 15200, 7200 and 3600 oysters/m^2 in that order. The estimated survival rate of oysters during the 12 month study was high (97.5%).

INTRODUCTION

Nursery culture of bivalve molluscs is an important phase of cultivation which links the production of small juveniles (spat) from hatcheries or natural spatfall with the grow-out phase to harvest size (Claus, 1981). Traditional methods for farming Sydney rock oysters (*Saccostrea commercialis*) to market size involve collecting spat on tarred hardwood sticks and on-growing them on sticks for 3-4 years. After being removed from the sticks, oysters which are below market size may be finished in intertidal trays (Korringa, 1976). This approach has formed the basis of one of Australia's most valuable aquacultural industries (Holliday et al., 1988; Nell et al., 1990).

In recent years the development of hatchery techniques and collection methods for natural spatfall has made the culture of unattached (single seed) Sydney rock oysters commercially possible (Holliday, 1985a). Compared with oysters produced using traditional methods, single seed oysters are less likely to grow together and hence mortalities and labour costs associated with separating oysters are greatly reduced (Holliday et al., 1988). However, high losses of spat were initially experienced by Sydney rock oyster farmers who used single seed because of inappropriate design or management of nursery systems. The nursery phase in single seed culture usually requires different production units and handling methods to those used for the grow-out phase (Claus, 1981). As several nursery systems used overseas proved to be unsuitable for local conditions, a system had to be developed to suit the Sydney rock oyster (Holliday, 1985b). The efficiency of a nursery system is affected by the stocking densities used, as growth rates of individual oyster spat decrease with increasing stocking density, while overall spat production (weight per unit area) increases (Neudecker, 1981).

The aim of the present study was to determine the optimum stocking densities for various size grades of Sydney rock oyster spat as part of an evaluation of sectionalised trays as intertidal nursery units for this species.

MATERIALS AND METHODS

Sectionalised nursery trays (1.94 x 0.94 x 0.05 m) constructed of tarred 50 x 20 mm hardwood were divided crossways into six parallel sections each 0.25 m². Both the upper and lower tray surfaces were covered with PVC mesh (diagonal mesh size 3 mm). Three stocking density experiments were conducted within a 12 month period using these trays positioned on timber post and rail at the intertidal rack height used by commercial oyster farmers in Swan Bay, Port Stephens, N.S.W., Australia (32° 44'S; 152°E; Fig 1),.

Spat were detached from various types of collectors used on a catching lease in Salamander Bay, Port Stephens (Fig 1) and were then on-grown in forced-flow upwellers (Bayes, 1981; Wisely, 1983), before being stocked in nursery trays for the first experiment.

For each experiment there were six stocking densities (Table 1) with four replicate tray sections per density and treatments were randomly allotted among the sections and trays. Individual spat were not counted when stocked but were allotted on a pooled weight basis in relation to the average spat weight for an initial sample. Each month the trays were removed from the lease and average oyster weights were determined as above. Dead oysters were counted, total weights recorded and live oysters returned to the trays which were then randomly assigned on the lease to minimise any effect of lease position on growth. Each experiment was terminated when spat in the high density treatments began growing through the upper mesh layer. At the end of Experiments 1 and 2, spat were pooled and, to minimise variances in individual weight, the pooled spat were graded with three PVC mesh screens with only the middle grade used to stock the next experiment. The densities used were selected to provide a range from very lightly stocked to densely stocked with most of the floor area of the tray section being covered by a single layer of closely packed spat.

Experiment 1 involved estimated stocking densities of 300, 1000, 1700, 2400, 3100 and 3800 spat/section (1200-15200 spat/m²). The average initial weight was 0.09 g/spat (based on the pooled weight of 700 spat). This experiment ran for 13 weeks (January to April).

Experiment 2 involved estimated densities of 200, 600, 1000, 1400, 1800, 2200 spat/section (800-8800 spat/m^2) and an average initial weight of 1.15±0.02 g/spat (x±SD; n=6 for groups of 100 spat). This experiment ran for 13 weeks (April to July).

Experiment 3 involved estimated densities of 300, 500, 700, 900, 1100 and 1300 spat/section (1200-5200 spat/m^2) and an average initial weight of 1.56±0.07 g/spat (x±SD; n=5 for groups of 100 spat). Because growth rates in the early phase of this experiment were relatively slow, it was extended to a total period of 22 weeks (July to December).

Daily salinity and temperature data were obtained with hydrometers and thermometers at three commercial oyster depuration plants near the nursery lease in Swan Bay (Fig. 1).

Statistical Analyses

Homogeneity of variance was confirmed using Cochran's test (Winer, 1971) and data were analysed using ANOVA. Mean values were compared using the "least-significant differences" technique (Sokal and Rohlf, 1981). Linear regression was performed for all experiments to examine the relationship between stocking density and average weight gain. To satisfy the assumption of homogeneity, weight gain data for Experiment 2 was transformed (log x) prior to ANOVA and regression. Survival data were transformed (arcsine $x^{0.5}$) prior to ANOVA. Results from tray sections where physical damage to the tray section may have allowed losses of spat were not included in analyses. Throughout this paper data are presented as mean ± standard deviation ($\bar{x}$±SD).

RESULTS

The estimated survival rate of the spat over the twelve month period was very high (97.5%) and was not affected by stocking density in any of the three experiments ($P>0.05$).

In each of the three experiments average individual oyster weight gain decreased with increasing stocking density ($P<0.05$; Fig. 2). However, in Experiment 1 average weight gain for the lowest stocking density (1200 spat/m^2) was lower than that recorded at 4000 spat/m^2 ($P<0.05$; Fig. 2). In this experiment it was evident that a very low stocking density (1200 spat/m^2) was unfavourable, probably because excessive oyster movement caused by wave action on the sparsely-stocked tray sections caused shell abrasion; spat were ball-shaped with thick shell walls. At equivalent densities (no./m^2) the effect of stocking density on growth was much more pronounced (Fig 2). Spat growth was depressed during Experiments 2 and 3 (Fig. 3) when low water temperatures were recorded in July (12.1±1.1°C) and August (13.1±1.8°C; n=20/month). Variances were homogeneous for each sampling time except for the July samples in Experiment 2 (Fig 3). The standard deviation values for the July samples, in increasing order of stocking density were 0.10, 0.25, 0.08, 0.06, 0.08, and 0.08 g.

In each of the three experiments, final biomass increased with increasing stocking density over the whole range tested (Table 1). Biomass gain generally increased as stocking density increased until a plateau was reached (Fig. 4). The exception was Experiment 1 for which biomass gain increased with increasing stocking density throughout the range tested. It should be noted that for Experiment 1 the optimum density was the maximum level used and a higher density may have produced even better biomass gain values. The optimum stocking densities in terms of biomass gain for Experiments 1, 2 and 3 were 15200, 7200 and 3600 spat/m^2 in that order. It should be noted that in Experiment 3 a marginally higher biomass gain was obtained at 4400 spat/m^2 but this was not a significant improvement over stocking with 3600 spat/m^2 ($P>0.05$). Final biomass levels at the optimum stocking density for each experiment were similar (11.3-13.0 kg/m^2; Table 1).

Average water temperature and salinity levels were as follows: Experiment 1 (n=63), 22.0±1.7°C, 33.6±2.1‰, ranges 16-27°C, 28-40‰; Experiment 2 (n=63), 14.3±2.5°C, 25.6±0.6‰, ranges 10-21°C, 17-36‰; and Experiment 3 (n=91), 18.8±3.3°C, 26.6±4.0‰, ranges 10-27°C, 9-39‰.

DISCUSSION

Unlike traditional cultivation methods for the Sydney rock oyster, single seed methods allow for manipulation of juvenile oyster densities. The results of the present study indicate that the choice of stocking density has a major effect on yields from sectionalised trays. In each of the three experiments, individual spat growth decreased with increasing density, probably because of competition for food. Hadley and Manzi (1984) concluded that food was the growth limiting factor for clams (*Mercenaria mercenaria*) stocked at a range of densities in a raceway nursery system.

A variety of criteria could be used to assess optimum stocking density. The higher growth rates at low densities enhance the value of individual oysters, however, the value of production per unit area may be relatively low. Neudecker (1981) concluded that for small Pacific oyster spat (*Crassostrea gigas*), maximum growth was the best criterion for optimum stocking density because faster growth rates allowed for an earlier transfer to subtidal trays with a larger mesh size. Optimum density may also be influenced by survival rate, although in all of the present experiments estimated survival rates were very high and unaffected by density. The choice of stocking density should be based on economic considerations (Maguire and Leedow, 1983). As the data required for a comprehensive economic analysis of single seed nursery culture are not yet available, an alternative approach of using maximum biomass gain as the criterion for optimum density was used here. The estimate of biomass used in this study was total oyster weight but depending on the thickness of the shell, this is not always an accurate guide to the value of an oyster. Other factors such as meat condition, shell shape and shell size can also influence value per oyster. Specifically farmers often sort harvested oysters into groups of differing values on the basis of shell length. However, for single Sydney rock oysters, there is a close relationship between total oyster weight and shell length (C. J. Mason, personal communication, 1990).

The management of nursery units involves more than the choice of stocking density. As the spat grow they may fill the available tray space and grow through the mesh. In Experiment 2 and 3 the tendency for the spat to grow through the mesh prior to harvest was much more evident than in Experiment 1. Towards the end of Experiments 2 and 3, there was evidence that growth rate decreased at high densities (Fig 3). A similar pattern was evident in the growth data for small Pacific oyster spat in subtidal nursery trays (Neudecker, 1981). This emphasizes the need to periodically reduce the density (number/m^2) as the spat grow. As this process is relatively labour intensive, it may be preferable to avoid high stocking densities and hence frequent handling of the trays. Neudecker (1981) recommended the adjustment of densities every 2-3 weeks, but this is likely to be too labour intensive for the oyster farming industry in New South Wales. However, more frequent reductions in densities than those used in the present study may be worthwhile.

Excessively small mesh sizes, particularly if exacerabated by marine fouling, could restrict flow rates and reduce the amount of food available for oysters. The initial tray mesh size must be small enough to retain juvenile spat but as they grow, spat can be moved to larger mesh sizes to increase water flow. In the present study 3 mm mesh was used for the twelve month duration of the experiments as it prevented spat loss due to wave action and provided protection against predation and heat stress during intertidal exposure (Potter and Hill, 1982). In contrast Neudecker (1981) increased the mesh size as the spat grew.

Spat growth rates appeared to be depressed during the cooler months in Experiments 2 and 3 (Fig. 3). This observation was consistent with results from a nursery experiment over 12 months at three intertidal sites within Port Stephens (Holliday et al., in press). Similarly, Nell and Livanos (1988) showed that in the range of 12-30°C, growth rates of Sydney rock spat, fed to excess in the laboratory, increased as temperature increased.

Sectionalised trays proved to be appropriate nursery units for Sydney rock oyster spat and were particularly successful for sustaining very high survival rates. In a twelve month period spat in the present experiment grew from 0.09 g to 4.9-6.0 g/spat. Data for the equivalent growth phase for Sydney rock oysters grown on sticks in conventional intertidal leases are not available, but 3-4 years are usually required for them to reach market size (>40 g; Korringa, 1976).

Traditional intertidal trays used for on-growing oysters approaching market size are often subjected to severe wave action which washes the oysters into the tray corners resulting in overcrowding, reduced growth rates, and eventual mortality. In this study, the increased number of partitions in the sectionalised trays reduced spat movement and minimised overcrowding. The upper and lower mesh layers also prevent predation of spat by fish and spillage from trays.

Claus (1981) noted that the appropriateness of nursery technology is influenced by geographic location and economic considerations and emphasized that two dimensional nursery systems require more space than more sophisticated three dimensional nursery systems. However, space is not a limitation in New South Wales as the Sydney rock oyster industry is based largely on two dimensional intertidal culture through to market size and the area required for nursery culture is negligible compared with that needed for the grow-out phase. The determination of optimum stocking densities for juvenile Sydney rock oysters in sectionalised trays will allow for more cost efficient usage of trays and lease space. Key factors include capital and operating costs associated with acquisition of trays, depreciation, replacement, lease infrastructure and labour costs for relocation of trays during grading operations.

Subsequent to the completion of this study and that by Holliday et al. (in press), sectionalised trays were widely adopted by farmers culturing single seed Sydney rock oysters (Holliday et al., 1988). The suitability of this nursery system has helped foster the expansion of single seed oyster farming as an alternative to traditional stick culture methods which no longer provide adequate return on capital in some estuaries in New South Wales (Marshall and Espinas, 1987; Espinas et al., 1988).

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TABLE 1. Production of Sydney rock oyster spat (*Saccostrea commercialis*) at various stocking densities in sectionalised trays ($\bar{x}\pm SD$)[1]

Stocking density (spat x $10^3/m^2$)	Final biomass[2] (kg/m^2)	Biomass gain[2,3] (kg/m^2)
Experiment 1		
1.2	1.6±0.1	1.5±0.1[a]
4.0	5.4±0.1	5.0±0.1[b]
6.8	7.9±0.3	7.3±0.3[c]
9.6	9.8±0.7	8.9±0.7[d]
12.4	10.8±0.7	9.7±0.7[e]
15.2	12.0±0.4	10.7±0.4[f]
Experiment 2		
0.8	1.8±0.1	0.8±0.1[a]
2.4	4.8±0.1	2.0±0.1[b]
4.0	7.3±0.1	2.7±0.1[c]
5.6	9.1±0.2	2.7±0.2[c]
7.2	11.3±0.2	3.0±0.2[d]
8.8	13.0±0.2	2.9±0.2[cd]
Experiment 3		
1.2	5.2±0.3	3.3±0.3[a]
2.0	7.7±0.6	4.6±0.6[b]
2.8	10.2±0.8	5.8±0.8[c]
3.6	13.0±0.3	7.4±0.3[d]
4.4	14.3±0.4	7.5±0.4[d]
5.2	15.1±1.0	7.0±1.0[d]

1 The average initial whole spat weight values for Experiments 1,2 and 3 were 0.09g, 1.15g and 1.56g in that order and the duration of each experiment was 13, 13 and 22 weeks (respectively).

2 Biomass values based on whole weight of live spat.

3 Within this column mean values from the same experiment are not significantly different if they share a common letter in the superscript ($P>0.05$).

Fig. 1. Map of Port Stephens, NSW, Australia, with the nursery lease in Swan Bay used for Experiments 1, 2 and 3.

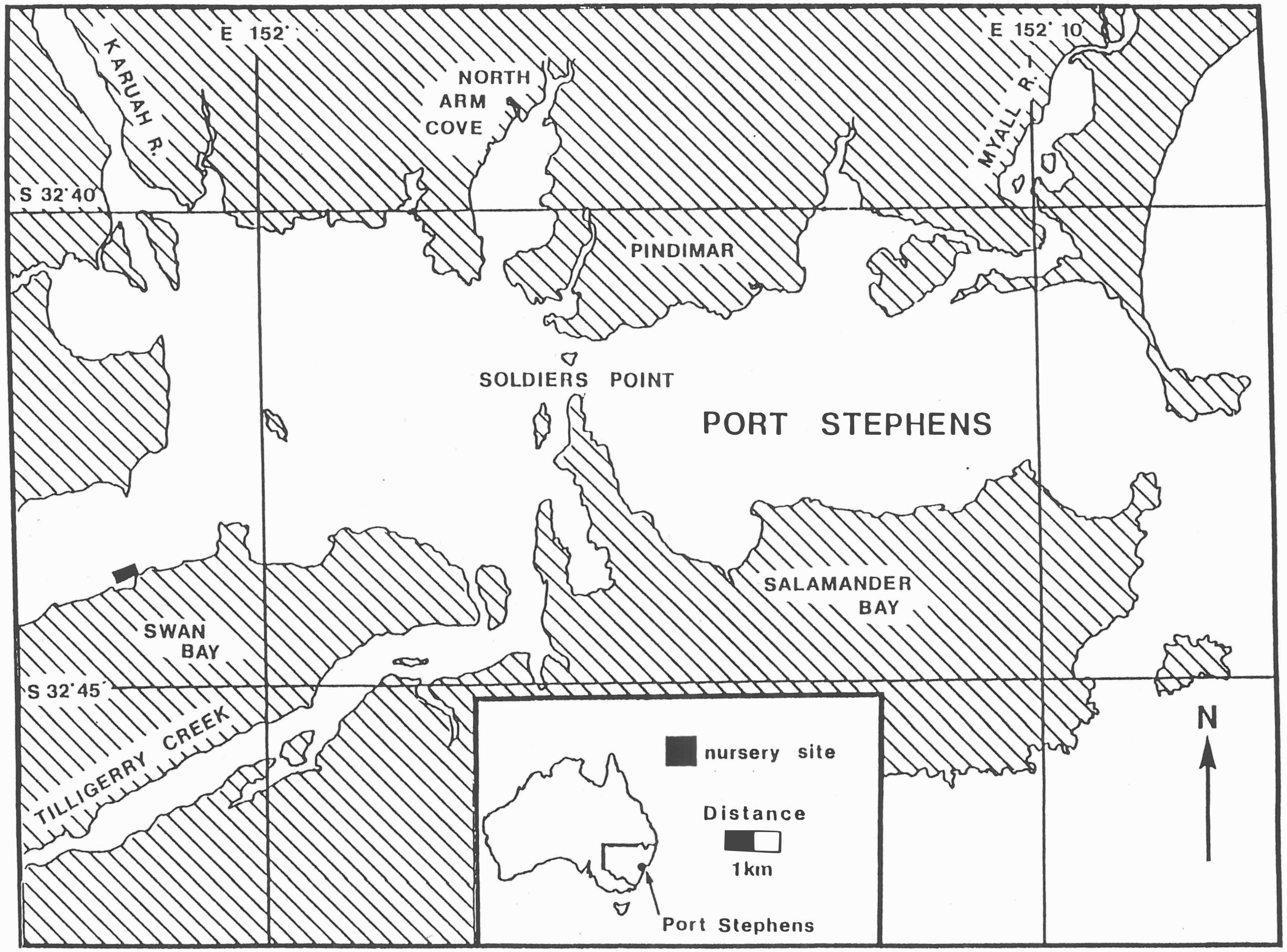

E 152'
E 152' 10'
KARUAH R.
NORTH
ARM
COVE
MYALL R.
S 32'40'
PINDIMAR
SOLDIERS POINT
PORT STEPHENS
SALAMANDER
BAY
SWAN
BAY
S 32'45'
TILLIGERRY CREEK
nursery site
Distance
1km
Port Stephens
N

Fig. 2. Growth of Sydney rock oyster spat (*Saccostrea commercialis*) at a range of stocking densities in sectionalised trays.

Footnote: [1] Means, within each experiment, which share a common letter in the superscript are not significantly different (P>0.01).

[2] Data for Experiment 2 were transformed (log X) prior to ANOVA and regression analysis.

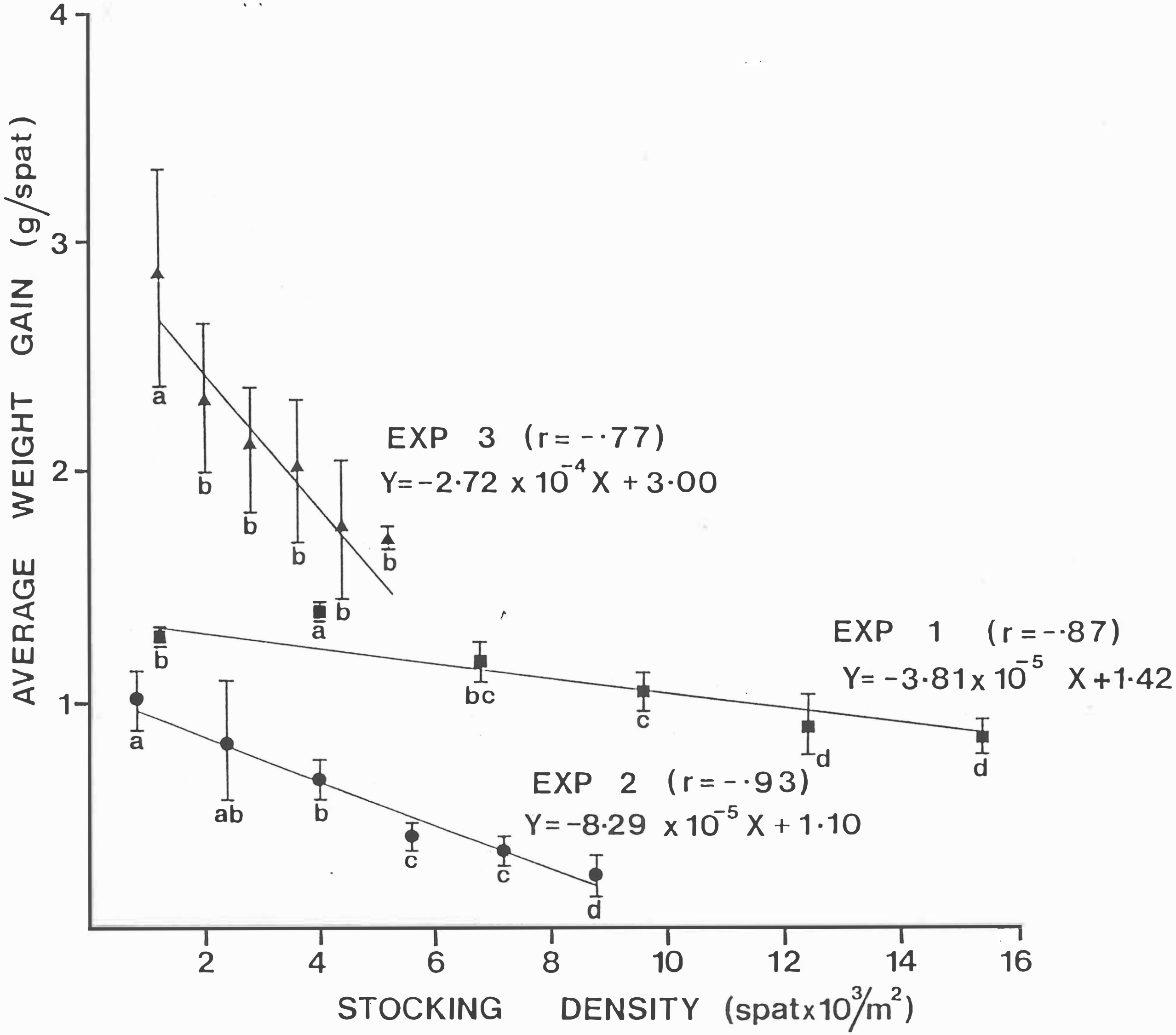
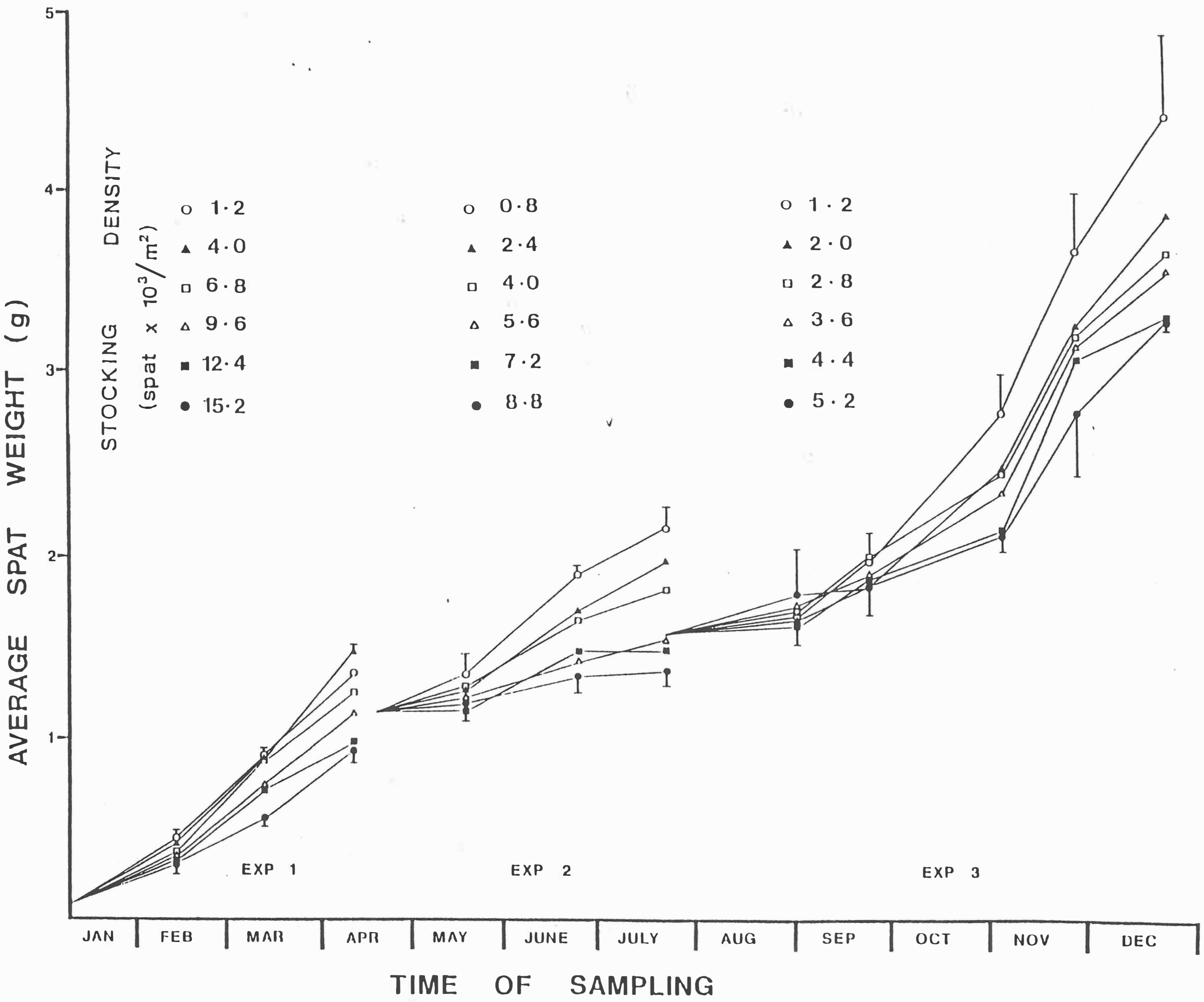
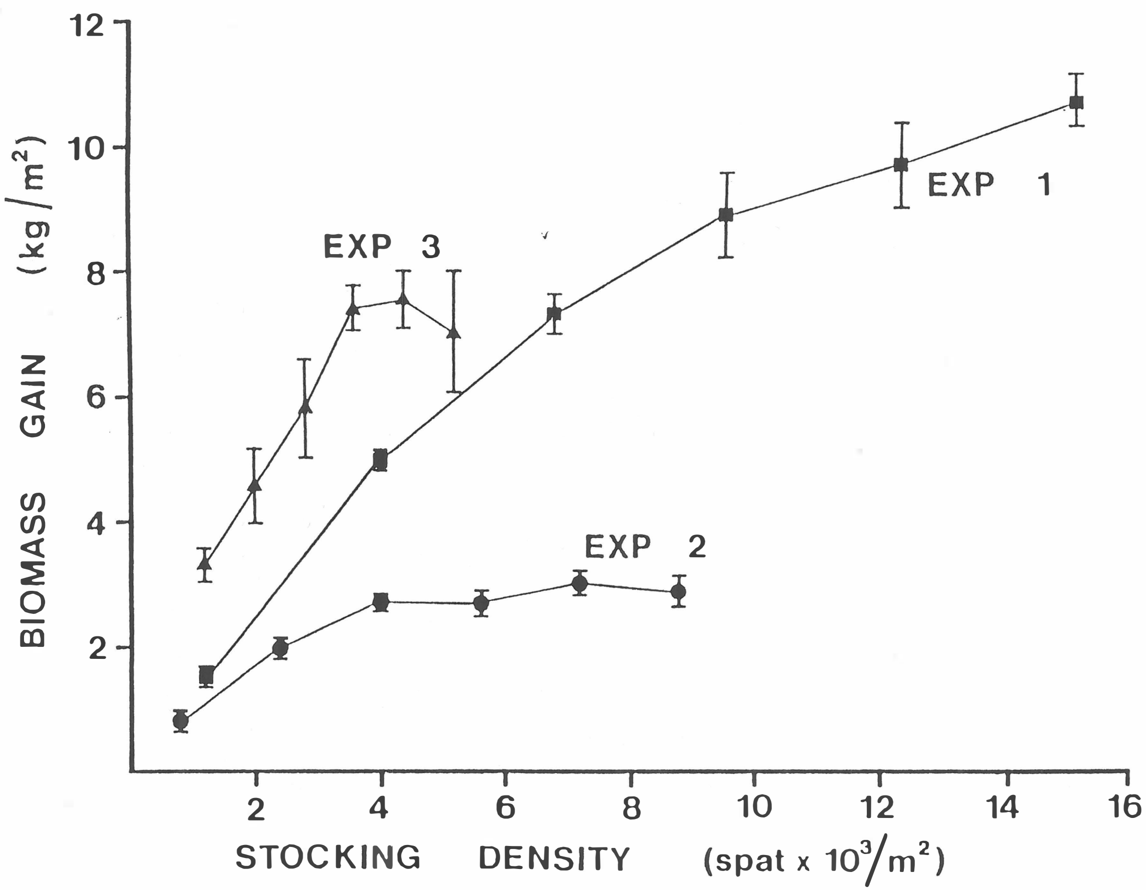

AVERAGE WEIGHT GAIN (g/spat)
EXP 3 (r = -·77)
Y=-2·72 x 10^-4 X + 3·00
EXP 1 (r = -·87)
Y= -3·81 x 10^-5 X + 1·42
EXP 2 (r = -·93)
Y= -8·29 x 10^-5 X + 1·10
STOCKING DENSITY (spat x 10^3/m^2)

Fig. 3. Growth of Sydney rock oyster (*Saccostrea commercialis*) spat through time at a range of stocking densities ($\bar{x} \pm SD$). Only the standard deviation values for the largest and smallest size groups at each sampling time have been included.



AVERAGE SPAT WEIGHT (g)
STOCKING DENSITY (spat x 10³/m²)
1·2
4·0
6·8
9·6
12·4
15·2
0·8
2·4
4·0
5·6
7·2
8·8
1·2
2·0
2·8
3·6
4·4
5·2
EXP 1
EXP 2
EXP 3
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEP
OCT
NOV
DEC
TIME OF SAMPLING

Fig. 4. Biomass gain over the duration of the experiments for Sydney rock oyster (*Saccostrea commercialis*) spat grown at a range of stocking densities.


EXP 1
EXP 2
EXP 3
BIOMASS GAIN (kg/m²)
STOCKING DENSITY (spat x 10³/m²)
2
4
6
8
10
12
2
4
6
8
10
12
14
16

Effects of stocking density on juvenile Sydney rock oysters, *Saccostrea commercialis*, in cylinders

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ABSTRACT

Holliday, J. E., Allan, G. L. and Nell, J. A. Effects of stocking density on juvenile Sydney rock oysters, *Saccostrea commercialis*, in cylinders.

Two size grades (13.5 and 18.2 mm average shell length/spat) of juvenile Sydney rock oysters, (*Saccostrea commercialis*) were grown at a range of stocking densities (0.5 to 6.0 l of oysters/cylinder) in PVC cylinders (0.73 x 0.27 m) for three months. For each grade, spat mortality was similar ($P>0.05$) for stocking densities of 0.5 to 4.0 l/cylinder ($\bar{x}\pm SE$; 11.7±1.1% and 24.3±2.4% respectively) but higher for the larger grade (33.3±1.7%; $P<0.05$) at the highest stocking density.

For both grades, weight gain and length increase declined as stocking density increased ($P<0.001$), although differences for initial densities above 3.0 and 4.0 l of oysters/cylinder, for the smaller and larger grades respectively, were not significant ($P<0.05$). Biomass gain and volume of oysters both increased with increasing stocking density ($P<0.05$), although, increases above initial densities of 2.0 l and 3.0 l of oysters/cylinder, for the smaller and larger grades respectively were not significant ($P>0.05$). For both grades, coefficient of variation for weight gain and shell length increase data, increased ($P<0.001$) with density.

For maximum growth in cylinders, juvenile oysters should be stocked at low densities of 0.5 or 1.0 l/cylinder for 0.2 and 0.4 g/spat respectively. However, to minimise capital and operating costs and maximise biomass gain, higher densities of 2.0 and 3.0 l of oysters/cylinder respectively should be used.

INTRODUCTION

The oyster industry in New South Wales (NSW), Australia has progressed from using rocks and mangrove stick, as substrates for both the collection and growth of oysters to market size, to the use of tarred hardwood sticks (Korringa, 1976; Malcolm, 1987; Quayle, 1988; Holliday et al., 1988). Sydney rock oysters (*Saccostrea commercialis*) are generally caught and either grown to market size on the sticks or knocked off the sticks and on-grown on tarred wooden trays (Malcolm, 1987). However, many farmers are now growing their oysters using "single seed" culture techniques (Holliday et al., 1988) by using natural spat (removed from synthetic collectors) or hatchery produced spat. A nursery phase follows where the unattached single oysters are grown in sectionalised trays or PVC cylinders (Holliday et al., 1988). Single seed culture eliminates laborious culling (separation of oysters), allows machine grading and ensures oysters are of more uniform shape (Holliday et al., 1988) with a larger shell cavity volume than oysters grown on sticks (Nell and Mason, 1991).

As oysters grow they are moved into nursery units with larger mesh sizes to allow greater water flow and to reduce problems with fouling (Holliday et al., in press). Problems with farming single seed oysters on nursery trays have been experienced in estuaries with high levels of suspended silt (Holliday et al., 1988). In these areas the deposition of silt on oysters can aggravate problems with infestation by mudworm (*Polydora* spp.) commensals which burrow into the oyster through the shell and cause shell blisters (Skeel, 1979). A PVC cylinder (Stanway Oyster Cylinder Pty Ltd.; 23 Brooklyn Rd, Brooklyn, NSW) which rotates with the tide, was developed by a New South Wales oyster farmer in response to this problem. This revolving action (one revolution per tide) helps remove silt from around the oysters.

Combined with site, stock and production systems, stocking density is an important option by which a farmer can influence oyster performance. Although the effects of stocking density have been determined for juvenile Sydney rock oysters in sectionalised trays (Holliday et al., in press), they are yet to be determined for cylinders which are rapidly growing in popularity. The objective of this study was to determine the optimum stocking density based on survival, biomass gain, individual weight gain and shell increase for two grades of juvenile Sydney rock oysters in cylinders. The effects of stocking density on size variation were also assessed as a wide range of spat sizes in a nursery system increases stock management costs (Newkirk, 1981; Askew, 1978).

MATERIALS AND METHODS

Cylinders were constructed of 3 mm PVC mesh, a PVC shaft and rigid buoyant PVC end caps which caused rotation in response to changes in tidal level (Fig. 1, 2). Cylinders were fixed to intertidal, horizontal hardwood frames supported by timber posts (Fig. 1).

Sydney rock oyster spat were obtained from a hatchery and initially held in a similar upweller nursery system to that described by Bayes (1981), prior to being stocked in the experiment. Two grades of spat were used. For the smaller grade the initial weight of individual spat ($\bar{x}\pm$SE, n=400) was 0.24±0.01 g and the shell length (n=1000) was 13.5±0.1 mm. Five stocking densities of 0.5, 1.0, 2.0, 3.0 and 4.0 l of oysters, with four replicate cylinders per density were used. Spat were stocked on the basis of volume as this is the method used by most oyster farmers. The total weight of oysters (n=4) for each volume were: 0.5 l (300.4±0.04 g), 1.0 l (600.4± 0.1 g), 2.0 l (1200.2±0.04 g), 3.0 l (1800.3±0.03 g) and 4.0 l (2400.4± 0.01 g).

For the larger grade the initial weight of individual spat (x±SE, n=500) was 0.41±0.001 g and the shell length (n=200) was 18.2±0.1 mm. Six stocking densities of 0.5, 1.0, 2.0, 3.0, 4.0 and 6.0 l of oysters/cylinder with four replicate cylinders per density were used. The total weight of oysters (n=4) for each volume were: 0.5 l (245.4±0.03 g), 1.0 l (490.3±0.04 g), 2.0 l (980.3±0.1 g), 3.0 l (1470.5±0.1 g), 4.0 l (1960.4±0.1 g) and 6.0 l (2941.3±0.1 g).

Stocking densities of 0.5 to 6.0 l of oysters/cylinder occupied between 1.3 and 15.6% of the total volume of a cylinder (42.2 l/cylinder). All cylinders were deployed in the Hawkesbury River, NSW (33° 30'S; 151° 15'E), on a growing lease at a similar height (intertidal) to that used for growing Sydney rock oysters on sticks (Malcolm, 1987; Holliday et al., 1988).

At the completion of the experiment, the shells of dead oysters were examined for mudworm blisters and burrows. Total numbers of spat at stocking and harvest times were estimated by dividing total weight per cylinder by the average weight. This data was then used to estimate percentage mortality at harvest. Final average individual spat weight was estimated by weighing 100 randomly selected live individuals per replicate and average individual shell length by measuring 50 shell lengths per replicate. The total weight of all oysters in each replicate was used to calculate final biomass and biomass gain. Initial and final volumes of oysters were measured (after immersion to fill cavity volume) using a large calibrated measuring cylinder (1.0±0.005 l). The experiment ran for 120 days (February to May 1990) based on the recommended period between grading and thinning by Holliday et al. (1991), using sectionalised trays and that used by farmers for other nursery units.

Statistical Analysis

For each grade, differences between treatments were assessed using one-way ANOVA as the number of densities within grades were different. Homogeneity of variance was evaluated using Cochran's Test (Winer, 1971) and means were compared using Tukey's *w* (Winer, 1971). To satisfy the assumption of normality and/or homogeneity of variance, volume increase data for the smaller grade were transformed (log x) and mortality data for both grades were transformed (arcsine $x^{0.5}$) prior to ANOVA. Coefficient of variation (100 x SD/x; Sokal and Rohlf, 1981) for both weight gain and shell length increase was calculated as an indicator of size variation of oysters within each treatment. Simple one parameter models were used to describe the data for both grades. For weight gain and length increase, exponential models ($y=e^{a+bx}$) gave the best fit.

RESULTS

Mortality for the smaller grade (11.7±1.1%, range 9.7-15.2%) was unaffected by stocking density (P>0.05). For the larger grade, spat mortality was similar (22.5±2.3 range 19.3-25.1%; P>0.05) for stocking densities of 0.5-4.0 of oysters/cylinder but higher (33.3±1.7%; P<0.05) for 6 l/cylinder. No mudworm blisters and burrows were found in the shells of dead oysters. Maximum individual spat weight gain was recorded at densities of 0.5 and 1.0 l/cylinder for the smaller and larger grades respectively. For the smaller grade, average individual spat weight gain and average individual shell length increase declined ($P<0.001$) from 2.5±0.03 to 0.6±0.04 g/spat and 18.6±0.3 to 7.0±0.7 mm/spat respectively with increasing stocking density of 0.5 to 4.0 l of oysters/cylinder (Figs. 3A, 3B). Similarly, for the larger grade, average individual spat weight gain and average individual length increase declined ($P<0.001$) from 3.3±0.02 to 1.2±0.03 g/spat and 17.1±0.3 to 9.7±0.4 mm/spat respectively by increasing density from 0.5 to 6.0 l of oysters/cylinder (Figs. 4A, 4B).

Maximum biomass gain and volume increase were recorded for both grades at the highest densities. For the smaller grade, biomass gain and volume gain increased from 2.7±0.2 to 4.7±0.1 kg of oysters/cylinder and 5.7±0.2 to 11.1±0.5 l of oysters/cylinder respectively with increasing stocking density of 0.5 to 4.0 l of oysters/cylinder (Figs. 3C, 3D). Similarly, for the larger grade, biomass gain and volume increase both increased with density from 1.6±0.02 to 4.8±0.1 kg of oysters/cylinder and 3.2±0.2 to 11.2±0.2 l of oysters/cylinder respectively with increasing stocking density of 0.5 to 6.0 l of oysters/cylinder. Differences between the two lowest densities were not significant ($P>0.05$) for length increase (smaller and larger grades) and weight gain (large grade; Figs. 4C, 4D).

Coefficient of variation for weight gain and shell length gain increased with stocking density for both grades ($P<0.001$). For the smaller grade, coefficient of variation for weight gain and shell length gain increased from 33.9±1.9 to 101.4±7.5 and 13.2±0.6 to 32.0±1.4 respectively as stocking density increased from 0.5 to 4.0 l of oysters/cylinder (Figs. 3E, 3F). For the larger grade, coefficient of variation for weight gain increased from 29.7±1.3 to 66.1±3.5 by increasing stocking density from 0.5 to 4.0 l of oysters/cylinder and shell length gain increased from 11.1±1.2 to 20.1±1.5 by increasing stocking density from 0.5 to 6.0 l of oysters/cylinder (Figs. 4E, 4F).

DISCUSSION

Cylinders were suitable for nursery culture of juvenile Sydney rock oysters ranging in average shell length from 14 to 32 mm. The rotating action of the cylinder with tidal movement appeared to reduce the build-up of silt on the oysters thereby eliminating the need to regularly wash the crop and minimising the risk of mudworm infestation (Skeel, 1979; Holliday et al., 1988). This is a major advantage in estuaries with a heavy silt load where silt deposits on oysters impedes their cultivation on trays.

Although mortality was unaffected ($P>0.05$) by mudworm or stocking density (with the exception 6 l of oysters/cylinder for the larger grade), spat growth declined with increasing density and biomass gain did not increase significantly at the three highest densities for each grade. This indicates that densities should be reduced periodically to optimise production. However, operating costs associated with retrieving, grading, sorting (live and dead), restocking (thinning crop) and securing cylinders back on the lease, are important considerations when choosing a stocking density. Newkirk (1981) found large variations in spat sizes in the first year for the European oyster (*Ostrea edulis*) and recommended culling a small percentage of each batch if the gains after labour costs for grading were warranted. Spencer et al. (1985) found that labour and equipment, accounted for 25% of operating costs in the first year of growth and Neudecker (1981) recommended altering densities every 2-3 weeks. Holliday et al. (in press) considered this excessive for Sydney rock oysters in nursery trays and altered densities every three to five months in a 12 month experiment.

When determining optimum stocking densities for juvenile Sydney rock oysters in PVC cylinders, a number of criteria need to be examined. Ultimately, optimum stocking density should be based on economic considerations (Maguire and Leedow, 1983; Holliday et al., in press) as it is important to have cost effective usage of nursery units and lease space. However, data for a comprehensive economic analysis of single seed culture based on Sydney rock oysters were not available. If initial costs of spat are high, then the appropriate criteria for optimum stocking density should be survival then maximum individual spat weight gain. Spencer et al. (1985) when estimating costs of trials using single Pacific oysters (*Crassostrea gigas*), found that the purchase of hatchery spat accounted for 59% of production costs in the first year of growth, but concluded that the small advantage in growth with low stocking densities, may be outweighed by the extra costs of labour and equipment.

Using an economic model for European and Pacific oysters, Askew (1978) found that growing time to market size was crucial for the viability of an operation as smaller slow growing oysters (10% of the crop) required three times the growing period to reach market size. Neudecker (1981) also concluded that for juvenile Pacific oyster spat, maximum spat growth was the best criterion for optimum stocking density as rapid growth allowed for a quicker transfer from smaller to larger mesh trays and spat required a shorter growing period to reach market size.

Holliday et al. (in press) used maximum biomass gain as a criterion to determine optimum stocking density for juvenile Sydney rock oysters in sectionalised nursery trays, as in NSW, the initial cost of spat harvested from collectors with natural catch is relatively low (Holliday et al., 1988), while capital and labour costs for tray culture are high (Marshall and Espinas, 1987). Based on production results for nursery trays (Holliday et al., in press), operating costs, including lease infrastructure, capital and labour are higher for cylinders than for trays.

To optimise biomass gain, while maintaining high individual weight gain and shell length increase, and minimising size variation, stocking densities of 2.0 and 3.0 l of oysters/cylinder, should be used for oysters of a similar size to the smaller and larger grades used here.

ACKNOWLEDGMENT

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Fig. 1. PVC nursery cylinders in the Hawkesbury River, NSW, used for growing juvenile Sydney rock oysters. The cylinders are fixed to hardwood frames elevated off the estuary bottom by timber posts. Oysters in the cylinders are submerged for about 90% of the time compared with about 70% for those on the traditionally used timber trays deployed on similar frames at the same growing height.

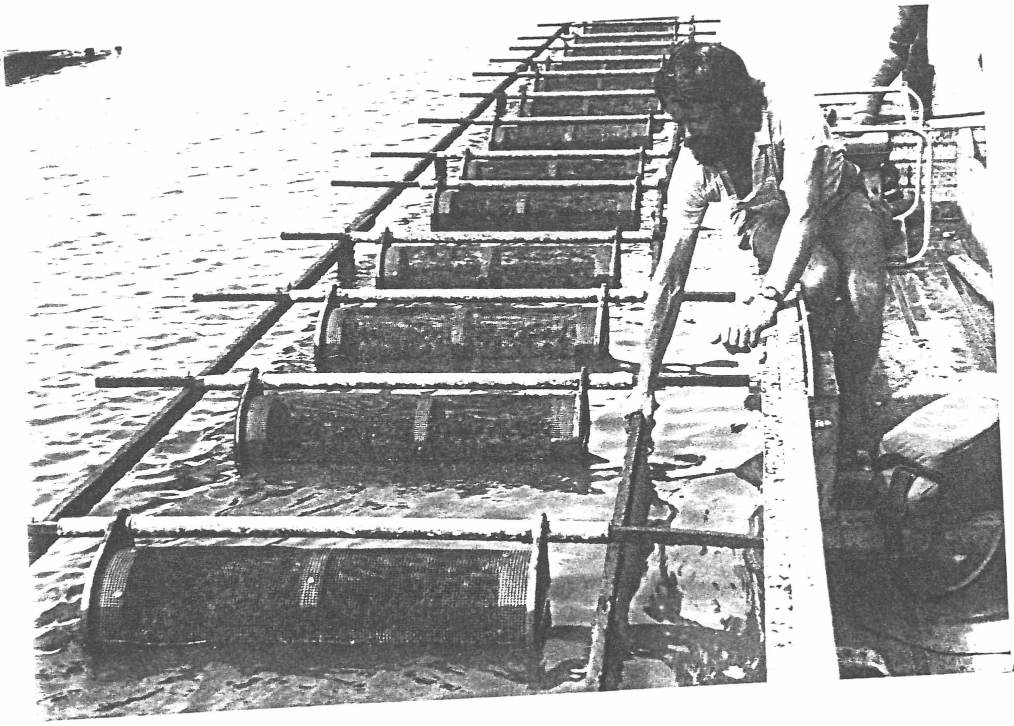
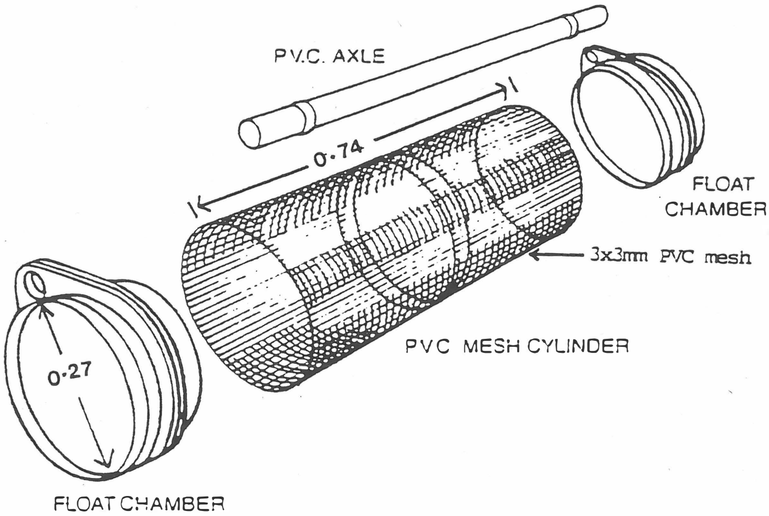
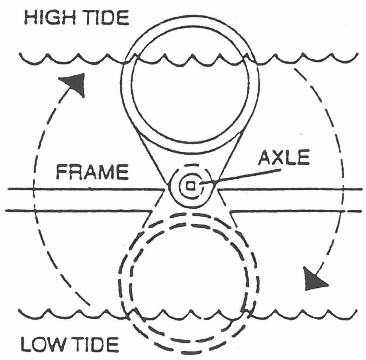


Fig. 2. PVC cylinder for oyster nursery culture: A) An exploded view of the cylinder, B) The rotating action of the cylinder.


P.V.C. AXLE
0·74
FLOAT CHAMBER
3x3mm PVC mesh
0·27
PVC MESH CYLINDER
FLOAT CHAMBER

A.


HIGH TIDE
FRAME
AXLE
LOW TIDE

B.

Fig. 3. Effects of stocking density on the smaller grade (average 0.2 g $spat^{-1}$ and 13.5 mm $spat^{-1}$) of juvenile Sydney rock oysters (*Saccostrea commercialis*) in PVC cylinders: A) weight gain, B) shell length increase, C) biomass gain, D) volume increase E) coefficient of variation for weight gain data, and F) coefficient of variation for shell length increase data. Symbols represent means and vertical bars standard errors of the means (n=4). Means with a similar letter are not significantly different ($P>0.05$).

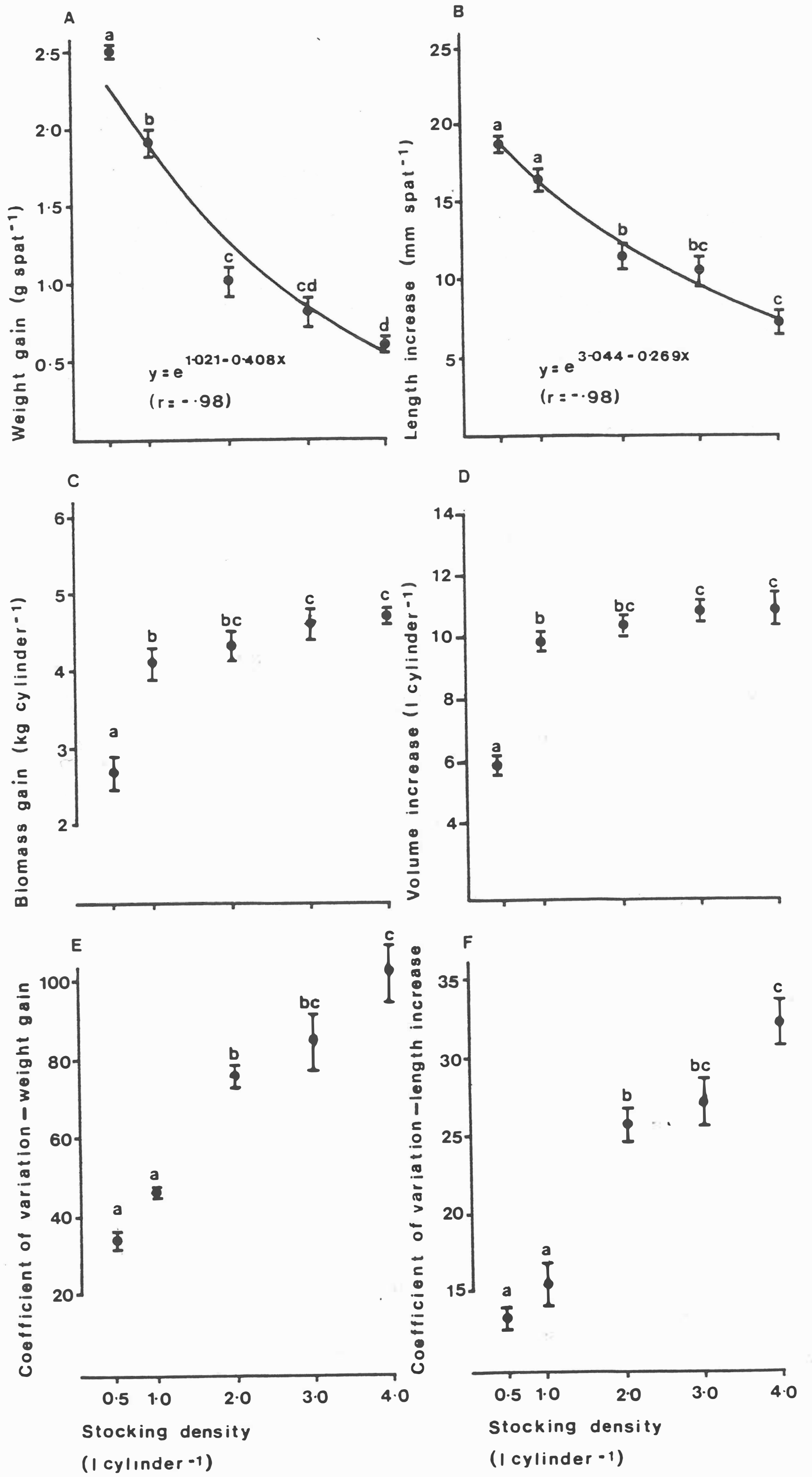
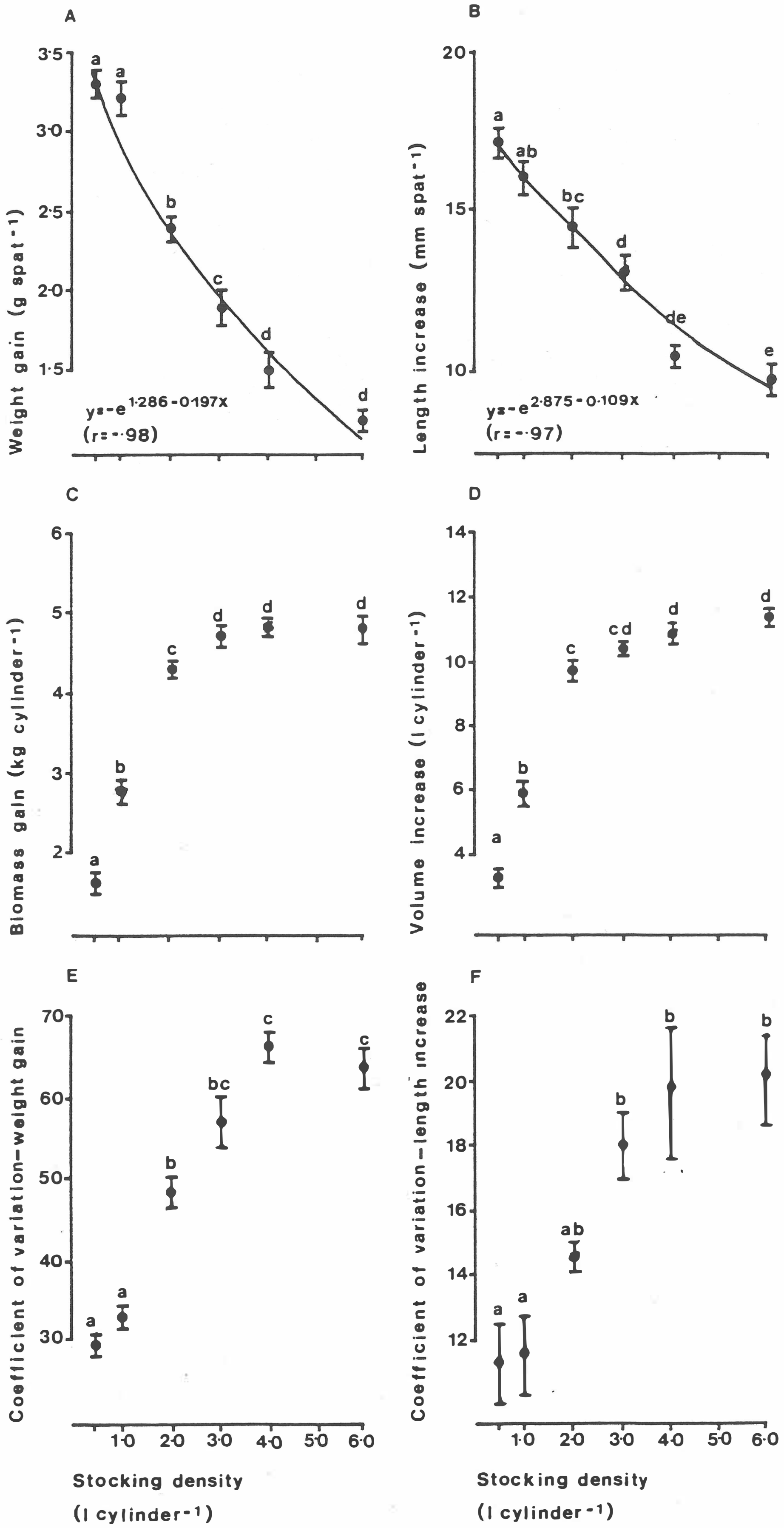

A
a
b
c
cd
d
2·5
2·0
1·5
1·0
0·5
Weight gain (g spat⁻¹)
y = e^1·021-0·408x
(r= -·98)
B
a
a
b
bc
c
25
20
15
10
5
Length increase (mm spat⁻¹)
y = e^3·044-0·269x
(r= -·98)
C
6
5
4
3
2
Biomass gain (kg cylinder⁻¹)
a
b
bc
c
c
D
14
12
10
8
6
4
Volume increase (l cylinder⁻¹)
a
b
bc
c
c
E
100
80
60
40
20
Coefficient of variation - weight gain
a
a
b
bc
c
F
35
30
25
20
15
Coefficient of variation - length increase
a
a
b
bc
c
0·5
1·0
2·0
3·0
4·0
Stocking density
(l cylinder⁻¹)
0·5
1·0
2·0
3·0
4·0
Stocking density
(l cylinder⁻¹)

Fig. 4. Effects of stocking density on the larger grade (average 0.4 g $spat^{-1}$ and 18.2 mm $spat^{-1}$) of juvenile Sydney rock oyster (*Saccostrea commercialis*) in PVC cylinders: A) weight gain, B) shell length increase, C) biomass gain, D) volume increase E) coefficient of variation for weight gain data, and F) coefficient of variation for shell length increase data. Symbols represent means and vertical bars standard errors of the means (n=4). Means with a similar letter are not significantly different (P>0.05).



A
B
C
D
E
F
Weight gain (g spat⁻¹)
Length increase (mm spat⁻¹)
Biomass gain (kg cylinder⁻¹)
Volume increase (l cylinder⁻¹)
Coefficient of variation–weight gain
Coefficient of variation–length increase
y=-e1·286-0·197x
(r=-·98)
y=-e2·875-0·109x
(r=-·97)
Stocking density
(l cylinder⁻¹)

SECTION 5

GROWING UNITS

An assessment of hatchery settlement techniques and nursery units for Sydney rock oysters, *Saccostrea commercialis*

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ABSTRACT

Holliday, J. E., Allan, G. L. and Diver, L. P. An assessment of hatchery settlement techniques and nursery units for Sydney rock oysters, *Saccostrea commercialis*.

Four experiments were conducted to assess hatchery settling techniques and nursery systems for the Sydney rock oyster (*Saccostrea commercialis*). Settlement was assessed using PVC collectors in a commercial fibreglass tank and chips of scallop shell in a downweller system. The preformance of various grades juvenile oysters (0.7, 0.9 and 1.25 mm) was assessed from discs, trays and cylinders, deployed on an intertidal lease, and from a commercial on-shore upweller nursery.

Similar and commercial settlement of Sydney rock oysters was obtained on PVC discs (57.0±12.75% of larvae stocked) in a fibreglass tank, and on chips of scallop shell in a downweller system (59.4±1.5% of larvae stocked). For discs, layer had no effect ($P>0.05$) on settlement (755.5±35.9 spat/disc).

The best growth was on PVC discs (increase in shell length 5.7±0.5 mm/spat; range 1.8-12.4 mm/spat), 61 days after deployment, however, spat survival was poor (4.6±0.7%), although post-harvest survival was high (92.6±0.5%).

Average spat growth for combined grades stocked was higher ($P<0.05$) in trays (3.0±0.2 mm) than cylinders (2.6±0.2 mm). At harvest, spat survival in cylinders (43.4±7.3%), was higher ($P<0.05$) than trays (24.5±4.1%) with higher numbers ($P<0.05$) of spat retained in cylinders (60.1±9.5%) than trays (39.8±8.4%). A wide range of spat sizes were harvested from trays and cylinders (range 1.8-12.4 mm/spat).

The best spat survival (69.3±0.7%) and the highest retention (97.7±1.0%) were recorded from upwellers, located at the inlet to the Vales Point Power Station, Lake Macquarie, however, growth was poor (average increase in shell length 1.6±0.01

mm/spat) and variances high (range 0.7-12.4 mm/spat).

INTRODUCTION

Numerous techniques are used throughout the world to settle oyster larvae from hatcheries and natural spatfall and on-grow the juvenile oysters (spat) to harvest (Dupuy and Rivkin, 1972; Korringa, 1976; Holliday, 1985; Quayle, 1988). Traditional hatchery methods of setting spat on chips of scallop shell in downweller units (O'Sullivan and Wilson, 1976; Holliday, 1985; Jones and Jones, 1988) and ongrowing them through the nursery phases in upwellers have been widely used (Bayes, 1981; Lucas and Gerard, 1981; Claus et al., 1983; Jones and Jones, 1988). However, recent advances with a technique of settling oysters on substrata including discs, plastic sticks and whole oyster shell, for the nursery grow-out phase (Curtin, 1985; Jones and Jones, 1988), have produced viable and often cost effective results (Gunn, 1984). Other nursery systems used for spat production include lantern nets, submerged trays (Lucas and Gerard, 1981), intertidal sectionalised trays (Holliday et al., in press "a") and PVC cylinders (Holliday et al., 1988).

In recent years the industry has seen further development of new and existing hatchery settling and nursery systems, often without comparison. Similar growth rates of spat have been obtained from upwellers and submerged trays, with the best results from equipment that allowed maximum water flow (Lucas and Gerard, 1981). However, evaluating the various commercial nursery systems which operate under different conditions is difficult (Claus, 1981; Lucas and Gerard, 1981). Claus (1981), stated that due to the low margin of profit in commercial nurseries, slight variations in variable operating costs, may determine the viability of the operation.

The objectives of this study were firstly to assess settlement of Sydney rock oyster larvae on discs in a large fibreglass tank and on chips of scallop shell in a downweller system and secondly to evaluate spat performance on discs, in sectionalised trays, PVC cylinders and upwellers.

MATERIALS AND METHODS

Terminology

Settlement - defined as the numbers of oysters and barnacles which attached and were retained on the collectors in the period from deployment until settlement had largely ceased.

Recruitment - defined as the numbers of oysters retained on collectors from the end of settlement to the termination of the segment or experiment.

Larvae

For Experiment 1, larvae of the Sydney rock oyster were produced using established hatchery techniques (Walne, 1974; Holliday, 1985) in 20 000 l fibreglass tanks. Water temperature was maintained at (x±SE) 25.0±0.1°C and salinity at 30.0±0.2‰. The number of pediveliger larvae was estimated by counting subsamples (n=4) on a Sedgewick-Rafter and larvae from the same batch were stocked in a fibreglass tank (Segment 1) and downweller settling system (Segment 2).

Settling systems

For Experiment 1, Sydney rock oyster settlement was evaluated using the two main hatchery settling systems including settling larvae on PVC collectors in a commercial size tank and on chips of scallop shell in a downweller system.

Grading

Following larval settlement in the downweller system (Experiment 1, Segment 2), and after harvesting juvenile Sydney rock oysters (spat) from the nursery various systems including discs (Experiments 2), trays and cylinders (Experiment 3) and upwellers (Experiment 4), spat were graded with nylon and PVC screens. The nominal screen sizes (0.5, 0.7, 0.9, 1.7, 3, 4, 8 and 12 mm) are used throughout the manuscript to indicate spat sizes. To avoid spat losses during grow-out, the nominal screen size for harvesting juvenile spat is 4 mm when stocking on commercially used nursery units with 3.0 mm mesh (Holliday et al., in press "a"). For actual screen measurements and the size of spat retained on screens see Table 1.

Nursery systems

Juvenile Sydney rock oysters from Experiment 1 were deployed in four different nursery systems for evaluation of spat performances and nursery systems. It was not feasible to establish all treatments at both sites as there was no electricity to operate upwellers (Bayes, 1981) at North Arm Cove and the inlet at the power station was unsuitable for trays and cylinders due to the current velocity and depth of water (Holliday et al., in press "b"), so two sites were chosen to assess growth and survival in the four nursery systems. Disc, trays and cylinders were deployed at North Arm Cove, Port Stephens, NSW (32° 40' S; 152° 04' E) and upwellers at Vales Point Power Station, Lake Macquarie, NSW (33° 05' S; 151° 48' E).

Experiment 1 - Larval settling systems

Segment 1 - Fibreglass tank

Larvae were stocked at 39.6±1.2 x 10^4 in a fibreglass tank (2.4 x 1.6 x 0.9 m; 3000 l), similar to those used in commercial operations (Jones and Jones, 1988). A total of 300 discs (15 stacks x 20 layers) were deployed vertically on the tank floor. Each interlocking disc (20 x 140 mm) with wall thickness of 1 mm and surface area of 275 cm^2 was separated vertically by a 25 mm gap. Discs were aged for more than 12 months to optimise settlement (Gunn,1984; Jones and Jones, 1988). Light was eliminated from the tank to reduce the phototropic response of larvae and to encourage even settlement on all layers and surfaces of the discs (Ritchie and Menzel, 1969; Jones and Jones, 1988). An equal mix of the algae *Pavlova lutheri* and *Isochrysis* aff. *galbana* (clone T-iso; termed Tahitian *Isochrysis*) was fed twice daily at 88.9±3.9 x 10^3 cell/ml and water was exchanged every 48 h.

For Experiment 1, salinity and temperature were maintained at 30.2±0.1‰ at 25.1±0.5°C respectively for the nine day duration of the experiment. Settlement determined by counting spat on each disc.

Segment 2 - Downweller units

For Segment 2, four PVC downweller units (450 diam x 150 mm depth) were used to evaluate spat settlement, a technique described by Wilson (1976); Jones and Jones (1988) and Holliday (1985). Each unit had a layer (1 cm) of scallop shell chips covering a nylon mesh screen (0.2 μ) and units were partially submerged in a fibreglass tank (1700 l), with seawater gently sprayed (0.8 l/min) into each screen. Larvae were stocked at 19.8±0.6 x 10^4/unit. Based on feed rates used commercially (Holliday, 1985), an equal mix of *Pavlova lutheri* and Tahitian *Isochrysis* was fed daily at 11.6±1.0 x 10^4 cells/ml, through the settlement and nursery phases. Water was partially exchanged daily with a total exchange every 48 h. Post-settled spat were washed twice daily with a light spray of sea water to remove detritus and faeces. At the completion of Segment 2, spat from each replicate were graded with 0.5, 0.7 and 0.9 mm nylon mesh screens and settlement for each grade estimated by volume and counting spat from 1 ml subsamples (n=4).

Experiment 2 - Discs.

For Experiment 2, initial size of spat was estimated at 0.95±0.01 mm by measuring 50 shell lengths. Initial density 755.0±1.0 spat/disc and was determined at settlement. Five replicate groups, each of three stacks of discs (3 x 20 discs/replicate) from the settlement tank were enclosed in a 12 mm PVC mesh bag, to reduce predation from fish and crabs. Discs were randomly allocated a position on rail supported by posts with the middle of each stack of discs occupying the mid-tidal and traditional growing level (Malcolm, 1987; Quayle, 1988). To ensure that overcatch of oysters did not compound results, natural settlement was assessed by regular deployment and inspection of additional stacks of discs.

Spat recruitment was recorded from one stack (20 discs) of each replicate group. Spat were flexed off the discs and graded. Live and dead spat were counted from a stack of each replicate group and grade. This stage of Experiment 2 ran for 41 days from January to February, 1988 and was terminated when spat were observed growing onto one another and as they had reached a suitable size for stocking on commercially used nursery trays (Holliday et al., in press "a').

Post-harvest mortality was then assessed by ongrowing spat from one stack of each replicate in cylinders (n=5; Holliday et al., 1988). Spat were stocked at

50% coverage of effective surface area of the cylinder, to minimise the effect stocking density has on growth and survival (Holliday et al., in press "a"). At the completion of Experiment 2, spat were graded using the following mesh sizes: 4.0, 8.0 and 12.0 mm, before separating and counting live and dead oysters. This stage of Experiment 2 ran for 35 days from February to March, 1988.

Experiment 3 - Sectionalised trays and cylinders

Spat from the downweller set system (Experiment 1, Segment 2) were sorted into three grades and initial spat numbers estimated by volume and by counting spat from 1 ml subsamples (n=4). Spat smaller than 0.7 mm were not used as they were too small for the mesh size covering the nursery units. Four replicates of each grade of spat were randomly allocated to a sectionalised tarred hardwood tray (1.94 x 0.94 m) each divided into 12 sections (0.12 m^2), and to 12 PVC cylinders (0.74 m length x 0.27 m diam). Both types of nursery units were covered with stainless steel mesh (0.5 mm^2). To minimise the effect stocking density has on growth and survival (Holliday et al., in press "a"), spat from the three grades (0.5, 0.7 and 1.25 mm) were stocked < 50% coverage of surface area at densities of 9375±1017, 31216±630 and 7251±81/replicate in that order.

Experiment 3 ran for 102 days from January to April, 1988 and was terminated when deterioration of the stainless steel mesh covering the nursery units was observed. Spat from each replicate was graded. Spat from grades >1.7 mm were counted and in the grades < 1.7 mm, estimated from dry weight and by counting spat from 1 ml subsamples (n=5).

Experiment 4 - Upwellers

Spat from Experiment 1 were graded with a 0.5 and a 0.7 mm screen. Spat numbers were estimated from volume and by counting spat in 1 ml subsamples (n=4). A total of $104.5 \pm 1.1 \times 10^4$, 0.5 mm and $12.2 \pm 0.1 \times 10^4$, 0.7 mm spat were stocked into two upweller units (450 diam x 150 depth) with 500 μ mesh screens and located at the power station inlet.

Spat were grown using a commercial management technique, which entailed regular grading and restocking at reduced densities in upweller units with larger screen sizes (Bayes, 1981). At harvest, spat numbers in each grade were estimated by counting the numbers of live and dead oysters from five replicate 1 ml subsamples (n=5). As with trays and cylinders, the experiment ran for 102 days from January to April, 1988.

Statistical analysis

For Segment 1 (Experiment 1), the effect of layer on settlement was assessed using one-way ANOVA. Survival and retention data for Experiment 3 was transformed (arcsine $x^{0.5}$) prior to ANOVA. In Experiment 3, growth, survival and retention of the various grades of spat stocked for trays and cylinders were compared using t-tests. Homogeneity of variance was confirmed using Cochran's test (Winer, 1971) and means compared using Tukey's honesty significant difference method (Sokal and Rohlf, 1981). Throughout this paper data are presented as $\bar{x}\pm$SE.

RESULTS

Experiment 1 - Larval settling systems

Segment 1 - Fibreglass tank

Average settlement was 755.5±35.9 spat/disc. Total settlement on the discs was equivalent to 57.0±12.7% of larvae stocked. Layer had no effect (P>0.05) on settlement with spat evenly distributed on the 20 layers of the discs.

Segment 2 - Downweller units

Average spat settlement on chips of scallop shell in the downweller system was similar to that of the fibreglass tank with 59.4±1.5% of larvae stocked settling. When graded with nominal screens, spat numbers included:< 0.5 mm screen, 0.8±0.1 x 10^3; 0.5 mm screen, 32.7±1.7 x 10^3; 0.7 mm screen, 41.3±1.9 x 10^3 and 0.9 mm screen, 20.2±2.2 x 10^3 (Table 2).

Experiment 2 - Discs.

The highest growth was on discs (shell length increase 5.7±0.5 mm, Table 3; range 3.1-19.9 mm) 61 days after deployment with spat were retrieved 41 days earlier than other treatments. Average recruitment was 127.5±1.0 spat/disc. All spat were retained on screens ≥ 1.7 mm with 50.2% retained on screens ≥ 4.0 mm screen (Table 4). Percentages of spat retained on 1.7, 3.0, 4.0 and 8.0 mm screens consisted of the following: 15.4±2.4%, 35.9±2.0%, 40.7±2.6% and 9.5±1.3% in that order (Table 4). However, survival at harvest (4.6±0.7% spat/disc) was poor (Table 3), probably due to a build-up of air, trapped under the centre of each disc with the rising tides. Total spat losses were high, partly due to spat overcrowding one another and dislodging themselves from the discs. Only 5.9±0.7%. of spat were retained on discs at harvest (Table 3). Post-harvest survival of spat was high (97.5±0.5%.; Table 5). Settlement of oysters and barnacles during this experiment were negligible.

Experiment 3 - Sectionalised trays and cylinders

Average shell length increase at harvest for combined grades stocked (0.7, 0.9 and 1.25 mm), was higher (P<0.05) in trays (3.0±0.2 mm) than cylinders (2.6±0.2 mm; Table 6). When stocked with the largest grade of 1.25 mm, spat growth in trays (3.8±0.2 mm) was higher (P<0.001) than cylinders (2.6±0.2 mm; Table 6). There was a wide range of spat sizes in both nursery units at harvest (range 1.7-8.0 mm; Table 4). For the three grades stocked, the percentage of spat retained on screens ≥ 4.0 mm screen varied greatly between trays (average 21.4%) and cylinders (average 11.9%; Table 4).

Average spat survival at harvest for combined grades stocked was higher (P<0.05) in cylinders (43.4±7.3%) than trays (24.5±4.1%; Table 3). Survival in cylinders when stocked with 0.9 mm and 1.25 mm spat, was higher (P<0.01; 40.9±15.9% 12.1±4.4% respectively) than trays (69.8±3.7%; 36.0±2.4% respectively; Table 6).

High spat losses were recorded at harvest from both trays and cylinders. For combined grades, spat numbers retained in trays were lower (P<0.05; 39.8±8.4%) than cylinders (60.1±9.5%; Table 3). When stocked with 0.9 mm and 1.25 mm spat, retention in cylinders was higher (P<0.05; 56.5±9.2%; 95.5±3.2% respectively) than trays (15.7±6.3%; 68.5±7.0% respectively; Table 6).

Experiment 4 - Upwellers

Survival and retention of spat in upwellers was excellent (69.3±0.7%; 97.7±1.0%. respectively; Table 3), however, growth was poor with an average increase in shell length over 102 days of 1.6±0.01 mm and with only 3.3% of spat retained on a 4 mm screen at harvest (Table 3). Average number of spat per upweller unit at harvest was 54041±523.

DISCUSSION

Both the fibreglass tank and the downweller settling systems had a commercially level of settlement of Sydney rock oysters. Although a similar number of larvae settled in each system, caution must be used when comparing the systems as the stacks of discs were not independent of one another and thus not replicated. However, the result is encouraging for farmers anticipating settling Sydney rock oysters on PVC collectors, for immediate deployment on their intertidal nursery leases. In North America, there has been wide acceptance of the technique of delayed or remote setting Pacific oyster larvae using large fibreglass tanks and various substrata including old oyster shells and PVC sticks (Jones and Jones, 1988; Roland and Broadley, 1990; Holliday et al., in press "c"). The settled collectors are deployed on oyster leases for on-growing, thus minimising the high labour costs associated with the on-shore nurseries with upwellers.

Upwellers proved to be the most suitable nursery unit for growing juvenile hatchery spat of 0.7 mm, based on the high survival (69.3%) and retention (97.7%). As trays and cylinders could not be established at both sites, caution must be used when comparing spat performances from the various nursery units. Oyster retention and survival was highest in upwellers at the inlet to the Vales Point power station, although, growth was poor. The present study was conducted during the summer period, however, a comparative study of spat (initial weight 1.6 g) during winter, using sectionalised trays at an intertidal site in Port Stephens and upwellers at the same inlet site, showed the best growth and survival from the upwellers (Holliday et al., in press "b"). Although survival from upwellers was high for this study, subsequent survival of spat settled on scallop shell chips has been consistantly low at a number of nursery sites in NSW, including the outlet site at Vales Point Power Station (Nell et al., unpublished data).

The best growth was recorded from discs at an estuarine lease in North Arm Cove, Port Stephens, where both retention and survival (4.6± 0.7%) were low. However, better survival (66%) was recorded over a similar period of the year from discs deployed closer to the entrance and in the natural catch area of Port Stephens, (Holliday, 1989, unpublished data). Bayes (1981), reported that turbidity affected growth and survival of juvenile Pacific oyster spat (*Crassostrea gigas*) and that nursery sites with the lowest silt load had the highest survival. High salinities (33.6±1.4‰; Holliday et al., in press "b") and low silt loads (3.6±0.7 mg/l total suspended solids) have been recorded at the nursery site at Vales Point power station (Holliday, 1987, unpublished data).

Although spat growth in trays and cylinders was better than upwellers, it is not feasible to stock trays with < 1.25 mm spat, or cylinders with < 0.9 mm spat as survival and retention were low (Table 6). Oyster losses from trays and cylinders are unexplained, however, it appears that the shells of dead oysters were ground up with movement over the steel mesh screens, caused by wave action.

A wide range of spat sizes in a nursery system in undesirable as it increases the necessity for grading and increases costs (Newkirk, 1981; Askew, 1987; Holliday et al., in press "a"). Although all nursery systems in this study had a wide range of spat sizes at harvest (Table 4), the highest proportion of spat retained on screens ≥ 4.0 mm, the optimal harvest size for commercial use, were from discs (50.2%), followed by trays (21.4%), cylinders (11.9%) and upwellers (3.3%).

After 102 days exposure to salt water, corrosion was observed in the stainless steel mesh covering the trays and cylinders and is considered unsuitable for commercial oyster culture.

This study demonstrated that commercial sets of Sydney rock oysters could be obtained by using discs in fibreglass tanks and chips of scallop shell in a downweller system. The on-shore upwellers proved to be the most reliable nursery system, although spat settled on PVC discs had the highest growth rates. It is possible that spat losses from trays, cylinders and discs could have been reduced by selecting a different nursery site. Further research is needed to investigate the the recent high mortalities of spat in upwellers and as operating costs, coastal space and energy becomes more expensive, on-shore nurseries will have to be further evaluated (Lucas and Gerard, 1981; Claus, 1981).

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TABLE 1

Size of Sydney rock oysters *Saccostrea commercialis*, and screens used for grading experiments.

	Screen Sizes (mm)		Spat Sizes (mm)	
Nominal	Measured		Shell Lengths	
	$\bar{x}\pm$SE	Ranges	$\bar{x}\pm$SE	Ranges
0.5	0.6±0.01	0.5-0.7	0.9±0.01	0.7-1.2
0.7	0.9±0.01	0.9-1.0	1.2±0.02	0.8-1.5
0.9	1.2±0.01	1.1-1.2	1.4±0.02	1.0-1.8
1.25	1.7±0.01	1.7-1.8	2.2±0.03	1.6-2.7
1.7	1.4±0.1	1.2-1.6	2.3±0.1	1.8-2.9
3.0	2.9±0.9	2.3-3.4	4.1±3.1	3.0-5.5
4.0	5.0±1.0	4.2-6.1	5.2±0.1	3.9-7.7
8.0	9.4±0.3	8.9-9.9	8.5+0.2	5.8-12.4
12.0	12.6±0.1	11.6-14.5	12.6±0.2	8.8-17.2

TABLE 2

Production data for Sydney rock oyster larvae *Saccostrea commercialis*, settled on scallop shell chips in a downweller unit (Experiment 1, Segment 2)[1]

Nominal Screens[2] (mm)	Number of Spat		
	Live[3] ($x10^3$)	Dead[3] ($x10^3$)	Clumps[3,4]
<0.5	0.8 ± 0.1	7.2 ± 0.4	0
0.5	32.7 ± 1.7	5.0 ± 0.2	44.8 ± 9.7
0.7	41.3 ± 1.9	1.6 ± 0.2	413.8 ± 69.8
0.9	20.2 ± 2.2	0	601.6 ± 42.0

1 Larvae were stocked at 19.8±0.6 $x10^4$/downweller unit and settlement recorded after 12 days.
2 Nominal pore size of screen used to grade spat. Spat< 0.5 mm passed through the 0.5 mm screen.
3 Values are $\bar{x}$±SE (n=4 replicate downweller units).
4 Scallop shell chips with two or more spat attached.

TABLE 3

Average growth, survival and retention of juvenile Sydney rock oysters *Saccostrea commercialis*, for combined grades stocked in various nursery units (Experiments 2, 3 & 4).

Nursery System	Shell Growth[1] (length mm)	Survival[1] (%)	Retention[1,2] (%)
Discs	5.7 ± 0.5	4.6 ± 0.7	5.9 ± 0.7
Trays	3.0 ± 0.2	24.5 ± 4.1	39.8 ± 8.4
Cylinders	2.6 ± 0.2	43.4 ± 7.3	60.1 ± 9.5
Upwellers	1.6 ± 0.01	69.3 ± 0.7	97.7 ± 1.0

1 Values are $\bar{x} \pm SE$.
2 Total spat retained in the nursery system at harvest.

TABLE 4

Size distribution of Sydney rock oysters *Saccostrea commercialis*, harvested from various nursery units (Experiments 2, 3 & 4).

Size Ranges Stocked (mm)	Size Ranges of Spat at Harvest (mm)				
	0.5	1.7	3.0	4.0	8.0
	Size distribution of spat (%)[1,2]				
Discs					
0.95	-	15.4± 2.4	35.0±2.0	40.7± 2.6	9.5±1.3
Trays					
0.7	-	91.3± 8.2	6.2±5.6	2.1± 2.0	0.4±0.5
0.9	-	43.8±15.6	23.6±7.1	27.5± 9.3	5.2±1.5
1.25	-	53.6± 6.4	17.5±5.6	23.2± 2.6	5.8±0.7
Cylinders					
0.7	-	61.0±18.9	18.0±4.6	17.8±12.0	3.2±2.3
0.9	-	84.6± 9.8	10.1±5.9	4.8± 3.6	0.5±0.3
1.25	-	73.4± 2.5	17.1±1.9	7.2± 0.6	2.3±0.2
Upwellers					
0.6	3.4±0.1	72.2± 0.6	21.0±0.3	2.6± 0.1	0.7±0.1

[1] Values are $\bar{x}$±SE.
[2] Spat from various nursery units graded on nominal screens.

TABLE 5

Survival of Sydney rock oyster spat *Saccostrea commercialis*, harvested from discs (Experiment 2).

Screen sizes (mm)	Spat per grade[1] (%)	Survival[1,2] (%)
4.0	11.5 ± 1.6	99.5 ± 0.1
8.0	35.2 ± 1.8	97.7 ± 0.8
12.0	53.4 ± 3.3	95.4 ± 0.7

1 Values are $\bar{x} \pm SE$. Initial spat numbers per cylinder were 3266.6±452.4.

2 Spat survival after harvest from discs and ongrown for four weeks in cylinders.

TABLE 6

Performance of juvenile Sydney rock oysters *Saccostrea commercialis*, stocked at various grades in trays and cylinders (Experiment 3)[1,2]

Initial Grade (mm)	Increase shell length (mm)		Survival (%)		Retention (%)	
	Tray	Cylinder	Tray	Cylinder	Tray	Cylinder
0.70	2.0±0.2	2.9±0.6	25.5±5.0	19.6± 7.4	35.2±5.2	28.5±11.9
0.90	3.3±0.4	2.2±0.3	12.1±4.4	40.9±15.9[a]	15.7±6.3	56.5± 9.2[a]
1.25	3.8±0.2	2.6±0.1[a]	36.0±2.4	69.8± 3.7[a]	68.5±7.0	95.5± 3.2[a]
Average for all grades	3.0±0.2	2.6±0.2[a]	24.5±4.1	43.4± 7.3[a]	39.8±8.4	60.1± 9.5[a]

1 Values are $\bar{x}\pm$SE. [a] indicates significant ($P<0.01$) differences.
2 Within columns, means with a common superscript do not differ significantly ($P>0.05$).

Comparison of three growing units for the cultivation of Sydney rock oyster (*Saccostrea commercialis*) spat in the Hastings River, NSW.

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ABSTRACT

Holliday, J. E. and Nell, J. A. Comparison of three growing units for the cultivation of Sydney rock oyster (*Saccostrea commercialis*) spat in the Hastings River, NSW.

Average whole weight of Sydney rock oysters (*Saccostrea commercialis*) grown in the Hastings River, NSW, in baskets was higher (14.2 g) than that of oysters grown in sectionalised trays (11.6 g), which in turn was higher than that of oysters in cylinders (9.8 g). Mortality was lowest for oysters grown in trays (9.2%), followed by oysters in baskets (23.8%), while those in cylinders showed the highest mortality (77.8%). The incidence of mudworm (*Polydora websteri*) infestation of oysters grown in trays, baskets and cylinders was 2.5, 22.5 and 94.1% respectively.

INTRODUCTION

Sydney rock oysters (*Saccostrea commercialis*) have traditionally been grown on sticks until they are between three and four years old (Malcolm, 1987). When they are knocked off the sticks, the plate grade (>40 g) oysters are sold and the smaller grades put on trays for on-growing (Malcolm, 1987). Since 1985, New South Wales (NSW) oyster farmers have been stocking smaller oysters (4-10 mm) on sectionalised trays (Holliday, 1985). This system has been extensively tested in Port Stephens, NSW (Holliday et al., 1991a, b). Rotating mesh cylinders were developed during the past decade for culturing oysters for estuaries where high silt loads in the water have led to a high incidence of mudworm infestation (Anonymous, 1985; Holliday et al., 1988) and cylinders have also been used successfully in the Nambucca River, NSW (Holliday, 1987) and the Hawkesbury River, NSW (Holliday et al., 1991c). A comparison of sectionalised trays and cylinders for the cultivation of Sydney rock oysters was made by Nell (1990) in Port Stephens, who found cylinders suitable for newly scraped-off spat, but reported slower growth rates for older oysters grown in cylinders, compared to those grown in sectionalised trays in the open and exposed waters of Port Stephens. Baskets made of folded plastic mesh, which have been used for over a decade in Tasmania (J. A. Nell, personal observation, 1980-1990), were first introduced into NSW by an oyster farmer, in 1989 (J. A. Nell, personal communication, 1990). The objective of this study was to compare three types of growing units for the cultivation of Sydney rock oyster spat (*Saccostrea commercialis*).

METHODS

The experiment was conducted in the Hastings River, NSW, 152° 50'S 31°25'E, from December 1989 to July 1990 (220 days).

The three growing units consisted of sectionalised trays, baskets and cylinders, with all units constructed with 9 mm plastic mesh. For each tray (n=4; 1.8 x 0.9 m), only two of the six compartments (270 x 875 mm) were stocked with spat. Cylinders (n=4; 0.73 x 0.27 m) were equally divided into two compartments by 9 mm PVC mesh (each with an effective surface of 220 x 350 mm) and all compartments stocked with spat. For each replicate, two folded mesh baskets (280 x 470 mm) were joined with two oyster sticks (1.8 m x 20 mm^2) with all baskets stocked with spat.

Compartments of trays, cylinders and baskets were stocked with 90, 50 and 30 Sydney rock oyster spat respectively, at densities that covered 25% of the usable surface area; this was well below the 70% tray coverage recommended for maximum biomass gain of Sydney rock oysters in sectionalised trays (Holliday et al., 1991b). The average whole weight and length of the spat at the start of the experiment was 4.1±0.9 g (x±SD; n=360) and 35.7±3.8 mm (x±SD; n=360) respectively.

Units were deployed on an intertidal timber rack, divided into two zones (split plot design) to allow for any differences in environmental conditions over the length of the rack. For each treatment, replicate units (n=2) were randomly allocated to a position in each zone. The trays and baskets were deployed with spat at the rack height used commercially, whereas cylinders, although deployed at rack height, were immersed for longer periods as they hung 300 mm below rack height during the ebb tides.

The whole weight and length of up to 30 oysters per nest were taken at the end of the experiment and up to ten oysters per nest were opened and examined for mudworm (*Polydora websteri*) infestation.

Statistical analyses

Homogeneity of variance was evaluated using Cochran's test and means compared using Tukey's *w* (Winer, 1971). Data from zones were combined for analayses as zone (assessed using two-way ANOVA) had no effect (P>0.05) on growth or survival. Mortality data was transformed (arcsin $x^{0.5}$) prior to ANOVA. Data was analysed with a one-way nested ANOVA and mean values compared using the "least significant differences technique" (Sokal and Rohlf, 1981).

RESULTS

Oysters in the baskets were significantly ($P<0.05$) heavier (14.2 g) than those in the trays (11.6 g) which in turn were significantly heavier ($P<0.05$) than those in the cylinders (9.8 g; Table 1). The length of the oysters in the trays (53.1 mm) did not differ significantly ($P>0.05$) from those in the baskets (52.6 mm) but those in the cylinders had smaller ($P<0.05$) shell lengths (39.9 mm; Table 1).

Oysters in the cylinders suffered a higher ($P<0.05$) mortality (77.8%) than in the baskets (23.8%), or trays (9.2%; Table 1). Infestation of surviving oysters with mudworm was higher ($P<0.05$) in cylinders (94.1) than in baskets (22.5%) or trays (2.5%; Table 1). Oysters in the baskets and cylinders were heavily covered in hairy mussels (*Trichomya hirsuta*) and in many instances oysters and mussels had clumped together at the end of the experiment. No mussels were found on the oysters in the trays.

DISCUSSION

Although at the same intertidal height, the higher growth rates of oysters grown in baskets compared to those in sectionalised trays, may have resulted from a more restricted water flow as trays compartments were divided with timber partitions. Lucas and Gerard (1981) found comparing oyster growth rates in two nursery systems, that the best growth was obtained from systems that allowed maximum water flow. Oyster growth rates in the cylinders may have also been affected by the high incidence of mudworm infestation (94.1%) and the regular rumbling in cylinders which can remove the new growing edge (frill) from the shell. Lower growth rates for oysters in cylinders compared to those grown in trays were also reported from an experiment in Port Stephens, NSW (Nell, 1990).

The high mortality for oysters grown in the cylinders (77.8%) was likely to have been caused by mudworm as indicated by the high level (94.1%) of mudworm shell blisters in the survivors (Skeel, 1979; Holliday et al., 1988; Table 1). This infestation was likely to have been caused by the longer immersion time of oysters in cylinders compared to those grown in the trays or baskets (Skeel, 1979). Wisely et al. (1979a) also attributed the high mortality (55%) of Sydney rock oysters grown subtidally in trays to mudworm infestations. The presence of hairy mussels on oysters in the baskets and cylinders may also have assisted the spread of mudworm, as the clumping of oysters and mussels increased silting and moisture retention on oysters, affection their ability to dry and destroy the worm with exposure at low tide (Skeel, 1979). It is not clear why oysters in the baskets and not trays were affected by mussel overcatch. It seems probable that the heavier mortality of oysters in the cylinders and baskets resulted from the heavy catch of mussels.

Caution must be exercised when applying the results from this study to other estuaries as the variables including disease, parasites, floods and fouling organisms which affect growth and mortality of oysters, change between estuaries (Wisely et al., 1979b). A separate study during the same period, reported excellent growth and survival rates for Sydney rock oyster spat grown at a number of densities in cylinders in the Hawkesbury River, NSW (Holliday et al., 1991c).

Although the growth rates for oysters in cylinders were lower than for those grown in either trays or baskets, cylinders are widely used by the NSW industry for newly scraped-off spat or small (4-6 mm) hatchery spat (Holliday et al., 1988). If oysters are grown below normal rack height, such as was the case with the cylinders in this experiment, care must be taken to avoid areas affected by mudworm and hairy mussels.

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TABLE 1

Comparison of performance of Sydney rock oyster (*Saccostrea commercialis*) spat grown intertidally in sectionalised trays, baskets or cylinders in the Hastings River, NSW, December 1989 to July 1990.[1]

Growing units	Performance indicators of oysters at end of experiment[2]			
	Whole weight (g)	Length (mm)	Mortality[4] (%)	Worm[3,4] (%)
Sectionalised trays	11.6±0.3[b]	53.1±1.7[b]	9.2±3.4[a]	2.5±4.6[a]
Baskets	14.2±1.1[c]	52.6±1.6[b]	23.8±10.5[b]	22.5±14.9[b]
Cylinders	9.8±1.3[a]	39.9±2.5[a]	77.8±9.7[c]	94.1±12.1[c]

1 Values are x±SD. Within each column, means with a common superscript do not differ significantly (P>0.05).

2 The whole weight and length of the oyster spat at the start of the experiment were 4.1±0.9 g (x±SD; n=360) and 35.7±3.8 mm (x±SD; n=360) respectively.

3 Mudworm (*Polydora websteri*) infestation in live oysters at the end of the experiment.

4 Data transformed arcsin $x^{0.05}$ prior to ANOVA.

SECTION 6

NURSERY UNITS

Evaluation of sites for nursery culture of single Sydney rock oysters, *Saccostrea commercialis*

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ABSTRACT

Holliday, J. E., Maguire, G. B. and Nell, J. A. Evaluation of sites for nursery culture of single Sydney rock oysters, *Saccostrea commercialis*.

Oyster spat growth and survival was measured at three sites and various conditions within Port Stephens, NSW. Survival of Sydney rock oyster spat over 12 months was high at 3 nursery sites (87.9±7.7%) but was significantly higher at Swan Bay than at North Arm Cove and Pindimar. Average weight gain (g/spat) was higher at North Arm Cove than at Swan Bay which was in turn a much better site for growth than Pindimar. Biomass gain (2.6±0.5 kg/m^2) was significantly lower at Pindimar than at other sites (5.8-6.0 kg/m^2). The best three month periods for spat growth at North Arm Cove and Swan Bay were August-October and February-April while the poorest period was May-July. Both these sites showed considerable potential as nursery sites.

Enhancement of spat growth rates was investigated during cooler months using heated effluent from the Vales Point Power Station, Lake Macquarie, NSW. Spat were grown for 18 weeks in sectionalised trays and/or in forced-flow upwellers at the inlet and outlet (effluent pond) of the power station and at a control site (Swan Bay). The largest biomass gain was obtained in upwellers at the inlet site (4.0±0.3 kg/1000 spat stocked) while spat in upwellers or trays at the outlet (effluent pond) lost 0.03-0.1 kg/1000 spat. Water temperatures at the inlet and outlet sites were, on average, 3.6 and 8.2°C higher, respectively, than at Swan Bay. The inlet channel was a promising site for nursery culture during cooler months.

INTRODUCTION

One of Australia's most valuable aquaculture industries is based on the Sydney rock oyster, *Saccostrea commercialis* (Holliday et al., 1988; Nell et al., 1990). Conventional intertidal methods of growing this oyster involve catching spat in summer on crates of tarred hardwood sticks (Malcolm, 1987) which are deployed for six months on more oceanic leases, separating the crates into single layers of sticks and transporting them to estuarine leases where they are on-grown to market size in 3-4 years (Korringa, 1976; Malcolm, 1987; Maguire et al., 1988). Oysters still below market size when removed from sticks are placed in trays and on-grown to market size. The nursery phase in this traditional system begins at settlement and usually lasts 12 months during which time oysters remain within the crates of sticks and are thus protected from predation by fish. After the initial phase on catching leases the crates are moved to special nursery (depot) leases in the upper reaches of estuaries. Single seed culture, an alternative approach to farming this species, is now being used by many farmers in New South Wales. Unattached spat from hatcheries or natural spatfall, are grown in trays or other enclosed units (Holliday et al., 1988). The nursery phase in single seed culture usually requires different production units and handling methods to those used for the grow-out phase (Claus, 1981). Compared with oysters produced using traditional methods, single seed oysters are less likely to grow together and hence mortalities and labour costs associated with separating oysters ("culling") are greatly reduced (Holliday et al., 1988).

Initial attempts by NSW farmers to use single seed spat resulted in high mortality rates. Investigations revealed that inappropriate nursery systems were initially used and that site characteristics may also have caused problems (Holliday, 1985a). Nursery or grow-out sites can vary greatly in their suitability due to a variety of reasons including current velocity, wave action, natural food levels, water temperature and salinity (Wilson, 1987; Brown and Hartwick, 1988). In the majority of the New South Wales estuaries spat catching leases are vacant for about six months of the year after the caught sticks have been moved to depot leases upstream. These vacant leases may have value as nursery areas for the culture of single Sydney rock oysters.

Another option to enhance the culture of juvenile oysters is through the use of thermal effluent (Jones, 1976; Margraf, 1977; Malouf, 1981). Aquarium studies indicate that, in the presence of excess food, Sydney rock oyster spat grow best at high water temperatures (30°C; Nell and Livanos, 1988).

The objectives of this study were to assess the differences among sites in Port Stephens and to determine the suitability of thermal effluent for nursery culture of single seed Sydney rock oysters. This formed part of a larger study which included the determination of optimum stocking densities for spat of different sizes (Holliday et al., in press).

METHODS

Experiment 1 - Evaluation of nursery sites in Port Stephens

Three sectionalised trays were positioned at the intertidal rack height (Malcolm, 1987) at each of four sites selected from the major farming areas within Port Stephens. Swan Bay, North Arm Cove and Soldiers Point are located within the inner Port, and Pindimar (a major spat collection area) is in the outer Port (Fig. 1). This experiment ran from August 1985 to August 1986. The site at Soldiers Point was abandoned during this period as the trays broke up due to excessive wave action.

Sydney rock oyster larvae were settled on scallop shell chips in the Research Station hatchery at Salamander Bay and the spat were then held in forced-flow upwellers (Holliday, 1985b) prior to the experiment. Sectionalised nursery trays (1.94 x 0.94 m) constructed of tarred 50 x 20 mm hardwood were divided into six parallel sections (0.25 m^2) to minimise oyster damage from wave action and to maintain a more even surface coverage of spat. Both upper and lower tray surfaces were covered with a PVC mesh (3 mm) to eliminate the loss of spat from wave action and predation from fish. The trays were stocked with approximately 300 spat/tray section (1200 spat/m^2), estimated on a weight basis for spat with an initial weight of 4.0 ± 0.1 g ($\bar{x} \pm SD$; $n=5$ for samples of 300 spat). At three monthly intervals average spat weight was determined by weighing 100 spat from each section of the tray. After six months the amount of spat in each section was reduced by half on a weight basis to prevent overcrowding. Overall mortality was estimated by dividing the total weight of spat harvested from a tray by the average final spat weight. Corrections were made for the reduction in density. Growth coefficient values (G_{90}) were calculated to allow for differences in sampling periods and initial spat weights (Spencer and Gough, 1978).

$$G_{90} = \frac{90}{\text{Duration (days)}} \times \ln \frac{\text{Final weight (g/spat)}}{\text{Initial weight (g/spat)}}$$

Temperature and salinity readings were taken monthly from the three sites at a depth of 1 m, at the time of M.L.W., using a Yeo-Kal temperature/salinity conductivity meter (Yeo-Kal Electronics, Brookvale, NSW, 2100).

Experiment 2 - Nursery culture using thermal effluent

This experiment was established at three sites: the Swan Bay lease used in Experiment 1, the inlet channel of Vales Point Power Station and the outlet (primary effluent pond) of Vales Point Power Station. Vales Point is at Lake Macquarie, NSW (Fig. 2), about 100 km south of Port Stephens. Upwellers were used at the inlet and outlet sites at the power station while sectionalised trays were used at the outlet site and on the intertidal lease in Swan Bay. As water level at the outlet site was constant the trays at this site had to be subtidal. Upwellers could not be installed on the lease at Swan Bay as there was no electricity to operate the pump. It was also not feasible to install trays in or adjacent to the inlet channel at the power station because of the water depth and strong current. The experiment ran from April to September 1986 (18 weeks).

Four forced-flow upweller units (constructed from PVC pipe 1 m x 250 mm diam), were positioned vertically at the inlet channel and the primary effluent pond. Water was pumped from the effluent pond rather than the outlet channel because turbulence in the channel produces gas bubbles which may have deleterious effects on oysters (Malouf et al., 1972). Surface water from the outlet channel is diverted into the primary effluent pond. The upweller units were stocked with 1000 spat/unit. Each week the units were cleaned and seawater flow rates through each unit adjusted to 32 l/min. Four sectionalised nursery trays were stocked with oysters with three sections of each tray (comprised of six sections), stocked with 400 spat/section (1600 spat/m^2). The sectionalised trays were positioned subtidally on a fixed timber frame at a depth of 0.5

m in the primary effluent pond. All dead oysters in the upwellers and trays were counted to estimate survival rates and weight gain values were based on initial and final samples of 100-400 spat/replicate. The average initial weight of the spat was 1.63±0.13g (x±SD; n=16 groups of spat).

Weekly temperature and salinity readings were obtained (using a thermometer and hydrometer) at Swan Bay from data recorded at a commercial oyster purification plant adjacent to the nursery lease and from the inlet and outlet sites at the power station.

Statistical Analyses

Homogeneity of variance was confirmed using Cochran's test (Winer, 1971) and for Experiment 1, growth and survival data were analysed using ANOVA and mean values were compared using the "least-significant differences" technique (Sokal and Rohlf, 1981). For Experiment 2, "t-tests" (Winer, 1971) were used to compare oyster survival, average spat weight gain and biomass gain values for sites where similar nursery systems were used. Survival data were transformed (arcsine $x^{0.5}$) prior to ANOVA. Throughout this paper data are presented as mean ± standard deviation ($\bar{x}$±SD).

RESULTS

Experiment 1

Survival of spat over 12 months was high at each site (87.9±7.7%, n=3 sites) but was significantly higher ($P<0.01$) at Swan Bay than at North Arm Cove and Pindimar (Table 1). Average weight gain was significantly higher at North Arm Cove than at Swan Bay which was in turn a significantly better site for growth than Pindimar ($P<0.05$; Table 1). At North Arm Cove spat grew from 4.0 to 16.3 g in 12 months (Fig. 3). Overall biomass gain was similar at Swan Bay and North Arm Cove (5.8-6.0 kg/m^2) but was significantly lower ($P<0.01$) at Pindimar (2.6 kg/m^2; Table 1).

Spat grew at different rates (weight gain per unit time) at different times of the year and there were similarities in the growth rate patterns for North Arm Cove and Swan Bay (Fig. 3). Growth coefficient values (Table 2) indicated that spat grew best during August-October and February-April at Swan Bay (0.39±0.03; 0.46±0.08 respectively) North Arm Cove (0.55±0.07; 0.39±0.03 respectively), while May-July was the poorest period for growth at these two sites (0.11±0.05 and 0.15±0.03 respectively). Growth rates were more uniform throughout the 12 month study at Pindimar (range 0.15-0.35) although August-October (0.35±0.05) was also the best period for growth (Table 2).

There was little variation in temperature (Fig. 4) and salinity (Fig. 5) among sites although there was considerable seasonal variation.

Experiment 2

The best growth (4.1±0.4 g/spat), survival (99.1±0.6%) and biomass gain (4.0 ± 0.4 kg/1000 spat stocked) results were obtained in the upwellers at the inlet channel site (Table 3). The poorest results for growth, survival and biomass gain were recorded at the primary effluent pond site in upwellers (0.3±0.2 g/spat, 84.6±1.4% and -0.1±0.8 kg/1000 spat stocked, in that order) and trays (1.7±0.3 g, 30.8±0.2% and -0.03±0.3 kg/1000 spat stocked, in that order). The intertidal sectionalised trays in Swan Bay produced good growth (2.6±0.3 g), survival (85.0±5.6%) and biomass gain (1.9±0.4 kg/1000 spat stocked) results (Table 3).

There was little difference in salinity among the three sites. Average values [$\bar{x}$ ± SD, n=24 (range)] were as follows: 33.6±1.4‰ (31-36‰) at the inlet, 33.5±1.5‰ (31-36‰) in the primary effluent pond and 31.6±3.0‰ (26-36‰) at the intertidal site in Swan Bay. There was considerable variation in average water temperature. Average values [$\bar{x}$±SD; n=24 (range)] were: 18.5±3.4°C (14-28°C) at the inlet, 23.1±4.1°C (19-35°C) in the primary effluent pond, and 14.9±3.4°C (11-21°C) for the Swan Bay site. Thus, water temperatures at the inlet and outlet sites were, on average, 3.6 and 8.2°C higher than in Port Stephens, respectively (Fig. 6).

DISCUSSION

North Arm Cove and Swan Bay proved to be the most suitable nursery sites in Experiment 1 (Table 1). Although there was little difference in the average salinity level among the three sites, North Arm Cove and Swan Bay, located within the inner port, are considered to be more estuarine as they are influenced by the Karuah River (Fig 1). However, more intensive monitoring of abiotic and biotic variables eg. potential food supply, than was undertaken in this study would be needed to explain differences in growth results among the three sites (Brown and Hartwick, 1988).

Data on seasonal variation in spat growth rates using growth coefficient (G_{90}) values (Table 2), indicate that August-October and February-April were the better periods for growth at Swan Bay and North Arm Cove. At these two sites, the temperature data, although based on monthly readings, indicate that poorest growth occurred during the coolest period (May-July). Similarly, growth coefficient values calculated from growth data presented by Holliday et al. (in press) indicate that, at equivalent initial biomass levels, the slowest growth rates in that 12 month study occurred during the coolest months. While the use of growth coefficient values largely overcomes the problem of differences in initial weights, it should be noted that these values tend to decrease as spat weight increases (Spencer and Gough, 1978).

The observation that growth rates of spat were depressed during cooler months was consistent with the findings of Nell and Livanos (1988) who showed that in the range 12-30°C growth rates of Sydney rock oyster spat, fed to excess, increased as temperature increased. In the present study, Experiment 2 was conducted to see if growth rates of juvenile spat could be enhanced during cooler months by using thermal effluent from a power station. Previous studies in Lake Macquarie (Anon, 1983) showed that water at the inlet to the Vales Point power station had consistently higher winter minimum and summer maximum water temperatures than other areas in Lake Macquarie distant from the power station. During the present study, the inlet site was on average 4.6°C colder than the primary effluent pond although it was 3.6°C warmer (from mixing with the heated outlet water) than the control site in Swan Bay, Port Stephens.

As it was not possible to install both trays and upwellers at all three sites in Experiment 2, direct comparisons among sites must be interpreted with caution. However, by far the best growth, survival and biomass gain results were recorded from upwellers at the inlet site. Spat in trays at Port Stephens also grew well with a high survival rate (Table 3). Spat in upwellers and trays at the outlet site either grew poorly or suffered higher mortality than those in upwellers at the inlet channel. In contrast, Margraf (1977) obtained faster growth of the American oyster (*Crassostrea virginica*) in the outlet channel of a power station than in the inlet channel or at an estuarine control site. The difference between spat growth in trays at the outlet site and Port Stephens was even more notable as trays were subtidal at the outlet site and intertidal in Port Stephens. Previous studies on leases showed that subtidally grown Sydney rock oysters (30-39g) had a growth rate twice that of intertidally grown oysters (Wisely et al., 1979; Nell, 1989).

Malouf (1981) concluded that there are many factors which can adversely affect bivalves grown in thermal effluent, including temperature fluctuations, contamination of effluent with chlorine, increased disease risks and inadequate food levels to sustain the metabolic requirements of poikilothermic animals at elevated temperatures. Hodgson (1979) suggested that thermal effluent from Vales Point Power Station may have a growth limiting effect on entrained phytoplankton, perhaps due to mechanical damage, chlorination and turbidity in the thermal plume. However, he found no significant difference in chlorophyll-a levels between the inlet and outlet sites. In addition, the primary effluent pond was designed to receive floating hydrocarbon contaminants that were skimmed off from the outlet channel, although, in the present study there was no evidence of hydrocarbon contamination. It is not clear which, if any, of these factors actually depressed growth and survival rates in the primary effluent pond.

The results for the inlet channel were very encouraging and, following the completion of this study, a commercial nursery facility for Sydney rock oysters was established at this site. The study has also shown that the spat catching leases at Pindimar, which are vacant for six months of the year, could be used for the nursery culture of Sydney rock oysters, even though spat growth was better at the more estuarine leases in Swan Bay and North Arm Cove.

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Fig 1. Location of nursery sites in Port Stephens, NSW for Experiment 1.

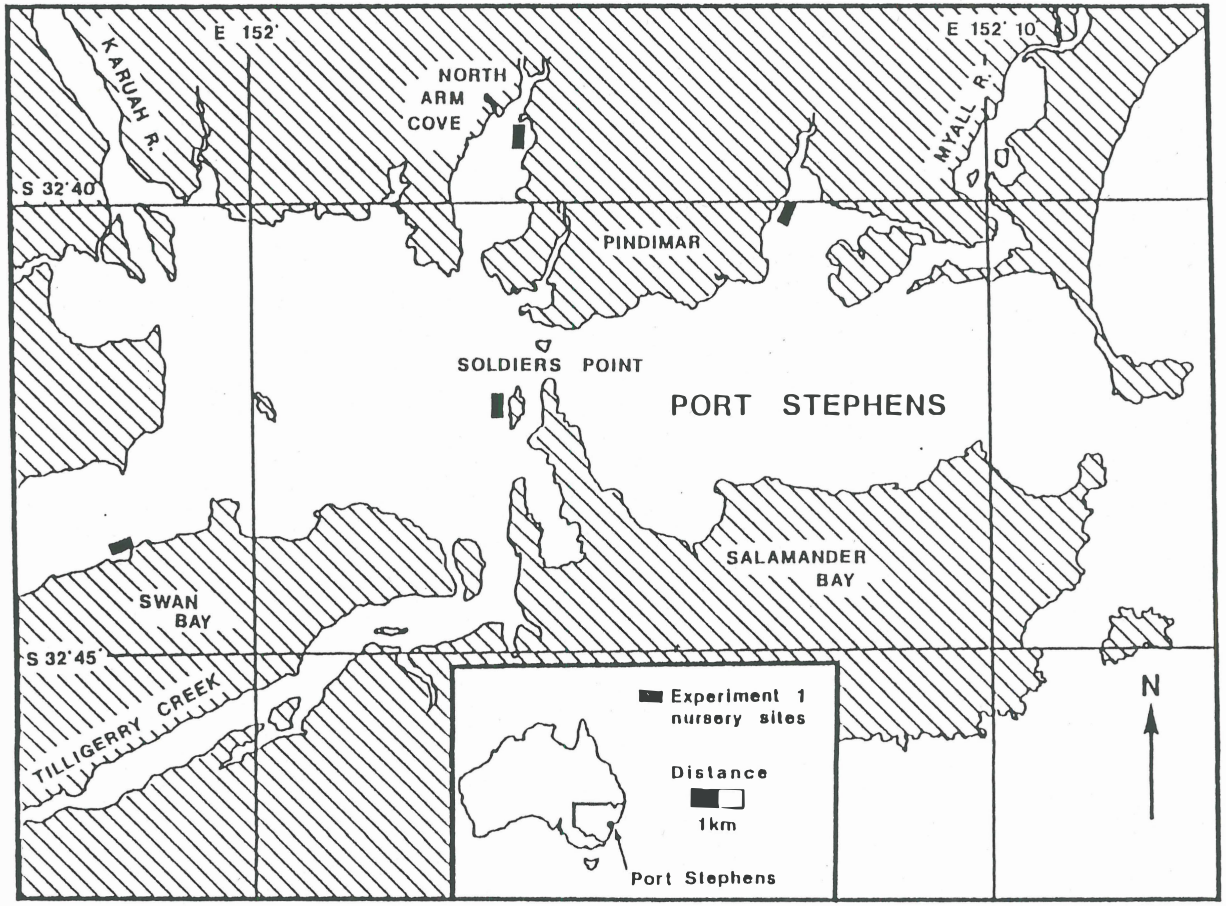

E 152'
E 152' 10'
KARUAH R.
NORTH
ARM
COVE
MYALL R.
S 32' 40'
PINDIMAR
SOLDIERS POINT
PORT STEPHENS
SALAMANDER
BAY
SWAN
BAY
S 32' 45'
TILLIGERRY CREEK
Experiment 1
nursery sites
Distance
1km
Port Stephens
N

Fig 2. Location of Vales Point Power Station, Lake Macquarie, NSW (33° 05^{1}S, 151° 48^1 E; Experiment 2).

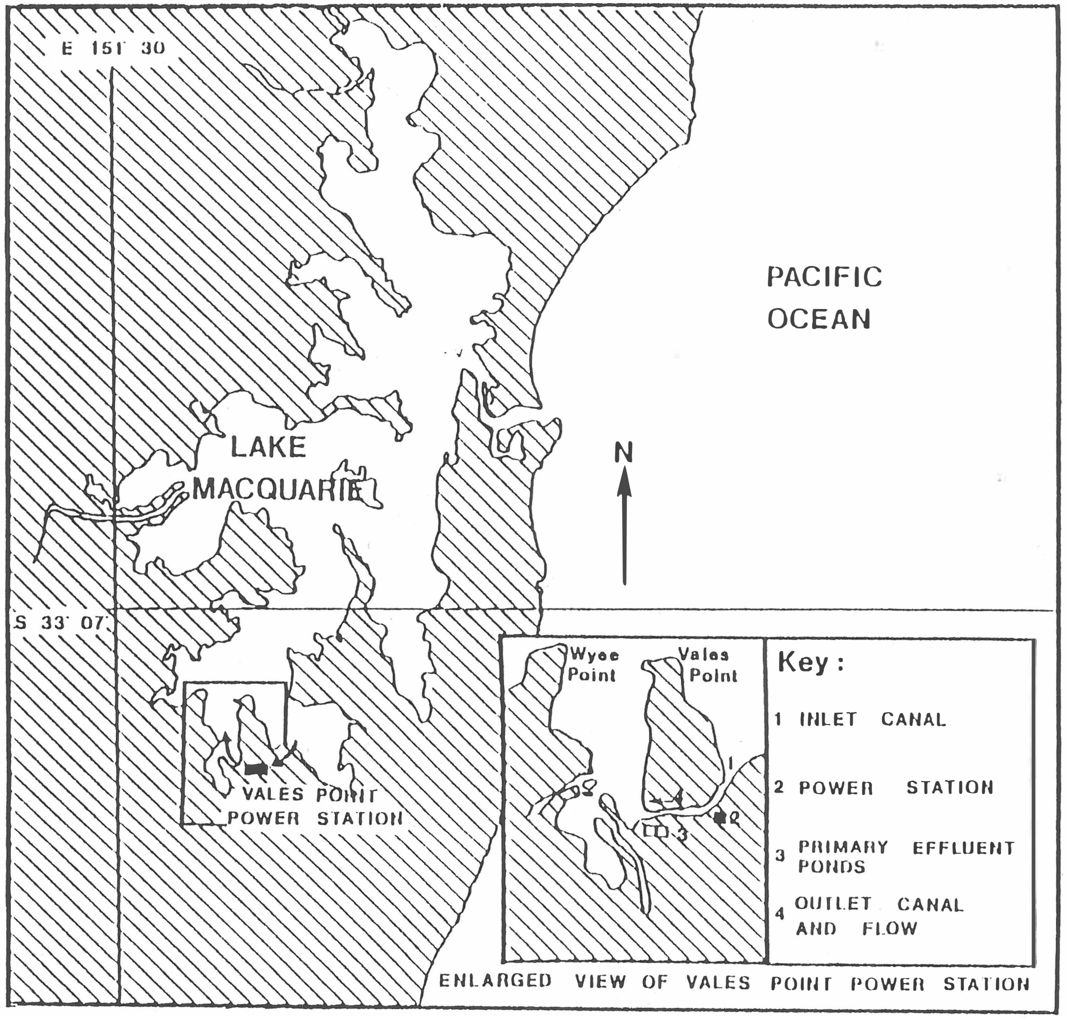
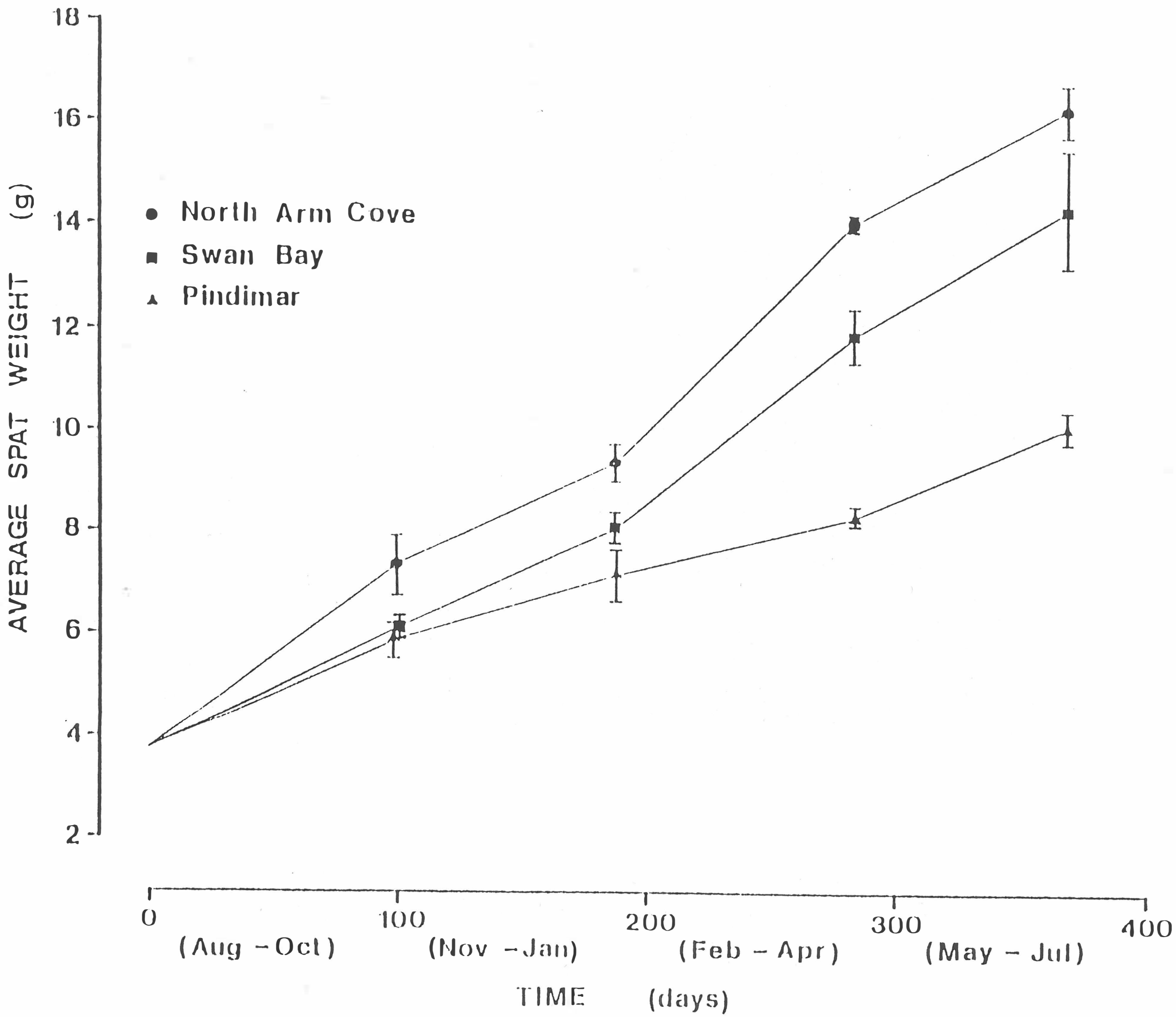

E 151' 30
S 33' 07
LAKE MACQUARIE
PACIFIC OCEAN
N
VALES POINT POWER STATION
Wyee Point
Vales Point
Key :
1 INLET CANAL
2 POWER STATION
3 PRIMARY EFFLUENT PONDS
4 OUTLET CANAL AND FLOW
ENLARGED VIEW OF VALES POINT POWER STATION

Fig 3. Growth of Sydney rock oyster (*Saccostrea commercialis*) spat in sectionalised trays over 12 months at nursery sites in Port Stephens, NSW (Experiment 1).



North Arm Cove
Swan Bay
Pindimar
AVERAGE SPAT WEIGHT (g)
18
16
14
12
10
8
6
4
2
0
100
200
300
400
(Aug - Oct)
(Nov - Jan)
(Feb - Apr)
(May - Jul)
TIME (days)

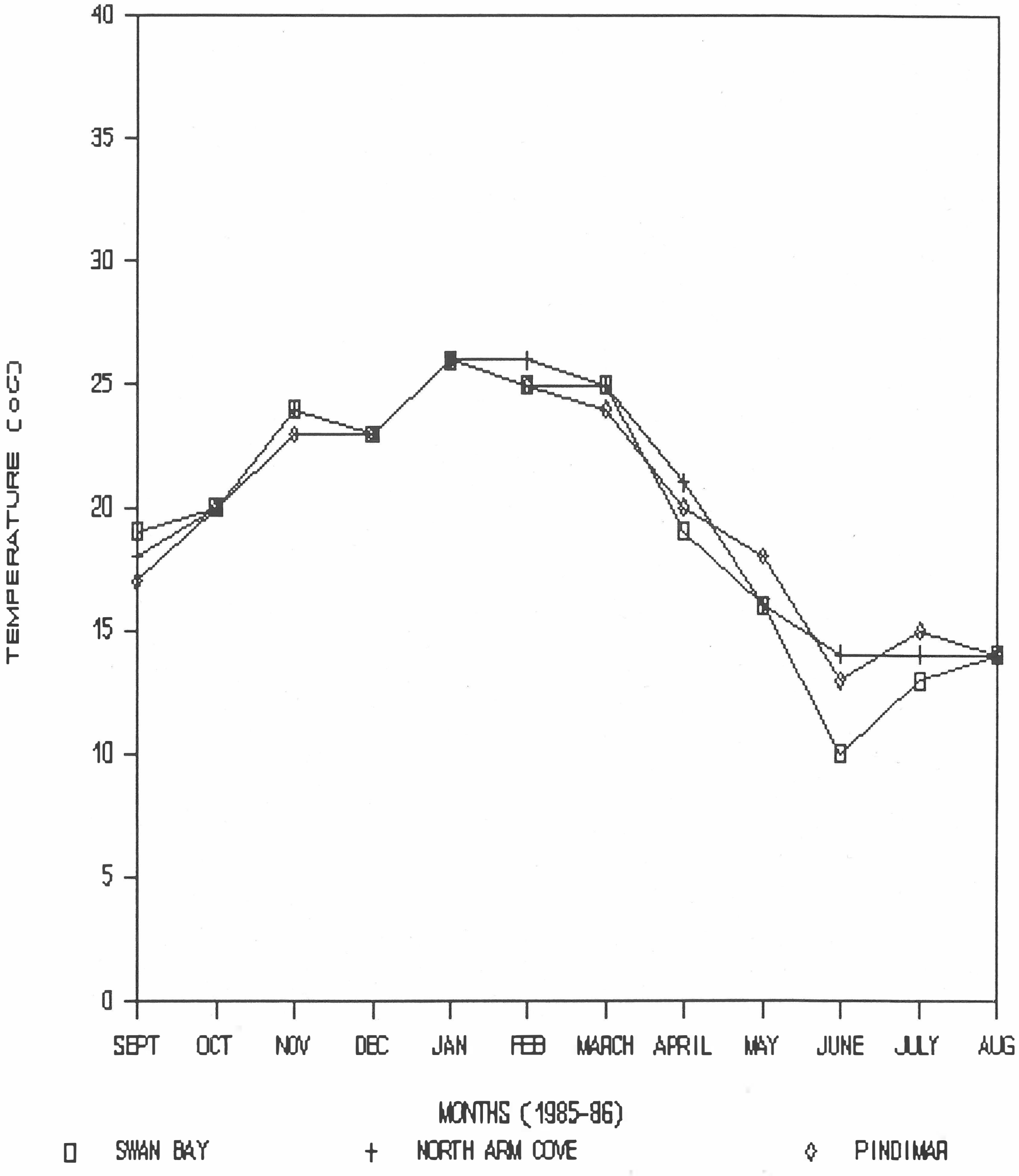


Figure 4. Temperature data for the three nursery sites in Port Stephens, NSW from September 1985 to August 1986 (Experiment 1).

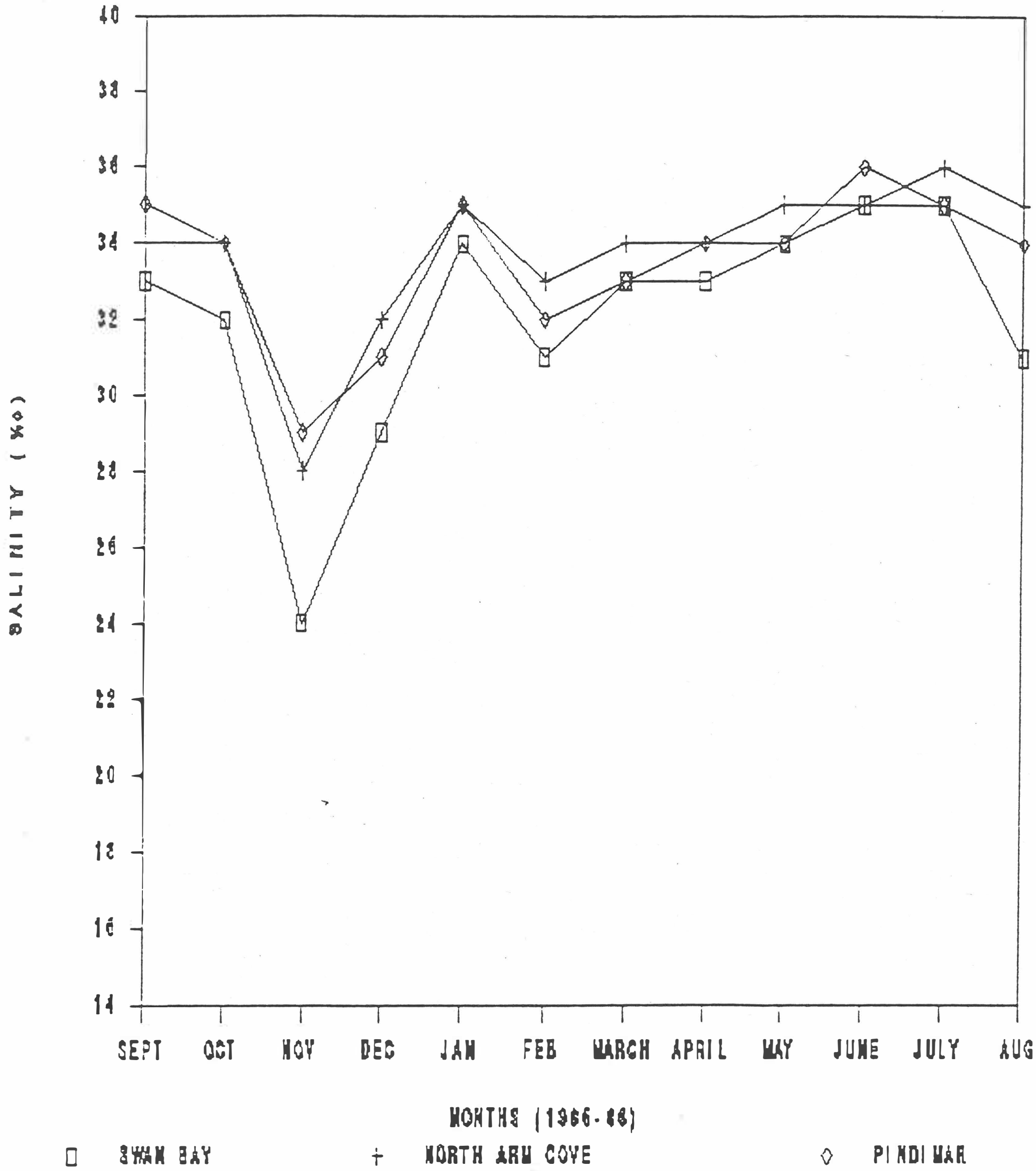


Figure 5. Salinity data for the three nursery sites in Port Stephens, from September 1985 to August 1986 (Experiment 1).

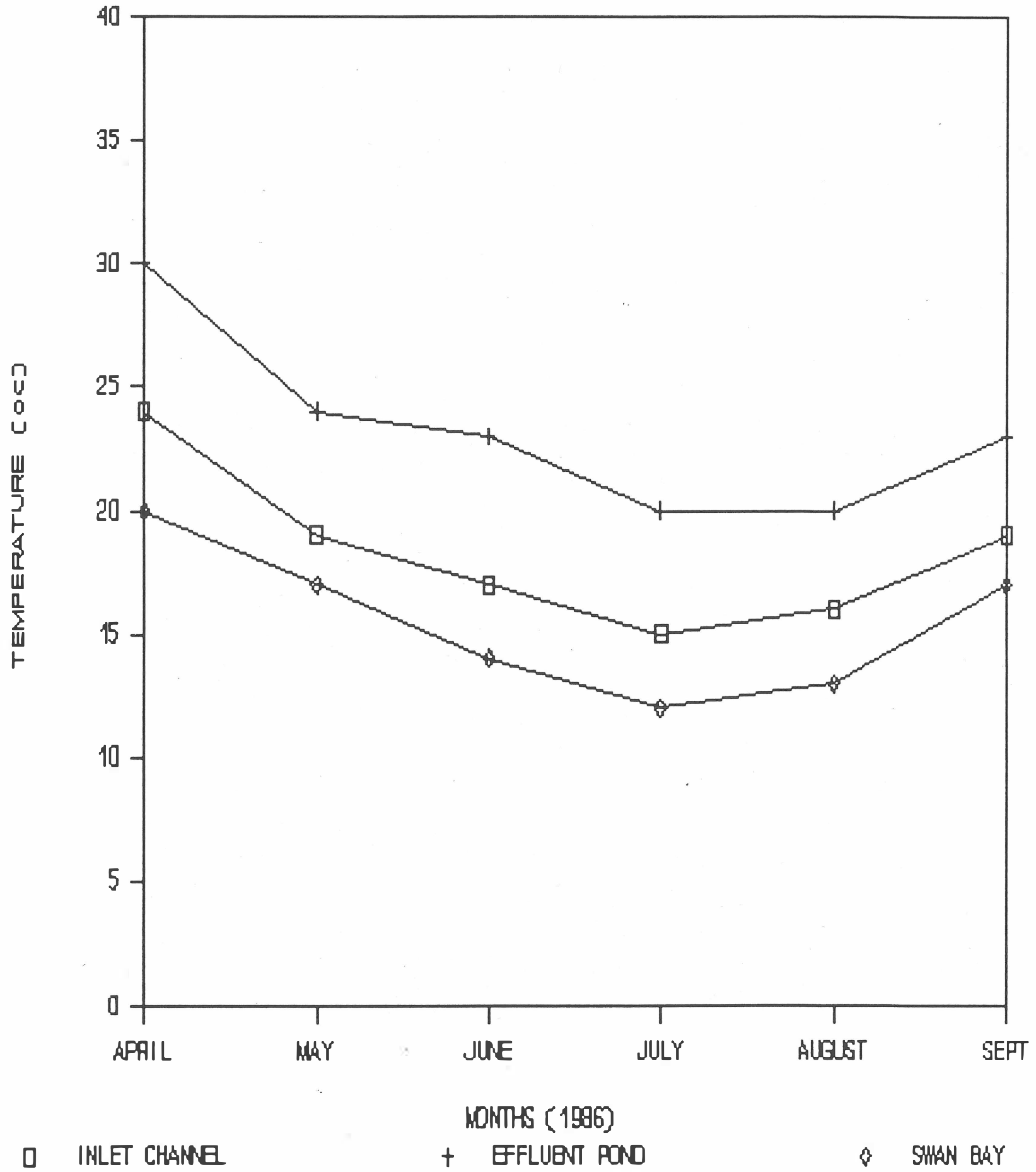


Figure 6. Temperature data for the inlet channel and effluent pond at Vales Point Power Station and the intertidal site at Swan Bay, Port Stephens, NSW, 1986 (Experiment 2).

TABLE 1. **Performance of Sydney rock oyster (*Saccostrea commercialis*) spat at three nursery sites in Port Stephens, NSW over 12 months ($\bar{x}$±SD; n=3; Experiment 1).**

Sites	Average weight[1,2] gain (g/spat)	Survival[1,3] (%)	Biomass[1,4] gain (kg/m^2)
Swan Bay	10.4±1.1[a]	96.7±3.1[a]	6.0±0.9[a]
North Arm Cove	12.3±0.5[b]	83.9±1.6[b]	5.8±0.2[a]
Pindimar	6.0±0.5[c]	83.0±4.7[b]	2.6±0.5[b]

1 Within each column means with different superscripts are significantly different ($P<0.05$).

2 Average initial weight of spat was 4.0±0.1g.

3 Data transformed (arcsine $x^{0.5}$) prior to analysis.

4 Sectionalised trays were stocked at 1200 spat/m^2 but midway through the twelve month study, spat densities were reduced by half to prevent overcrowding. Biomass gain values are based on an initial density of 600 spat/m^2.

TABLE 2. **Growth coefficient values for Sydney rock oyster (*Saccostrea commercialis*) spat grown at three sites in Port Stephens, NSW for 12 months ($\bar{x}\pm SD$; n=3; Experiment 1)[1]**

Site	Growth Coefficient (G_{90})[2]			
	Aug-Oct	Nov-Jan	Feb-April	May-July
Swan Bay	0.39±0.03	0.27±0.02	0.46±0.08	0.11±0.05
North Arm Cove	0.55±0.07	0.24±0.10	0.39±0.03	0.15±0.03
Pindimar	0.35±0.05	0.19±0.03	0.15±0.03	0.20±0.02

1 The experiment was carried out from 29.7.85 to 5.8.86 and the average initial weight of the spat was 4.0±0.1g. The initial weight for the period between sampling dates was the same as the final weight for the preceding period.

2 $$G_{90} = \frac{90}{\text{Duration (days)}} \times \ln \frac{(Wt)}{(Wo)}$$

Wo and Wt are the average initial and final weights of spat (g/spat) for a period respectively.

TABLE 3. Growth and survival data of Sydney rock oyster (*Saccostrea commercialis*) spat grown at the inlet and outlet to Vales Point Power Station and on an intertidal lease in Swan Bay, Port Stephens, NSW. (Experiment 2; $\bar{x}\pm SD$)[1]

Sites	Average Weight[2] gain (g/ spat)		Survival (%)		Biomass Gain (kg/1000 spat stocked)	
	Upweller	Tray[3]	Upweller	Tray	Upweller	Tray
Power Station Inlet Channel	4.1±0.4[a]	-----	99.1±0.6[a]	-----	4.0±0.3[a]	-----
Power Station Effluent Pond	0.3±0.2[b]	1.7±0.3[a]	84.6±1.4[b]	30.8±0.2[a]	-0.1±0.8[b]	-0.03±0.3[a]
Swan Bay	-----	2.6±0.3[b]	-----	85.0±5.6[b]	-----	1.9±0.4[b]

1 Within each column means with different superscripts are significantly different ($P<0.05$).

2 Average initial weight of the spat was 1.63 g. Spat were stocked in trays at 1200/m^2 and 1000 spat/upweller.

3 Trays were subtidal at the effluent pond and intertidal at Swan Bay.

Growing and winter conditioning Sydney rock oysters (*Saccostrea commercialis*) in prawn farming ponds in northern NSW

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ABSTRACT

Allan, G. L., Holliday, J. E. and Frances, J. Growing and winter conditioning Sydney rock oysters (*Saccostrea commercialis*) in prawn farming ponds in northern NSW.

Sydney rock oyster spat (*Saccostrea commercialis*) (average initial weight 2.2±0.1 g) and adults (average initial weight 17.2±0.3 g) were grown in continuously submerged PVC mesh bags a 2 ha fertilised brackish water pond (20 ML) stocked with leader prawns (*Penaeus monodon*) and in the water inlet channel (1.5 km x 15 m; 22.5 ML) of a prawn farm adjacent to the Clarence River, NSW. Despite reduced salinity levels (<15 ‰) survival rates of both spat and adults were high at both sites. Survival, weight gain and total biomass gain for spat and condition index of adult oysters were all significantly ($P<0.001$) better in the inlet channel than in the pond. After 12 weeks average weight gain and biomass gain values for spat in the inlet channel were 2.2 g/oyster and 467.8 g respectively compared with 0.7 g/oyster and 55.4 g respective for spat in the pond.

INTRODUCTION

The culture of oysters using on shore tanks or ponds which are fertilised to stimulate algal blooms has received considerable attention from research workers (King, 1977; Maguire et al., 1981; Nell, 1985; Manzi et al., 1987) and oyster farmers (Holliday et al., 1988). Enriched ponds may be useful for fattening oysters during these periods. NSW oyster farmers have trouble marketing their oysters during winter as the meats are often in poor condition (Holliday, 1988).

In NSW 160 ha of earthen ponds have been constructed for farming marine prawns. The bi-culture of prawns and oysters together may provide prawn farmers with a second crop and oysters farmers with enriched ponds for winter growth and conditioning of oysters. The objectives of this study were to assess the potential for using the water inlet channel and a fertilised 2 ha pond at a prawn farm, for growing spat and fattening or maintaining market condition of adult oysters.

METHODS

A 20 ha prawn farm adjacent to the Clarence River, NSW, owned and managed by Mr Frank Roberts, was chosen for this study. Two sites were used; a 2 ha fertilised pond (20 ML) used for growing leader prawns *Penaeus monodon* and the water inlet channel (1.5 km long, 15 m wide; 22.5 ML) for the farm. The inlet channel was closed to the estuary. In the pond oysters were located approximately 9 m downstream from an "Air-O_2" aerator and in the channel approximately 16 m downstream from twin 400 mm diameter pump outlet pipes. Both aerators and pumps generated a strong current when in operation.

Oysters and mesh bags were provided by Mr Wayne Moxham (Brooklyn, NSW). Each growing unit consisted of four mesh bags (450 x 900 mm; 6 mm mesh) supported by a tarred hardwood frame (1800 x 900 mm). A hardwood stake separated the frame into two halves and, as the top and bottom surfaces of each bag were stapled to this stake, each bag was separated into two sections (450 x 450 mm). The growing units were suspended beneath floating PVC pontoons at a depth of approximately 300 mm.

The experiment was run for 12 weeks from 15 March to 6 June 1990.

Juvenile oysters

Four replicate units, each with eight individual sections were placed at each site. An equivalent volume of oyster spat (average weight 2.2±0.1 g; $\bar{x}\pm SE$) was placed in each section. The average number and weight of oysters in each section was 262±2.5 and 523.6±2.0 g respectively. At the end of the experiment the number and weight of live and dead oysters was determined and the survival, average individual weight gain and the total biomass gain calculated for each section of each unit. Total recovery of oysters (live plus dead) for all sections was similar and greater than 90% and survival was based on the number of oysters present at the end of the experiment.

Adult oysters

Four replicate growing units, each with four sections, were placed at each site. Forty adult oysters (average initial weight 17.2±0.3 g in good condition) were placed in each section. Eight oysters, (two from each section) from more samples every two weeks and total weight, shell weight and oyster dry mean condition index determined for each oyster. An average for each replicate was then calculated.

$$\text{Condition index (\%)} = \frac{\text{dry meat weight (g) x 100}}{\text{Cavity volume (Lawrence and Scott, 1982)}}$$

Statistical analysis

The effects of site, and replicate growing units within sites, on performance indices for oyster spat were assessed using nested single-factor ANOVAs. Survival data were transformed (arcsine $x^{0.5}$) prior to analysis to satisfy assumptions of homogeneity and normality. For adult oysters, an average for whole weight and condition index (based on eight individual oysters) for each replicate unit was calculated for each site and each sampling period. The effects of site and time were analysed using two-factor ANOVAs. For all ANOVAs comparison between means were made using the T-method and homogeneity of variance was assessed using Cochran's test (Winer, 1971). Data is presented as mean ± standard error.

Temperature and salinity

Salinity levels were depressed throughout the study following prolonged rainfall. Mean salinity in the pond based on nine readings taken by prawn farm staff was 10.4 ‰ (range 7-14 ‰) and in the channel 11.9 ‰ (range 9-15 ‰). The mean temperature was 20.7° C (range 17.5-24.0°C) and was similar at both sites.

RESULTS

Performance indices for spat are given in Table 1. Survival was high (>82 %) for all treatments, however, it was significantly ($P<0.001$) higher in the channel (average for all units 88.5 %) than in the pond (average for all units 83.5 %). Both growth and biomass gain in the pond (0.7 g/oyster and 55.4 g respectively) were significantly ($P<0.001$) lower than in the channel (2.2 g/oyster and 467.8 g respective) (Table 2).

Poor growth of adult oysters was recorded and the affects of time and site were not significant ($P>0.05$). For condition index, however, site and time effects were significant ($P<0.001$) and there was a significant interaction ($P<0.001$). Oyster condition in the ponds declined steadily over time from 11.4 % at the start of the experiment to 5.7 % after 12 weeks. In the channel, however, oyster condition decreased initially but then improved to similar levels to those at the start of the experiment (Table 2).

DISCUSSION

The low salinity recorded during this experiment prevented an accurate assessment of the potential for growing and fattening oysters at prawn farms. However, although the survival range of salinity for adult oysters has been reported to be 15-30 ‰ (Nell and Holliday, 1988) it was encouraging that survival rates of both spat and adults were very high despite salinity levels remaining below the lower level of this range for the duration of this experiment.

Nell and Holliday (1988) found that the optimum salinity for growth of small Sydney rock oyster spat was 25-35 ‰ and that growth increased over the range 15-25 ‰. Growth of spat in the pond during the present study was slow, with an average increase of only 0.7 g/oyster. Despite low salinities, however, growth of spat in the channel was encouraging, with an average weight gain of 2.2 g/oyster over 12 weeks. This compared well with growth rates of approximately 1.8 g/oyster over 22 weeks for oysters at similar densities on trays in Port Stephens, NSW where average salinity and temperature values were 26.6 ‰ and 18.8°C respectively (Holliday et al., in press). However, it should be noted that faster growth rates have been recorded for oysters at lower densities (Holliday et al., in press) and/or using different culture systems (Holliday et al., in press; Holliday et al., 1990).

Maguire et al (1981) found that condition of oysters in prawn farming ponds improved rapidly over time, although oysters did not grow rapidly and mortality and mudworm infection rates were high. In addition, there was a thick accumulation of decaying organic material on the upper shell of pond oysters. In the present study no problems were observed with mudworm and, although there was some algal growth and accumulating of mud on the upper surface of oysters in the pond. The condition index of adult oysters at the start of the experiment (11.4 or 11.8 %; Table 1) indicated that they were in good condition (Nell, pers. comm). In the fertilised pond oysters lost condition and juveniles grew very slowly, although in the adjacent water inlet channel with a similar temperature and salinity regime, best condition of oysters was maintained and juveniles grew well. The ability to hold oysters in good condition can be of value to oyster farmers who wish to maintain continuity of supply for marketing.

Results from this study indicate that water inlet channels at prawn farms, which are similar to the one described here, may offer considerable potential for oyster cultivation. Although disappointing results were recorded in the fertilised prawn farming ponds better growth and condition of oysters in ponds may have been achieved under more favourable salinity conditions.

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TABLE 1

Performance indices for oyster spat (2.2 g/oyster average initial weight) grown in a fertilised 2 ha pond and the water inlet channel of a prawn farm adjacent to the Clarence River, NSW[1]

Site/Growing unit		Survival[2] (%)	Average weight gain (g oyster^{-1})	Total biomass gain (g)
Pond	1	79.2±1.5	0.9±0.1	46.4±12.3
	2	86.6±0.6	0.6±0.1	59.3±5.0
	3	82.3±2.0	0.7±0.0	48.2±13.0
	4	85.7±0.9	0.7±0.0	67.6±7.3
Channel	1	88.6±0.8	2.1±0.1	465.4±15.1
	2	89.7±1.0	2.3±0.1	503.1±25.6
	3	86.6±1.1	2.3±0.1	459.9±16.1
	4	89.1±1.0	2.2±0.0	442.6±19.1

1 Values are $\bar{x}$±SE (based on 8 replicate sections). Nested ANOVA results indicated that all performance indicators were significantly ($P<0.001$) higher in the channel than in the pond. The variation due to differences between replicates was also significant ($P<0.05$), however, the variation accounted for only 17.4, 0.9 and 0.4 % of the total variation for survival, average weight gain and total biomass gain in that order.

2 Data transformed (arcsine $x^{0.5}$) prior to analysis.

TABLE 2

Condition index and whole weight of oysters grown in a 2 ha pond and the water inlet channel of a prawn farm adjacent to the Clarence River, NSW[1]

	Condition Index (%)[2]		Whole weight (g/oyster)[3]	
Week	Pond	Channel	Pond	Channel
0	11.4 ± 0.4^{abc}	11.8 ± 0.4^{ab}	17.1 ± 0.3	17.4 ± 0.5
2	9.1 ± 0.2^{d}	8.6 ± 0.8^{dc}	16.9 ± 0.3	17.8 ± 0.5
4	6.6 ± 0.1^{ef}	9.5 ± 0.4^{cd}	18.1 ± 0.5	18.5 ± 0.5
6	6.0 ± 0.3^{3}	9.3 ± 0.4^{cd}	17.5 ± 0.4	18.5 ± 0.5
8	6.0 ± 0.4^{f}	10.6 ± 0.6^{bcd}	17.2 ± 0.1	17.4 ± 0.4
10	5.6 ± 0.2^{f}	12.0 ± 0.6^{ab}	18.0 ± 0.2	18.5 ± 0.6
12	5.7 ± 0.3^{f}	12.8 ± 0.4^{a}	18.2 ± 0.5	18.5 ± 0.4

1 Values are $\bar{x} \pm SE$ (n=4 replicate trays)

2 Results of two-factor ANOVA indicated that both site and dates significantly ($P<0.001$) affected condition index. As there was a significant interaction ($P<0.001$) between site and date a comparison of means for all combinations of time and site was made. For condition index means (at any site or date) sharing a common letter in the superscript were not significantly different ($P>0.05$)

3 Effects of site and date on whole oyster weight were not significant ($P>0.05$)

SECTION 7

LARVAL TRANSPORT

Cold storage effects on setting of larvae of the Sydney rock oyster, *Saccostrea commercialis*, and the Pacific oyster, *Crassostrea gigas*

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ABSTRACT

Holliday, J. E., Allan, G. L. and Frances, J. Cold storage effects on setting of larvae of the Sydney rock oyster *Saccostrea commercialis* and the Pacific oyster *Crassostrea gigas*.

Cold storage and transport of pediveliger stage larvae to commercial growers for delayed on-site setting reduces the cost of using hatchery produced seed. The percentage of Sydney rock oyster (*Saccostrea commercialis*) larvae which set following cold storage at 11°C for up to 98 hours was excellent (77-85%). Percentage of Pacific oyster (*Crassostrea gigas*) larvae set (68%) was unaffected by a storage temperature of 6°C for 98 h. Shell length and eyespot diameters may be useful criteria for assessing when pediveliger stage larvae are ready for storage. Critical values for shell length and eye spot diameter for Sydney rock oyster larvae were 292.2 μm and 20.3 μm and for Pacific oyster larvae were 325.4 μm and 14.2 μm respectively.

INTRODUCTION

Delayed or "remote" setting involves the storage and transport of pediveliger (competent to metamorphose) larvae from the hatchery to a site where the oysters are to be on-grown. The technique of remote setting of larvae was first attempted in North America during the early 1970's, using Pacific oysters (*Crassostrea gigas*) (Jones and Jones, 1988). Remote setting techniques with Pacific oyster larvae have gained wide acceptance in North America with commercial set rates of approximately 20-30% (Henderson, 1983; Roland et al., 1988).

Carlson (1981) suggested that storing Pacific oyster larvae at 5°C for 5 to 8 days actually increased the set rate, while Henderson (1981) showed that no reduction in set rate occurred when larvae were stored at 5°C for up to 6 days. A reduction in set rate and post set survival occurred when larvae were stored at 5°C beyond 8 days (Henderson, 1983). No reports of the effects of storage temperatures above or below 5°C on set rates of Pacific oyster larvae were found.

Australia's developing Pacific oyster industry in Tasmania, with an estimated half shell production of 1.6 million dozen for 1988/89 (Anon, 1988), is totally dependent upon hatchery production. In New South Wales, production of Sydney rock oysters

(*Saccostrea commercialis*) was estimated at 10.5 million dozen for 1988/89 (Anon, 1988). This industry is based on the collection of juvenile oysters (spat) in the wild (Holliday et al., 1988). However, following the development of hatchery techniques for breeding Sydney rock oysters (Holliday, 1985), an estimated 12 million 4-6 mm spat were sold to farmers from the two commercial hatcheries in New South Wales in 1988/89 (J. Nell, personal communication, 1990).

In Australia, hatchery produced Sydney rock and Pacific oyster seed is grown to about 4 mm shell length, usually in an upwelling nursery system, similar to the type described by Bayes (1981). The nursery phase can be very expensive, particularly for Sydney rock oysters, which grow at approximately half the rate of Pacific oysters (Nell, 1989).

Remote setting has not previously been attempted using the Sydney rock oyster. The objectives of this study were to determine whether the larvae could be stored for delayed settlement and, if so, to determine the effect of storage temperature and time. Local strains of Pacific oyster larvae were also settled following storage at 6°C for 4 days for comparison with Sydney rock oyster larvae.

METHODS

Larvae

Sydney rock and Pacific oyster broodstock were obtained from Port Stephens, New South Wales. Both species were stimulated to spawn on the same day by reducing salinity from 35 to 25‰. The fertilized eggs and larvae were then reared to pediveliger stage at 25±1°C and 30±1‰ using established techniques (Walne, 1974; Holliday, 1985). Pacific oyster larvae reached the pediveliger stage 18 days after fertilisation; Sydney rock oyster larvae after 22 days.

When larvae reached the pediveliger stage, and there were small numbers observed setting on the sides of the rearing tanks, they were harvested onto a partially submerged 200 μm screen. Larvae for each experiment were then divided volumetrically into 20 l buckets, one for each replicate. The larval concentrations in each bucket were estimated by counting the larvae in each of five subsamples using a Sedgewick-Rafter cell and a compound microscope. Eyespot diameter and shell length were measured for 250 larvae of each species using a binocular microscope with an ocular micrometer (±0.5 μm).

The larvae in each bucket were then drained through a funnel and retained using 100 μm nylon mesh (25 cm^2). The mesh was then secured with a rubber band. Each mesh pouch contained (means±S.E.) 170±3.1 (x 10^3) and 2.36±10.0 (x 10^3) larvae for the experiments with Sydney rock and Pacific oyster larvae respectively. The 25 cm^2 mesh pouches of larvae used as controls (no storage) were emptied directly into the setting container.

Storage

The pouches of larvae, wrapped in damp absorbent paper, were transported for two hours to the temperature control rooms in a portable 30 l refrigerator, set at 11±0.4°C. They were then rearranged into 5 l boxes, one for each treatment, and placed inside one of three fan-forced constant temperature cool rooms. The temperature inside one of the 5 l boxes in each cool room was logged using ANRITSU type T7001 data loggers (Electron Chemical Engineering Pty Ltd, Mobbs Lane, Carlingford, NSW, 2118). The mean temperatures (°C) maintained in the cool rooms were 1.4 (range 1.1-2.1), 6.0 (range 5.3-8.8), and 11.0 (range 10.3-11.3).

Set system

After the appropriate storage interval, the 5 l boxes containing the concentrated larvae in pouches were returned to the hatchery in the portable refrigerator. Larvae were washed into 5 l beakers of seawater (25°C, 33‰) and held for 45 minutes while the motility, colour, odour and mortality of the larvae were assessed. To avoid bacterial contamination of viable larvae, those treatments with total mortality in each replicate were not placed in the set systems. For each other replicate, the larvae were confined within a PVC screen (450 mm diam, 150 mm deep, 200 μm mesh size), partially submerged at a randomly allocated location inside one of five 1700 l fibreglass setting tanks. Within each PVC screen a conical shaped, lime and cement-coated PVC collector (355 mm diam, 80 mm high, surface area 1790 cm^2) was provided for the larvae to attach. Maximum numbers of Sydney rock oysters had attached to this type of collector during hatchery trials using a variety of commercially available collectors (Holliday, et al., unpublished data, 1989). Seawater (25.4±0.1°C, 29.8±0.3‰) was gently sprayed over the top of each PVC screen at the rate of 0.8 l/min. A 100% water exchange was carried out every second day, with a 50% exchange every other day, and tanks were fed an equal mix of algal species ("Tahitian" *Isochrysis* aff. *galbana, Pavlova lutheri* and *Dunaliella tertiolecta*) at a rate of 2.9 x 10^4 cells/ml/day.

The collectors were removed after 8 days. A template with four evenly spaced wedges (each spanning the radius of the collector, giving a total surface area of 199 mm^2), was randomly placed over the top and bottom surfaces of each collector, and the oysters contained within each wedge were counted. Oysters that settled on the PVC screens were removed and enumerated by weighing.

For Sydney rock oysters, nine treatments were provided with five replicates of each. Treatments comprised one control, where larvae were drained into 25 cm^2 mesh pouches and then put to set without storage; storage for 12, 98 and 194 h at 11°C; 98, 194 and 290 h at 6°C; and 98 and 194 h at 1.4°C.

For Pacific oysters, two treatments with five replicates for each were provided. These included a control (no storage) and 98 h at 6°C, close to the reported recommended storage temperature and time (5°C; 144 h) for this species (Henderson, 1981).

Statistical Analyses

For the experiment with Sydney rock oysters, differences in the numbers of oysters that set following different treatments were assessed using one way

ANOVA. Homogeneity of variance was evaluated using the Cochran's Test (Winer, 1971) and means were compared using Tukey's honesty significant differences method (Sokal and Rohlf, 1981). Data from treatments that suffered total mortality following storage were excluded from statistical analyses. Differences between set for the experiment with Pacific oysters were compared using a t-test (Sokal and Rohlf 1981). The differences between eye spot and shell diameters for the two species were compared separately using t-tests and the relationship between eye spot diameter and shell length for each species was evaluated using linear regression.

RESULTS

Set rates for Sydney rock oysters were excellent, with no significant difference ($P>0.05$) in numbers (x 10^3) which settled between controls (139±9 [means±S.E.]) and larvae stored at 11°C for 12 or 98 h (145±16 and 131±17 respectively), (Table 1). The percentage of larvae which settled was estimated to range from between 77 to 85% for these treatments. Significantly fewer oysters survived ($P<0.05$) when stored for 98 h at 1.4 and 6°C and 194 h at 11°C (Table 1). The percentage of larvae which set was estimated to range from 5-33% for these treatments. No larvae survived when stored for 194 h at 1.4 and 6°C.

There was no significant difference ($P>0.05$) in the number (x 10^3) of Pacific oysters which settled between the controls and larvae stored for 98 h at 6°C (159±21 and 163±15 respectively; Table 1). Approximately 68% of larvae were estimated to have set from both treatments.

The faster growing Pacific oyster larvae had a significantly ($P<0.05$) larger mean shell length (325.4±1.00 µm; n=250) than Sydney rock oyster larvae (292.2±0.87 µm; n=250), although the eyespot diameter was significantly ($P<0.05$) smaller (14.2±0.15 µm compared with 20.3±0.30 µm). Within the small size range measured for each species there was no significant relationship ($P>0.05$) between shell length and eyespot diameter.

DISCUSSION

The excellent set results for Sydney rock oyster larvae stored for up to 98 h at 11°C indicate that remote setting techniques have considerable potential for this species. Relatively inexpensive, commercially available equipment can be used to maintain a temperature of 11°C and consignments of oysters could be shipped to most locations within Australia, and overseas, within 98 h.

Estimates of the percentage of larvae of both species which set following optimum storage temperature and time ranged from 68% for Pacific oysters to between 77 and 85% for Sydney rock oysters. These rates are well in excess of the reported acceptable commercial rates of 20-30% for unfed Pacific oyster larvae and 37% for those fed on stored algal paste (Roland et al., 1988). In the present study larvae were fed live algae during settlement and this may have improved set rates.

Recommended larval shell lengths and eyespot diameters for remote setting Pacific oysters are >300 µm and 14 µm (Jones and Jones, 1988) and 300-320 µm and 15 µm (Roland et al., 1988). The size (325 µm range 290-373 µm) of Pacific oyster larvae in the present study was similar. Inherent differences between the local Pacific oyster strain and those used elsewhere may account for differences in set performance. If shell length and eyespot diameter were used as criteria for when to store pediveliger larvae for delayed set, the results of the present study indicate that appropriate measurements would be 292.2 µm and 20.3 µm for Sydney rock oysters and 325.4 µm and 14.2 µm for Pacific oysters.

Typically, consignments of 2.5 x 10^6 Pacific oyster larvae are shipped in mesh pouches from the North American hatcheries (Jones and Jones, 1988). The larger surface to volume ratio for smaller pouches was considered likely to result in higher larval mortality through dessication or physical abrasion of larvae in contact with the pouch material. The mean numbers (x 10^3) of larvae used here for each pouch was 170±3.1 and 236±10.0 larvae for Sydney rock and Pacific oysters respectively and was chosen to be large enough to simulate commercial scale shipments. Larger consignments may have produced even better results. No larvae were stored beyond 194 h at 11°C, although it is possible that some may have survived. The set performance of Pacific oysters following storage at temperatures above the recommended temperature of 5°C (Henderson, 1983) is also well worth examining.

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TABLE 1.
The effects of cold storage on settlement of eyed Sydney rock *Saccostrea commercialis*) and Pacific (*Crassostrea gigas*) oyster larvae [1]

Time (Hrs)	Temp (°C)	Sydney Rock Larvae ($x10^3$)	Sydney Rock Spat Set ($x10^3$)	Pacific Larvae ($x10^3$)	Pacific Spat Set ($x10^3$)
No storage		182±11[a]	139± 9[a]	233±10[a]	159±21[a]
12	11.0	157± 7[a]	145±16[a]		
98	1.4	175±12[a]	8± 2[b]		
98	6.0	186± 9[a]	55± 8[b]	238±11[a]	163±15[a]
98	11.0	177± 9[a]	131±17[a]		
194	1.4	147± 8[a]	0[2]		
194	6.0	148± 7[a]	0[2]		
194	11.0	173± 8[a]	28± 5[b]		
290	6.0	184± 9[a]	0[2]		

[1] Mean±S.E. Within columns, means with a common superscript do not differ significantly (P>0.05), n=5.

[2] Treatments excluded from statistical analysis.

SECTION 8

CONCLUSION

CONCLUSION

This study has shown that PVC sticks are a viable alternative to the traditional tarred hardwood stick for settlement and retention of natural Sydney rock and Pacific oyster spat. The slurry-coated PVC discs were by far the best collector type for settlement of hatchery reared Sydney rock oyster larvae, although, PVC slats and slurry-coated slats also caught commercial numbers of spat. Orientation and surface composition of PVC collectors affected ($P<0.05$) settlement of Sydney rock oysters.

A sectionalised trays, developed by modifying the traditional timber growing tray and PVC cylinders proved to be successful nursery units for the culture of juvenile Sydney rock oysters. For sectionalised trays, optimum stocking densities based on biomass gain for 0.09, 1.15 and 1.56 g/oyster were 15200, 7200 and 3600 oysters/m^2 in that order. Optimum stocking densities for cylinders stocked with spat of 0.2 and 0.4 g/oyster were 2.0 and 3.0 l/cylinder respectively.

Comparative trials of various nursery units, found passive upwellers to be the most effective nursery units for survival and retention of newly settled juvenile Sydney rock oysters (minimum initial length 0.5 mm), despite the high mortalities (85%) which have been consistantly recorded from several NSW commercial nurseries using upwellers. Maximum shell growth was recorded from spat settled on PVC discs. For larger spat (initial weight 4.1 g and length 35.7 mm), best growth was recorded from spat grown in PVC baskets and the lowest growth from those in PVC cylinders, while the highest survival was in sectionalised trays.

An evaluation of a number of potential nursery sites for the culture of Sydney rock oysters found the inlet to the Vales Point Power Station, Lake Macquarie, to be an excellent site for culturing very small juvenile oysters (minimum initial length 0.5 mm) during winter. Over the winter months, better growth, meat condition and survival were obtained from larger juvenile Sydney rock oysters (range initial weight 2.2-17.2 g) grown subtidally in PVC mesh bags, then those grown in an adjacent fertilized prawn farming pond (20 Ml). For sectionalised nursery trays the best growth and survival were obtained during spring and autum at the more estuarine sites in Port Stephens, NSW.

Optimum storage temperature to transport pediveliger Sydney rock oyster larvae at sites remote from the hatchery was 11°C for up to 98 h, with excellent settlement (77-85%). This storage temperature is clearly different to the 6°C temperature found to be suitable in the experiment and presently used in the USA for transporting and commercially settling Pacific oyster larvae.

Results from these studies have been encouraging, and following their completion, numerous NSW farmers are now using the single seed culture techniques including PVC collectors and nursery growing units. The development of the sectionalised nursery tray and the determination of optimum stocking densities for the trays and cylinders, has helped NSW farmers improve the shape and uniformity of oysters and allowed them to alter their densities during grow-out.

Productivity should also improve with single seed culture as it dramatically reduces the large numbers of tarred catching sticks required, eliminating the need for large and expensive punts to transport them to the catching areas and reduces the amount of spat catching area or lease required. A comparative assessment of the various nursery systems has provided the farmer with information to choose the most suitable nursery unit for his operation. Subsequent to this study, a commercial nursery facility was established at the inlet to the Vales Point Power Station, Lake Macquarie. This study also showed that the more oceanic spat catching leases at Pindimar, which are vacant for six months of the year, could be used for nursery culture of Sydney rock oysters. Finally, the determination of storage time and temperature for Sydney rock oyster larvae, will reduce the cost of producing hatchery seed (as the initial and expensive on-shore nursery phase is eliminated) while allowing the farmer to settle larvae on a range of PVC collectors at the farm site and to utilise his nursery leases.

SECTION 9

APPENDIX

APPENDIX 1

Refereed manuscripts

1 Holliday, J. E., Maguire, G. B. and Nell, J. A., 1988. Alternative cultivation methods for the Sydney rock oyster (*Saccostrea commericalis*). In: L. H. Evans and D. O'Sullivan (Editors), Proceedings First Australian Shellfish Aquaculture Conference, Perth, October 1988. Curtin Univerity of Technology, Perth, WA, pp. 234-265.

2 Holliday, J. E., Allan, G. L. and Frances, J. 1991. Cold storage effects on setting of larvae of the Sydney rock oyster, *Saccostrea commercialis* and the Pacific oyster, *Crassostrea gigas*. Aquaculture, 92: 197-185.

3 Holliday, J. E., Magurie, G. B. and Nell, J. A. 1991. Optimum stocking density for nursery culture of Sydney rock oysters (*Saccostrea commercialis*) Aquaculture, 96: 7-16.

4 Holliday, J. E., Maguire, G. B. and Nell, J. A. 1991. Evaluation sites for nursery culture of single Sydney rock oysters (*Saccostrea commercialis*). Fisheries Technical Bulletin, NSW Fisheries, Salamander Bay, 5: 7p.

Submitted to refereed journal

5 Holliday, J. E., Allan, G. L. and Nell, J. A. 1991. Effects of stocking density on juvenile Sydney rock oysters *Saccostrea commercialis*, in cylinders. Aquaculture.

6 Holliday, J. E., Allan, J. L., Frances, J. and Diver, L. P. 1991. Evaluation of commercially-used collectors for the settlement or growth of Sydney rock oysters, *Saccostrea commercialis* and Pacific oysters, *Crassostrea gigas*. Aquaculture.

For combined Fisheries Bulletin

7 Holliday, J. E., Allan, G. L. and Diver, P. L. An assessment of hatchery settlement techniques and nursery units for Sydney rock oysters (*Saccostrea commercialis*).

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13 Holliday, J. E., 1988. Single seed production of Sydney rock oyster (*Saccostrea commercialis*). Proceedings Brackish Water Fish Culture Research Open Day, 1988, pp 3-10.

14 Holliday, J. E., 1989. Developments in setting and nursery techniques for Sydney rock and Pacific oysters. Proceedings Brackish Water Fish Culture Research Open Day, 1989, pp 29-41.

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16 Holliday, J., Allan, G. and Diver, L. 1990. An evaluation of nursery systems for the Sydney rock oyster (*Saccostrea commercialis*). Proceedings Brackish Water Fish Culture Research Open Day, 1990, pp 29-32.