OYSTER SETTLEMENT AND RECRUITMENT STUDY

PROJECT N° 88/104

FINAL REPORT TO FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

BY
STEPHEN M^c^ORRIE

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1. INTRODUCTION

The New South Wales (NSW) oyster industry is based almost entirely on the cultivation of the Sydney rock oyster *Saccostrea commercialis*. The current annual production of this highly esteemed seafood is valued at the farm gate in excess of 30 million dollars annually (Nell,1993). As with other commercially viable forms of aquaculture the Sydney rock oyster industry is dependent on a reliable source of seed stock (commonly known within the industry as spat) to be on-grown to a marketable product. The development of the Sydney rock oyster industry in NSW and southern Queensland has been based on the consistent annual spatfall (the natural seasonal settlement) of the Sydney rock oyster. Although there have been recent advances in the hatchery production of *S. commercialis* (Holliday,1985a,b; Holliday et al 1988) the industry at this stage is still totally dependent on natural spatfall for seed oysters. This dependence on natural spatfall leaves the industry vulnerable to any decrease in the annual production of existing commercial spat catching areas and as such the annual production of marketable oysters may reflect past poor spatfall years.

As a result of the reliable and wide spread spatfall of the Sydney rock oyster that occurs at Port Stephens NSW this estuary evolved as the major source of spat for the Sydney rock oyster industry. In recent years the estuary has produced in excess of 75% of the industry's annual spat requirements (Anon,1986). In 1986 commercial leases in Port Stephens produced approximately 3.5 million sticks caught with spat to be on-grown both locally and in other estuaries in NSW and southern Queensland (Anon,1986).

In recent years the Port Stephens area has experienced rapid growth in both tourist and residential development. Concern had been expressed as to the possible effects that a number of these developments adjacent to commercial catching areas may have had on the commercial oyster spatfall in these areas. It was recognised by both the oyster industry and NSW Fisheries that it was in the industry's long term interest that it's dependence on Port Stephens as the primary source of Sydney rock oyster spat be reduced. This requirement was further illustrated quite dramatically by the proliferation of the introduced Pacific oyster *Crassostrea gigas* at Port Stephens. This oyster was first introduced into southern Australia by the CSIRO in 1947 in an attempt to establish a commercial oyster industry in lieu of a viable commercial native rock oyster (Thomson,1952). By 1973 the Pacific oyster had found it's way to Port Stephens and it's presence was of concern to NSW Fisheries (Wolf & Medcof,1973) and although the introduction and proliferation of the oyster was causing serious problems in the cultivation of the native rock oyster *Saccostrea glomerata* in New Zealand it was regarded only as a curiosity by most NSW oyster farmers. In 1985 an alarmingly large and unexplained settlement of Pacific oysters occurred in Big Swan Bay, a major growing area in the upper reaches of Port Stephens. Since that time the oyster has spread rapidly throughout Port Stephens and subsequently Pacific oyster spat began to appeared in large numbers in other estuaries on stock originating from Port Stephens. By this time the Pacific oyster had rapidly displaced the native rock oyster as the species cultivated in most commercial growing areas in New Zealand. At the request of the oyster industry, controls were put in place by NSW Fisheries to limit the spread of this species from Port Stephens to other oyster producing estuaries in NSW. These controls currently prohibit the export of spat from Port Stephens and imposed strict inspection criteria on the inter estuarine movement of other more mature oyster stocks. As a result of a large scale colonisation by the Pacific oyster of both natural foreshore and man made structures in Port Stephens, and after considerable debate, the NSW Minister for Fisheries in 1992 granted permission for the commercial cultivation of the Pacific oyster to carried out at Port Stephens. Since that time many oyster farmers in Port Stephens have found that, using their traditional methods, it is no longer viable to cultivate either species in many areas of Port Stephens due to the heavy over-catch of Pacific oysters on their crops, and have since abandoned cultivation in these areas. However, a number of farmers are currently attempting to develop new methods to deal with the over-catch problem.

Currently oysters are grown commercially in 31 estuaries in NSW. The commercial cultivation of oysters in many of these estuaries as well as those in southern Queensland had developed as a result of the reliable supplies of spat available from Port Stephens. Subsequently, the events in Port Stephens have had a dramatic impact on the Sydney rock oyster industry. Oyster farmers in many estuaries have now been forced to investigate alternative sources of oyster spat to be on-grown on their leases. Although a number of other commercial spat catching areas do exist, at present only anecdotal evidence exists as to the reliability of these areas and to the extent to which they may be expanded to increase the amount of spat available to the industry. Unfortunately, little is known of either the planktonic dispersal stage or settlement behaviour of the Sydney rock oyster, or factors that determine the success or failure of the natural spatfall of the oyster. It is recognised that for the survival, growth, and future management of the industry it is essential to better understand the settlement regime of the Sydney rock oyster in order to:

(i) preserve the existing spatfall regimes of commercial spat catching areas.

(ii) develop criteria for the identification and assessment of other spatfall areas not currently exploited; and

(iii) enable, through a fuller understanding of settlement regimes, the development of more efficient methods of commercial spatfall utilisation.

1.2 OBJECTIVES

In view of the need to protect existing catching areas and increase the supplies of spat to the industry by increasing production from existing catching areas as well as expanding where possible these areas outside Port Stephens, the following broad research objectives were set.

(1) To identify factors which determine the efficiency of areas consistently producing good settlements of spat of the Sydney rock oyster *S. commercialis* and the Pacific oyster *C. gigas* in Port Stephens, NSW.

(2) To assess the potential of existing spatfall areas outside Port Stephens for the alternative supplies of Sydney rock oyster spat to the oyster industry.

(3) To identify other possible Sydney rock oyster settlement areas throughout NSW and conduct preliminary investigations as to their potential as commercial oyster catching areas.

(4) To develop a methodology and criteria, which can be used by the grower, for the identification and evaluation of potential commercial oyster settlement areas.

(5) To propose, through a fuller understanding of the settlement regimes of both the Sydney rock oyster and Pacific oyster, more efficient methods of commercial spatfall utilisation.

1.3 BIOLOGY OF THE SYDNEY ROCK OYSTER AND PACIFIC OYSTER

1.3.1 GEOGRAPHIC DISTRIBUTION

1.3.1.1 The Sydney Rock Oyster

The natural distribution of the Sydney rock oyster *Saccostrea commercialis* extends from Wingham Inlet in Victoria (37°S), through NSW and into northern Queensland (Roughly,1933; P.Dixon, personal communication,1988). Although the species colonises the exposed rocky coastline over most of it's range, it is most abundant within estuaries where it readily colonies hard clean intertidal substrates such as rocks, mangroves and man-made structures. The oyster also readily settles and grows sub-tidally, however the siltation of many estuaries and proliferation of the mud worm *Polydora websteri* which cause significant mortality in oysters (Smith,1981/1982) has greatly reduced the number of sub-tidal areas in which the oyster can now settle and survive.

1.3.1.2 The Pacific Oyster

The Pacific oyster *Crassostrea gigas* is now farmed commercially in Tasmania and South Australia in the absence of a suitable native rock oyster. In many areas where it is cultivated it now colonises both sub-tidal and inter-tidal substrates. Attempts to establish Pacific oyster populations in Victoria were initially thought to be unsuccessful, however, wild populations have since been reported. The oyster is now found in many NSW estuaries, where largely as a result of the inter-estuarine transport of commercial oyster stocks, it's range has extended as far north as the Hastings River (S 31°25') (D. Reid, unpublished data, 1990).

1.3.2 LIFE HISTORY

Both the Sydney rock oyster and Pacific oyster are hermaphrodites, that is, they belong to a group of organisms that have the ability to change their sex. The sexes are separate and generally the majority of oysters spawn in their first year as males, however, by the time they have grown to a marketable size most will have changed sex to female (Roughly,1933; Quayle,1988). Female Sydney rock oysters of a marketable size can produce in excess of 20 million eggs annually (L. Goard, personal communication,1991), while large female Pacific oysters may produce in excess of 50 - 100 million eggs annually (Quayle,1988), males of both species are capable of producing hundreds of millions of sperm. Both species have a simple reproductive system. When the sex organs have developed sufficiently, environmental cues such as temperature, salinity, availability of food etc, stimulate both male and female oysters to simultaneously discharge their sperm and eggs into the surrounding water where fertilisation takes place. Following fertilisation the developing planktonic larval oysters swim and feed on minute single celled marine plants (phytoplankton). The larval stage generally lasts about three weeks, however it is temperature dependant and may be extended by low water temperatures. During the larval stage predation by other marine organisms, starvation, unfavourable environmental conditions, and loss of larvae to the open sea, all account for the destruction of vast numbers of larvae each year. Those larvae that do survive to the settlement stage seek out suitable sites where they permanently attach, undergo a massive change of form (metamorphosis) and become recognisable as small oysters commonly referred to as spat.

1.4 COMMERCIAL OYSTER FARMING PRACTICES

Prior to European settlement, Sydney rock oysters were collected for food by aborigines along the coast line and some shell deposits in aboriginal kitchen middens have been dated to approximately 6,000 B.C. (Malcolm,1971). During the early colonisation of NSW the Sydney rock oyster was regularly gathered for food and vast amounts of the shell of live and dead oysters were burnt for the production of building lime. Natural stocks of the oyster were depleted to such an extent that an act of parliament was passed prohibiting the burning of live oysters (Roughley,1933).

The cultivation of oysters first began in NSW began in 1868 (Malcolm,1971). Over the years a number of methods have been used for the commercial cultivation of oysters (Croft,1967,1968; Malcolm, 1971). The most common method in use to-day is the rack system of cultivation using sticks and trays developed at Port Stephens in the 1930's (Croft,1967). The advantage of this method of cultivation is that it allowed oysters to be moved within and between estuaries enabling the oyster farmer to take advantage of optimum growing conditions both within his estuary and in other estuaries in NSW.

1.4.1 OBTAINING SPAT

The first stage of commercial cultivation is the procurement of spat, this involves the placement of catching material on racks constructed on commercial catching leases located in areas of reliable spatfall. The catching material is generally placed on the catching leases between the months of December and March to take advantage of the natural settlement of the Sydney rock oyster which usually takes place between the months of January and June.

Until recently the most commonly used catching material was the commercial hardwood oyster stick which is approximately 1.8 metres long and approximately 25mm^2. Frames of sticks are made with the aid of a jig attached to a sturdy nailing bench. Sticks are nailed parallel, approximately 10cm apart, to stick runners approximately 20cm from either end. Frames are generally made either 1.8 or 0.9m wide and consist of approximately 18 or 9 sticks depending on the width of the frame. Two frames are then interlocked to form a single layer and crates comprising five or six layers are built up. These crates are then dipped in tar to protect the timbers from marine borers during the commercial grow out period of the oyster. At the commercial catching leases the crates are placed on the racks and are fixed in position by wire ties. The racks consist of parallel rails approximately 1.2m apart, nailed to posts driven into the bottom. The racks support the crates above the sea floor just above low water neap tide. The tar, apart from providing protection from marine borers, provides a clean surface to which the oyster larvae readily attach, metamorphose and grow and also facilitates the removal of the oyster from the stick. The crates also afford protection to the newly settled oysters from the ravages of fish and the hot summer sun.

1.4.2 TRANSFERING TO DEPOT

Experience has shown that commercial oyster catching areas are invariably not good growing areas. Therefore after 6 to 10 months, when the oysters have grown sufficiently, the crates are moved to racks in more estuarine areas where better growth can be expected. Here in the "depot" they remain until the following winter by which time the oysters are approximately 18 months old and in most cases have grown sufficiently to withstand the ravages of fish predation. The individual crates are then broken down into single frames or crates and are nailed out in a single layer on growing racks.

1.4.3 CULLING, GRADING AND ON-GROWING

The oysters are left on the growing racks until sufficient growth has occurred for the oyster to reach market size, this usually takes between 30 and 42 months from settlement. At this stage the sticks are removed from the racks and taken to a shore based culling shed. Once in the culling shed the oysters are knocked from the sticks and separated into three grades; those 40g and over are sold as plate oysters, those 30 to 40g are either opened and sold as bottle oysters or placed either in trays or more recently in baskets to be put out on the growing racks for further growth to plate grade, smaller oysters are either returned to the growing lease in trays or baskets for further growth or sold within the industry as culled spat.

Trays are usually about 1m wide and range in length from 1.8 to 2.7m. They consist generally of a square tarred 75x25mm hardwood frame the floor of which consists of chicken wire or plastic mesh. This construction allows for good water circulation around the growing oysters allowing them to reach market size rapidly. In order to minimise losses of tray oysters due to wave action, tray leases are generally constructed in sheltered areas.

Plastic mesh baskets developed and used extensively by the Tasmanian and South Australian Pacific oyster industry are finding ready acceptance by many NSW oyster farmers and are replacing traditional trays in a number of areas. Baskets are made by folding commercial plastic mesh into an oblong shaped envelope, typically 450x350x250mm. A number of baskets (usually 3) are placed side by side and impaled at either end by an oyster stick which bind and support the baskets and enable the module to be attached to a traditional oyster rack using either nails or large rubber bands made from discarded car inner tubes. As with trays, baskets allow good water circulation around the growing oysters, they also have the added advantage of being able to be place in more exposed growing areas.

Oysters removed from sticks and on-grown using trays or baskets are generally considered to be of superior quality and shape as plate oysters when compared to stick grown oysters. Oysters in trays or baskets may also be moved by the oyster grower within or between estuaries to take advantage of optimum growth conditions and enables small oysters and spat which would otherwise be lost during the culling process to be grown to a marketable size.

1.4.4 RECENT ADVANCES IN COMMERCIAL OYSTER PRODUCTION

Competition in the market place from single seed (single oysters grown unattached to a substrate) Pacific oysters and recent advances in the hatchery production of single seed Sydney rock oysters at the Brackish Water Fish Culture Research Station (Holliday,1985a,b; Holliday et al.,1988) have had a significant impact on the NSW oyster industry. There is little doubt that the uniform and superior shape of single seed oysters provides these oysters with a considerable advantage in the market place, as well as facilitating a reduction in labour costs due to greater flexibility in handling. The realisation by the industry of these obvious benefits has led to rapid advances in the production of single seed oysters from naturally caught spat. The most notable of these developments has been the 'Stanway oyster cylinder system' (Moxham,1985; Holliday et al.,1988) and the sectionalised tray system (Holliday,1985; Holliday et al.,1988), which enable single spat scraped or flexed from a variety of catching material to be grown to a size that can be placed in trays or baskets and on-grown as single seed oysters.

1.4.5 ALTERNATIVE SOURCES OF SPAT

The Tasmanian and South Australian Pacific oyster industries are currently based entirely on hatchery produced single seed spat. It may be argued therefore that the hatchery production of single seed Sydney rock oyster spat is a viable alternative to the collection of natural spatfall for the Sydney rock oyster industry. However, hatchery production of the Sydney rock oyster will most likely supplement rather than replace natural spatfall for the following reasons:

(i) Currently production costs associated with the hatchery production of single seed spat are considerably higher than those of single seed produced from natural spatfall. It is therefore unlikely that hatchery production of single seed spat will be commercially viable where a reliable natural spatfall resource exists. As such there is little commercial incentive to establish commercial oyster hatcheries in NSW.

(ii) Single seed oyster produced either by hatcheries or from natural spatfall must invariably be on-grown using tray, basket or cylinder methods of cultivation. Areas suitable for these types of cultivation are limited. Leases in many areas are subject to heavy wind generated wave action and unless protected by expensive breakwall systems are suitable only for the cultivation of stick oysters.

(iii) Winter Mortality disease (Nell and Smith,1988) can cause periodic heavy losses of commercial oysters in estuaries in southern NSW. Many oyster farmers in these areas believe that oysters grown on sticks are not as vulnerable to the disease as those grown unattached and as such argue that the economic risks associated with the cultivation of oysters based entirely on single seed oysters is unacceptably high.

The market for hatchery produced spat would however expand rapidly if increased economic returns to the farmer could be demonstrated by oysters bred with characteristics such as faster growth, extended marketable condition, or resistance to Winter Mortality or QX disease the latter of which currently causes significant losses of commercial oysters in northern NSW irrespective of the method of cultivation. Currently a number of studies are being conducted by NSW Fisheries to investigate the possibility of producing a faster growing oyster by selective breeding and triploid induction.

2. THE LARVAL DISPERSAL, SETTLEMENT AND RECRUITMENT OF THE SYDNEY ROCK OYSTER AND THE PACIFIC OYSTER

The commercial importance of oyster culture to the fisheries of many countries has led to a considerable interest into the natural recruitment processes on which many of these fisheries rely (Andrews,1983; Carriker,1951; Kennedy,1986; Korringa,1941; Nelson,1957; Haven and Fritz,1985; Seliger et. al.,1982). However, oyster larval research has in many cases been severely hampered by low larval abundances as a result of oyster populations in serious decline (Andrews,1979,1983; Pritchard,1953).

Although the Sydney rock oyster industry is one of the most valuable aquaculture industries in Australia, little is known of the larval transport and settlement regimes of the Sydney rock oyster. While the larval dispersal stage of the Pacific oyster has been the subject of a number of studies, it is not known if the results of these studies can be extrapolated to the Australian marine and estuarine environments where it is now established. Port Stephens with its large quantities of broodstock of both species, its well defined and separate areas for the growing of oysters and the collection of spat, its highly productive and consistently heavy spatfall, provides a unique opportunity to investigate the settlement regimes of both the Sydney rock oyster and the Pacific oyster.

2.1 STUDY AREA

Port Stephens (Fig. 2.1) is a major NSW estuary approximately 150km north of Sydney and has one of the few all-weather entrances along the NSW coastline. It opens to the sea between Yacaaba and Tomaree Heads. The entrance is 1.3km wide and approximately 15m deep. The port penetrates some 23km inland, is up to 5km wide and covers an area of approximately 125km^2. The configuration of the estuary today is a result of the development of a series of coastal sand barriers laid down on the existing valley of the Karuah River and its tributaries during past changes in sea level. The present dual barrier system is separated by Tilligerry Creek to the south and the Myall River to the north (Thom,1965).

To the north, Port Stephens is bordered by outcrops of carboniferous sediments some over 100m in height. These shores have a cover of medium timber and are generally steep with minor alluvial deposits occurring at the heads of embayment. To the west and south west the relief is generally subdued with a cover of medium timber, mangroves and marshland. The south eastern shores are characterised by isolated carboniferous bedrock highs some up to 200m in height which are partially covered by deposits of wind blown sand of marine origin (Thom,1965; Anon,1979).

At Soldiers Point the estuary is divided into two basins of approximately equal volume by a constriction of land (Rochford,1951). At this point Middle Island forms

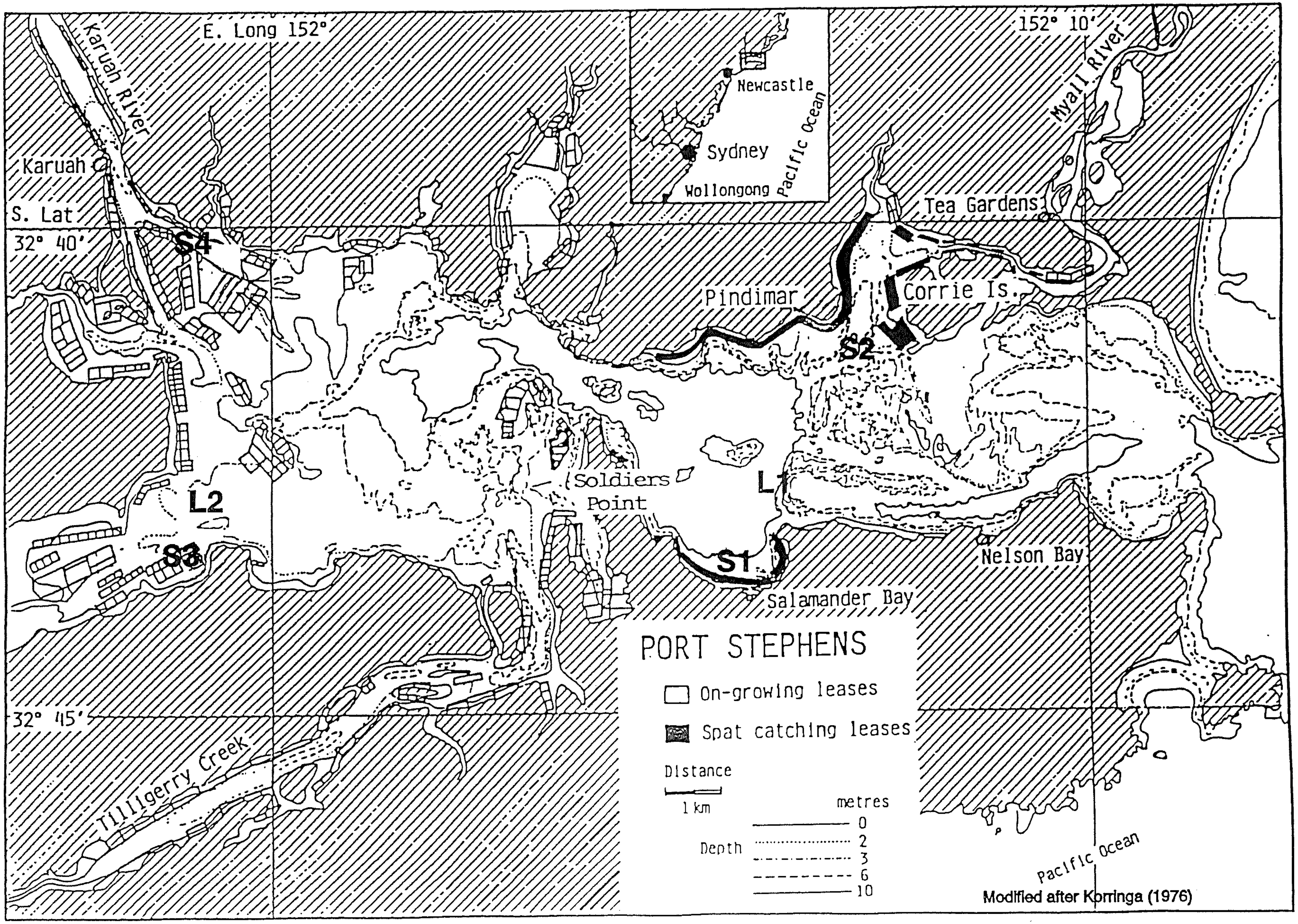


Figure 2.1 The location of oyster settlement and plankton monitoring sites in Port Stephens NSW. Settlement sites (S1, S2, S3, and S4,); Plankton sites (L1 and L2)

two channels, each approximately 400m wide and in places over 30m deep.

The eastern basin of the Port is in the early stages of infill by quartz sands of marine origin (Roy et al.,1980). These sands intrude approximately 7km into the eastern basin as far as Corlette Point to the south and the mouth of the Myall River to the north. This area of infill consists of a complex system of shoals and is generally shallow with depths of less than 5m. It is intersected by two well defined channels, Middle and South Channel. Of these, South Channel which hugs the southern shore line from Nelson Head to Corlette Head is the major navigation channel. This channel ranges in depth from less than seven meters adjacent to Corlette Point to a maximum depth of approximately 30m in the Nelson Head/Fly Point area. West of Corlette Point the eastern basin deepens rapidly to an average depth of approximately 15m, here bottom substrates are comprised mainly of estuarine muds and sandy muds.

To the west of Soldiers Point the estuary is shallow with an average depth of less than 3m. The bottom substrate consists mainly of non-marine mud and sandy mud associated with the deposition of sediments carried into the western basin by the Karuah River, Tillegerry Creek, Twelve Mile Creek and Reedy Creek.

The mean tidal range at Soldiers Point is approximately 1.7m at spring and 0.9m at neap tides (Anon,1970). In the channels either side of Middle Island and South Channel in the eastern basin tidal current velocities can exceed 1.5m per second during spring tides (Anon,1970).

Two major river systems flow into Port Stephens; the Karuah River with a catchment of approximately 2200 km^2 (Anon,1982) enters the western basin from the north west, while the Myall River with a catchment of approximately 760 km^2 enters the eastern basin from the north. Both these river systems experience strong tidal flows and tidal influence extends as far as Allworth in the Karuah River and Tamboy in the Myall River. Significant, though highly variable amounts of fresh water enter the Port from both river system.

In his study of Australian estuarine hydrology Rochford (1951) considered Port Stephens to be a unique estuary and came to a conclusion that as a result of its unusual physiogeographical features that the eastern basin was marine dominated, while the western basin was tidally dominated.

The collection of spat within Port Stephens is generally carried out on extensive intertidal leases in the marine dominated eastern basin of the estuary, while the growing and fattening of oysters is generally confined to the more estuarine western basin of the Port, west of Soldiers Point (Fig. 2.1). On the northern shore of the eastern basin commercial spat catching leases stretch from the narrows at Soldiers Point to Corrie Island and extend into the Myall River as far as the Tea Gardens bridge. While on the southern shore the major commercial spat catching leases are located in Salamander Bay with minor areas at Wanda Head and Kangaroo Point. Some spat catching of minor significance is also carried out at Dowardee Island at

Soldiers Point and periodically on-growing leases at the mouth of the Karuah River. In total the commercial spat catching leases in Port Stephens cover approximately 16 km of shoreline. Recent estimates (S.McOrrie, unpublished data,1992) indicate that fully utilised the catching leases of Port Stephens have the capacity to produce approximately 4 million sticks caught with spat.

2.2 THE SEASONAL ABUNDANCE AND SETTLEMENT OF THE LARVAE OF THE SYDNEY ROCK OYSTER *SACCOSTREA COMMERCIALIS* AND THE PACIFIC OYSTER *CRASSOSTREA GIGAS* IN PORT STEPHENS NSW (AUSTRALIA)

2.2.1 INTRODUCTION

The optimum marketing condition for the Sydney rock oyster (fat oyster) occurs when the gonad of the oyster is well developed prior to spawning. As a result of the desire by oyster farmers to market a premium oyster they have accumulated considerable knowledge as to the major spawning period of the Sydney rock oyster in their individual estuaries. This knowledge combined with observations of the occurrence of oyster settlement on both their maturing stock and oyster trays has enabled farmers to deploy their commercial catching sticks during the period that they believe will most likely result in a commercial catch of oyster spat. Over the years this has led to the development of a "set and forget" system of spat collection in which tarred sawn timber sticks are placed on commercial catching leases between the months of December and March to take advantage of the available natural spatfall of the Sydney rock oyster, thought to occur between the months of December and May. The following spring the sticks caught with oyster spat are removed from the catching leases and transported to the growing areas. At Port Stephens the major commercial oyster settlement areas are located in the marine dominated outer basin (Rochford,1951) of the port and are a considerable distance from commercial growing areas in the more estuarine inner basin (Rochford,1951) of the port (Fig. 2.1). The correlation between spawning activity and oyster settlement in the growing areas and the oyster settlement that occurs on the commercial catching leases is therefore purely speculative. The "set and forget" method of spat collection practiced by oyster farmers in Port Stephens has been subject to a number of major commercial settlement failures which have had a marked impact on subsequent oyster production both locally and throughout the industry. In Port Stephens these failures are said to occur about once every six years (Korringa,1976). The most recent of these major spatfall failures occurred in 1983 (G.Diemar, personal communication, 1989) and as with earlier failures no explanation could be given.

The proliferation of the introduced Pacific oyster has caused considerable problems for the cultivation of oysters in Port Stephens. In recent years the number of Pacific oysters in the port has increased rapidly and the oyster now settles in large numbers in many growing areas previously prized for their low incidence of oyster overcatch (Nell and Mason,1991; Reid,1991). In many areas previously used for the stick cultivation of Sydney rock oysters the Pacific oyster now settle in such large numbers on the sticks caught with Sydney rock oysters that they eventually smother the crop. To date no economically viable method has been developed to control the overcatch of Pacific oysters occurring on stick crops of Sydney rock oysters and in some prime growing areas at Port Stephens the stick cultivation of Sydney rock oysters now appears to be no longer viable. In most areas used for tray and basket cultivation it is now necessary to regularly remove oysters from the lease to kill the rapidly growing Pacific oyster overcatch either manually or by drying (Nell and Mason,1991) this has increased the labour component of production costs significantly. In commercial catching areas, when settling together on catching sticks, the faster growing Pacific oyster may rapidly smother the much slower growing spat of the Sydney rock oyster.

In catching areas where the Pacific oyster is now present many Sydney rock oyster farmers wishing to avoid a catch of Pacific oysters amongst their Sydney rock oyster catch are delaying the deployment of their catching sticks with little information as to the settlement period of the Pacific oyster or as to how the delayed deployment of sticks may impact on their commercial Sydney rock oyster catch. Due to the overwhelming numbers of Pacific oysters in Port Stephens changes to the Fisheries and Oyster Farms Act (1935) in 1992 allowed the cultivation of the Pacific oyster in Port Stephens. A number of Port Stephens farmers have since made a commercial decision to grow Pacific oysters on their leases. To be commercially viable these farmers require a reliable source of Pacific oyster spat. The extent to which natural spatfall of the Pacific oyster in Port Stephens can be exploited to provide this spat is unknown. The Pacific oyster in Port Stephens is in peak reproductive condition during the spring and early summer months (Nell,1986), however little is known of the seasonal settlement patterns of the oyster at Port Stephens or other estuaries in NSW.

Detailed information of the seasonal larval abundance and settlement of both the Sydney rock oyster and Pacific oyster in Port Stephens will be of considerable value to growers in this estuary as it will enable both more efficient management of crops and the optimisation of spatfall of both species. This information may also be of considerable use in the development of management practices to manage the overcatch of Pacific oysters in other estuaries in NSW where it is now established.

2.2.2 AIMS

To facilitate objective (1) section 1.2, it was necessary to determine the seasonal larval abundance and settlement patterns of the Sydney rock oyster and Pacific oyster in Port Stephens NSW.

2.2.3 METHODS

Data presented here from 1985 to 1987 was collected as part of the Salamander Bay Spatfall Study funded by Port Stephens Shire Council.

2.2.3.1 Oyster larval abundance

Oyster larval abundance, oyster settlement and hydrological data was collected regularly at site in Port Stephens over two periods. The first period (P1) between September 1985 and August 1987 embraced two consecutive settlement seasons the first (P1.1) from October 1985 to September 1986, and the second (P1.2) from October 1986 to late July 1987. Similarly the second period (P2) between June 1989 and August 1991 also embraced two consecutive settlement seasons the first (P2.1) from October 1989 to September 1990, and the second (P2.2) from October 1990 to late July 1991. During these periods the oyster larval component of the plankton was sampled regularly at 2 reference sites. Site L1 (Fig. 2.1) was located centrally and adjacent to the major settlement areas in the outer basin of Port Stephens while site L2 (Fig. 2.1) was located centrally and adjacent to the major oyster growing area in Big Swan Bay in the inner basin of Port Stephens, an area of consistent heavy Pacific oyster settlement. On each sampling occasion, 5 replicate vertical plankton hauls were made at each site. Sampling was always carried out at slack water low tide. Hauls were carried out using a conical 100μm nylon mesh net with mouth diameter of 0.36m. and an overall length of 1.9m, as described by Tranter and Smith (1974). The cod-end of the net was fitted with an internally threaded perspex ring to take a 180ml plastic jar. As it had been reported in the literature that most late-stage oyster larvae are mostly found close to the bottom (Carriker,1951,1961; Nelson,1955), the vertical haul net was modified to sample from as close to the bottom as possible. This modification (Fig. 2.1), consisted of three lead weights approximately 1 kg each, attached to the net mouth at the points of bridle attachment. A cone of 25mm mesh net attached over the bridles at the net mouth. Prior to lowering the net was folded and placed inside the mesh cone from below. It was then lowered to the bottom in the haul position. Water pressure and some entrained air held the net in position within the mesh cone and suspended the net mouth approximately 200mm above the bottom (Fig. 2.2). On hauling the net opened to its normal sampling configuration (Fig. 2.2). Net malfunction was rarely observed, however, on such occasions the net was washed and the procedure repeated. The 25mm mesh cone had the added advantage of excluding from the catch large jelly fish and ctenophores, which may occur in large numbers in Port Stephens during the summer months. The haul line was marked at half meter intervals. Haul distance was recorded with each sample which allowed the data to be standardised to number of larvae per 1000L. After each haul the catch was carefully washed into the attached plankton jar. The jar was removed and 20ml of preservative was added, the jar was labelled and sealed with a screw top lid and stored. The preservative was that recommended by Cullinay et al. (1975) and comprised; 5.0ml of 40% formalin, 1.0ml propylene phenoxitol, 10.0ml propylene glycol, buffered with sodium glycerophosphate to a pH of 8. Between samples the net was carefully rinsed to minimise cross sample contamination. When wind conditions warranted, a sea anchor was used to minimise wind induced boat drift. This greatly reduced problems associated with lowering and retrieving sampling equipment. To determine the size composition and the total number of oyster larvae present in each sample, individual plankton samples were washed down through a series of sieves of decreasing size, 500, 200, 140 and 100μm respectively. The

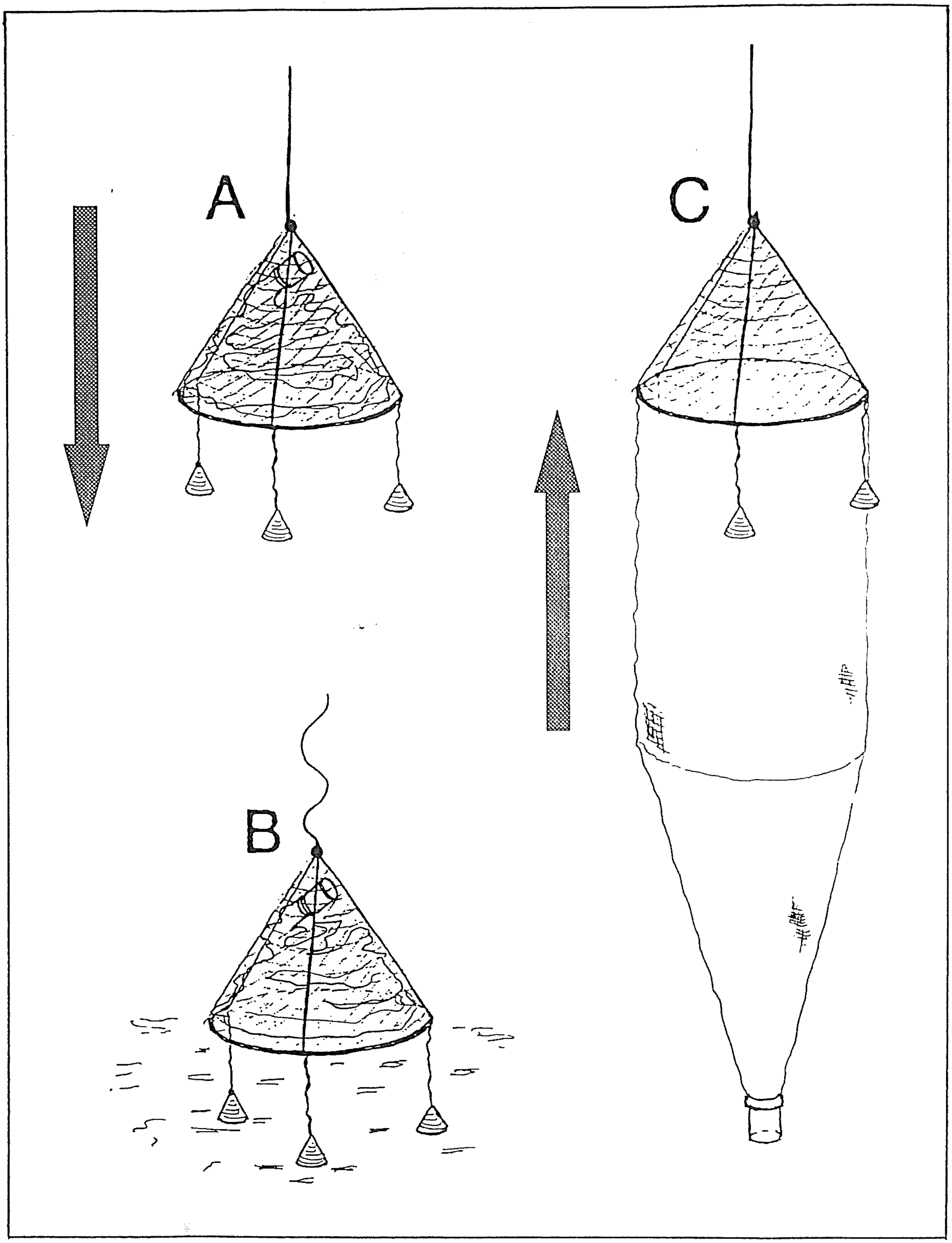


Figure 2.2 The vertical haul plankton net (A) in the lowering configuration; (B) in the the bottom resting configuration; and (C) in vertical haul configuration.

500μm sieve allowed oyster larvae to pass while retaining large plankton which may make counting difficult. The contents of the 200, 140 and 100μm sieves were carefully washed into separate 180 ml jars and allowed to settle. The contents of each jar were then transfered to a rotating plastic plankton counting ring, where the number of oyster larvae present were counted using a stereomicroscope and hand counter. Total counts were performed on all samples. After counting each sample was transfered to the original encoded 180 ml jar, preserved in 75% ethanol to inhibit the dissolution of the larval shell and stored for further reference. All eyed oyster larvae were identified and enumerated. The identifications of *S. commercialis* and *Crassostrea gigas* larvae present in the plankton samples were carried out with the aide of both the literature (Roughley,1933; Dinamani,1973) and larval reference set taken during larval rearing experiments for both species conducted at the NSW Fisheries Brackish Water Fish Culture Research Station.

For the purpose of this study, four arbitrary stages of development are defined:

1. Early stage - Those larvae passing through a 140μm sieve and retained on a 100μm sieve.

2. Mid stage - Those larvae passing through a 200μm and retained on a 140μm sieve.

3. Late stage - Those larvae retained on a 200μm sieve; and including,

4. Settling stage larvae - Those larvae retained on a 200μm sieve having a well defined pigmented eye spot.

Throughout the year large numbers of larvae of other bivalve species occur in the waters of Port Stephens, particularly during the summer months (M^{c}Orrie,1984). During the straight hinge stage of development most bivalve larvae are similar in appearance and cannot be separated at the species level (Chanley and Andrews,1971; Chanley and Chanley,1980). To avoid problems associated with the specific identification of straight hinge stage larvae a sampling net with a mesh size of 100μm was chosen. This mesh size retains only those larvae greater than approximately 120μm, by which stage oyster larvae can be discerned from the larvae of other species of bivalves in the plankton. The terminology used in the description of larval features is that of Chanley and Andrews (1971). All larval counts were standardised to larvae per 1000 litres of sea water.

2.2.3.2 Hydrology

Measurements of salinity and temperature were made with a Hamond Salinity-Temperature Meter (Yeo-Cal Australia Pty Ltd). The meter was calibrated regularly against standard sea water (provided by Yeo-Cal) and a reference thermometer (Zeal). Vertical depth profiles of temperature and salinity were taken on each plankton sampling occasion at each site. Measurements were made at the surface and one meter intervals there after. Individual profile data was pooled and the mean salinity and temperature value calculated for each site on each sampling occasion. As sampling was carried out from a 6m open boat, on some occasions severe weather conditions precluded collection of plankton samples and hydrological data at some sites.

2.2.3.3 Settlement

Settlement was monitored at 4 sites using 40 mm fibro cement strip (Fibro 40mm Cover Mould; James Hardie Ltd., Australia). Sites S1 and S2 (Fig. 2.1) were located on commercial catching leases in the outer basin of Port Stephens, while sites S3 and S4 (Fig. 2.1) were located in commercial growing areas in the inner basin of Port Stephens. In period 1, commercial settlement was monitored weekly using three replicate strips at each site. Each replicate consisted of a 480 mm x 40 mm x 5 mm strips deployed horizontally on commercial catching racks, at rack height. In period 2, five replicate strips were maintained at each site and were replaced bi-weekly where possible. Each replicate consisted of a single 480mm x 40mm x 5mm strip deployed horizontally on commercial oyster rack, at rack height. All collectors were inscribed with a code indicating site and deployment period. In the laboratory total counts were made of the number of *S. commercialis* and *C. gigas* spat settled on the under surface of each fibro strip. Counts were made with the aid of a stereomicroscope and hand counter. Counts were standardised to the number of spat settled per 100 cm^2 and to compensate for differences in periods of exposure expressed as spat settled per 100 cm^2 per day. Species identifications were verified where necessary by on growing. Outer port and inner port settlement means were calculated by pooling the data for sites S1 and S2 and sites S3 and S4 respectively.

2.2.3.4 Larval abundance, settlement and hydrology

The relationship between the larval abundance, settlement and hydrological parameters are presented graphically. To elucidate any relationship between larval abundance and temperature, the abundance of eyed larvae of both species was plotted against the corresponding site temperature mean.

2.2.4 RESULTS

2.2.4.1 Hydrology

A strong seasonal trend is evident in temperature data collected at sites L1 and L2 during periods 1 and 2 (Figs. 2.3, 2.4, 2.5 and 2.6). At site L2 the mean water temperature ranged from a winter minimum of 12.0°C during August 1986 to a summer maximum of 28.2°C in February 1987 during period 1 and from a winter minimum of 13.2°C during July 1990 to a summer maximum of 27.2°C in February 1990 during period 2. At site L1 the mean water temperature ranged from a winter minimum of 13.7°C in August 1986 to a summer maximum of 24.6°C in January 1987 during period 1 and from a winter minimum of 14.1°C in August 1990 to a summer

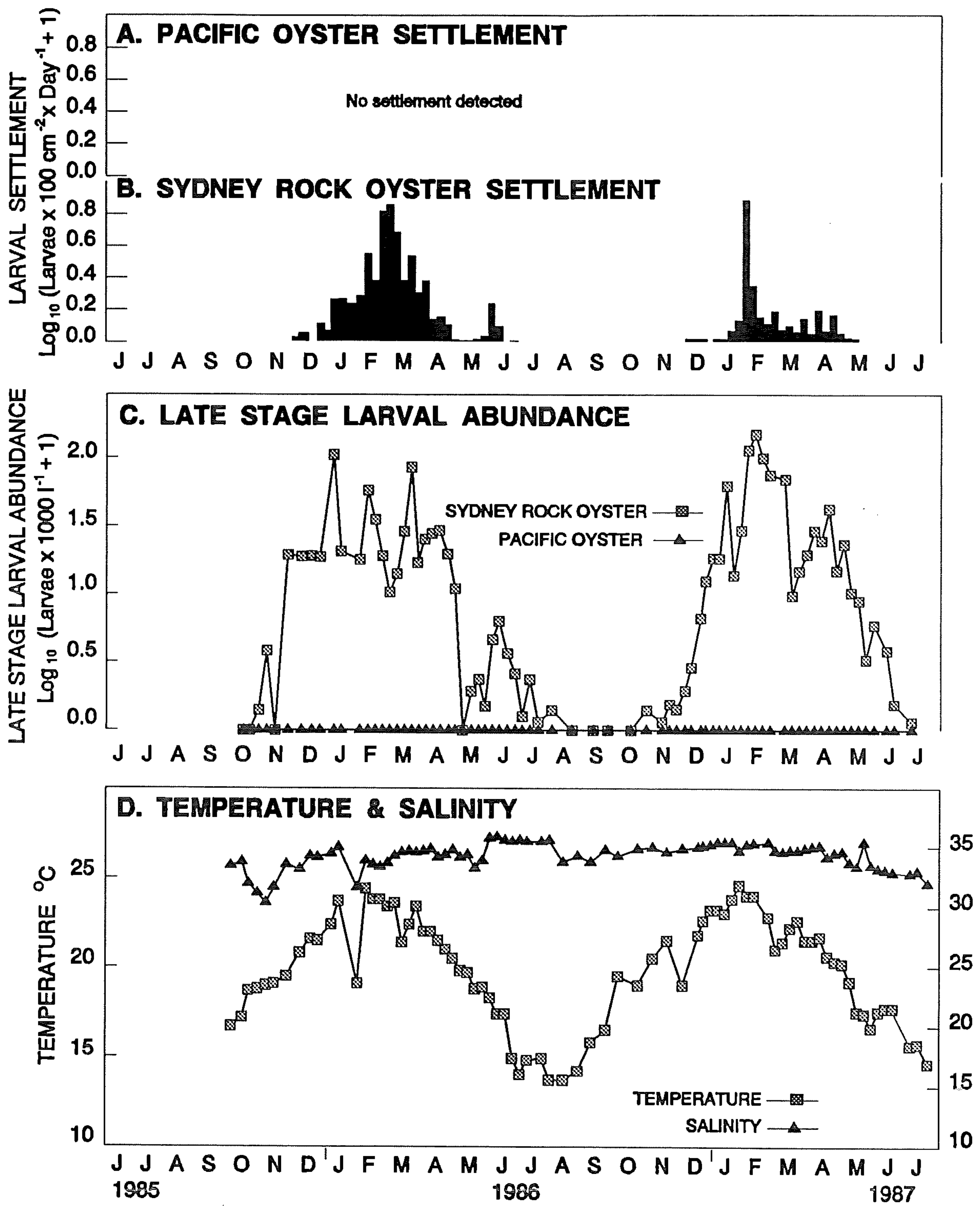


Figure 2.3 The larval abundance and settlement of the Sydney rock oyster and Pacific oyster in relation to mean water temperature and salinity in the outer basin of Port Stephens NSW (1985/1987). The settlement of Pacific oysters (A) and Sydney rock oysters (B) are expressed as Log(10)(x+1) of the mean settlement per under surface of Fibro strip (n=6) at site S1 and S2 per 100 sq cm per day. Oyster larval abundances are expressed as Log(10)(x+1) mean larval abundance of vertical plankton hauls (n=5) taken at site L1. Temperature and salinity (D) are expressed as the mean vertical profile temperature and salinity on each sampling occasion (from McOrrie, 1995).

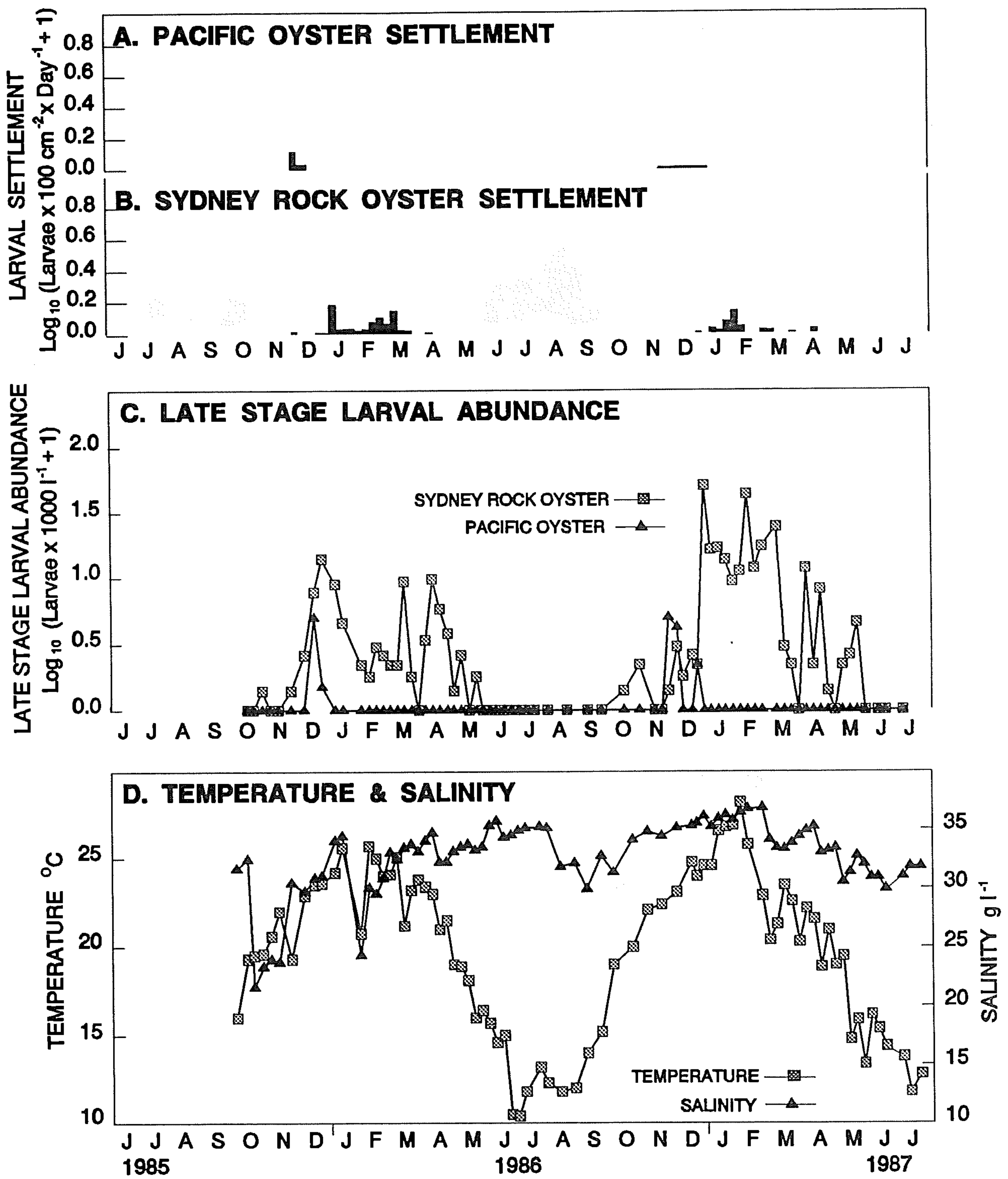


Figure 2.4 The larval abundance and settlement of the Sydney rock oyster and Pacific oyster in relation to mean water temperature and salinity in the inner basin of Port Stephens NSW (1985/1987). The settlement of Pacific oysters (A) and Sydney rock oysters (B) are expressed as Log(10)(x+1) of the mean settlement per under surface of Fibro strip (n=6) at site S1 and S2 per 100 sq cm per day. Oyster larval abundances are expressed as Log(10)(x+1) mean larval abundance of vertical plankton hauls (n=5) taken at site L2. Temperature and salinity (D) are expressed as the mean vertical profile temperature and salinity on each sampling occasion (from McOrrie, 1995).

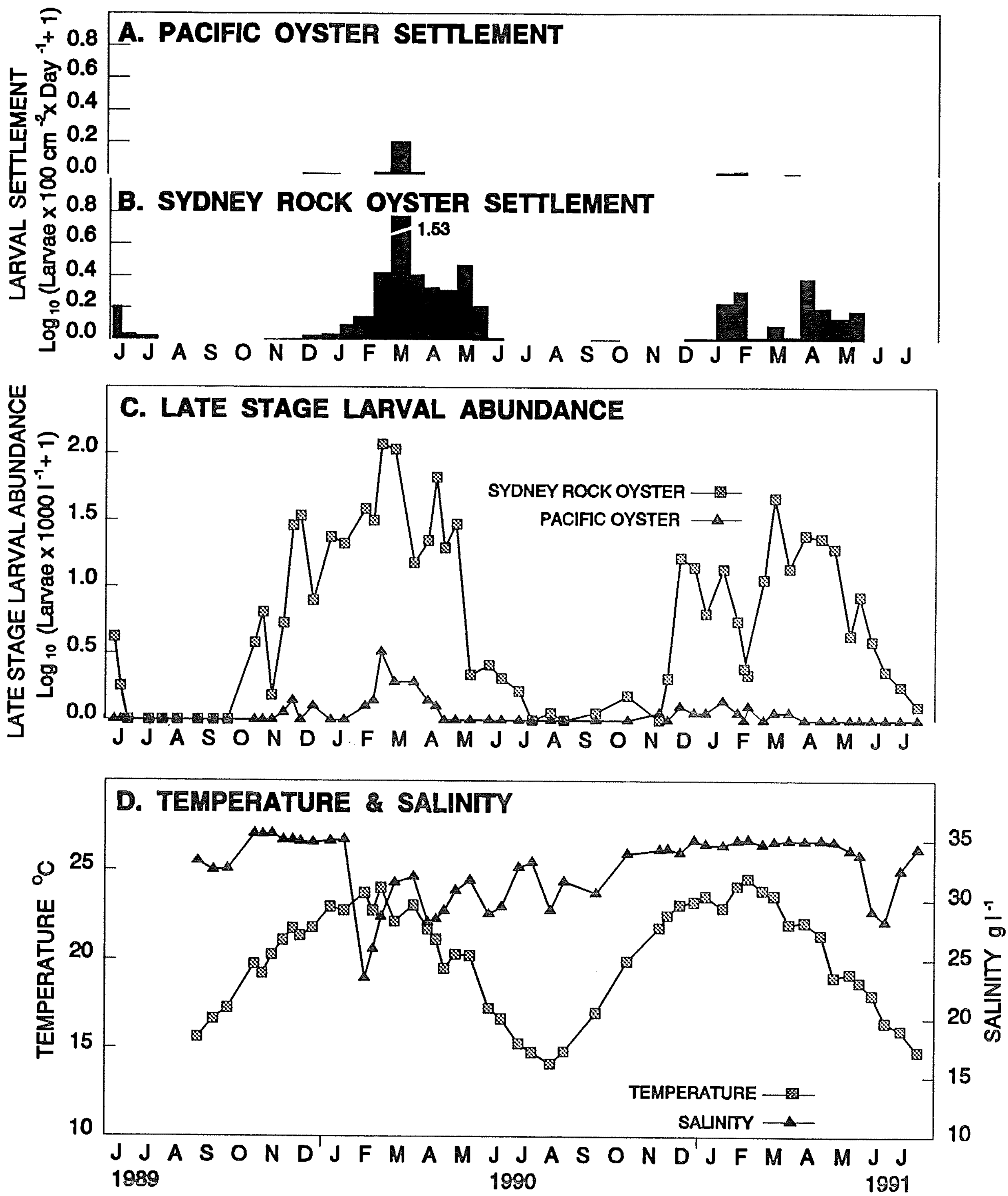


Figure 2.5 The larval abundance and settlement of the Sydney rock oyster and Pacific oyster in relation to mean water temperature and salinity in the outer basin of Port Stephens NSW (1989/1991). The settlement of Pacific oysters (A) and Sydney rock oysters (B) are expresse as Log(10)(x+1) of the mean settlement per under surface of Fibro strip (n=6) at site S1 and S2 per 100 sq cm per day. Oyster larval abundances are expressed as Log(10)(x+1) mean larval abundance of vertical plankton hauls (n=5) taken at site L1. Temperature and salinity (D) are expressed as the mean vertical profile temperature and salinity on each sampling occasion.

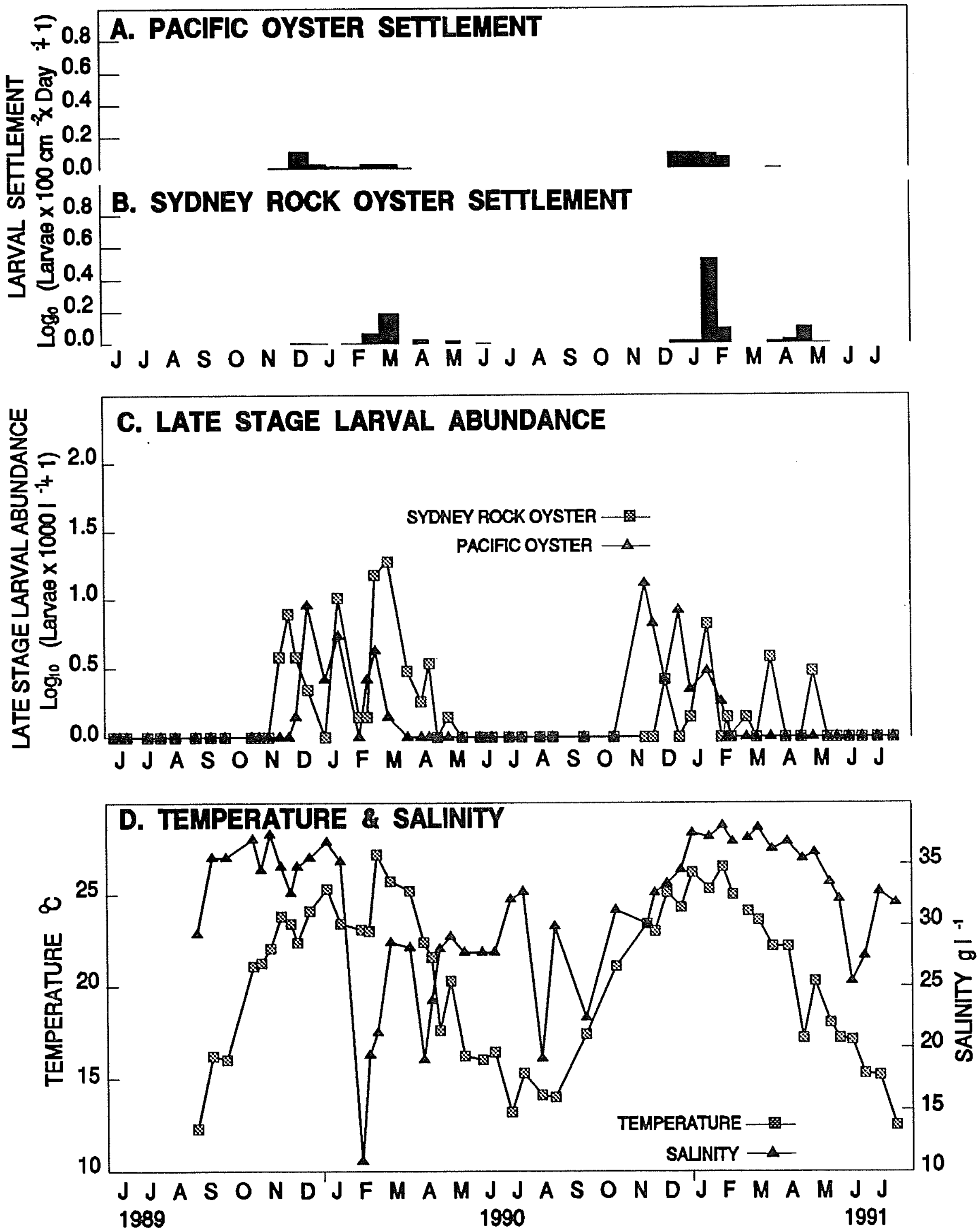


Figure 2.6 The larval abundance and settlement of the Sydney rock oyster and Pacific oyster in relation to mean water temperature and salinity in the inner basin of Port Stephens NSW (1989/1991). The settlement of Pacific oysters (A) and Sydney rock oysters (B) are expresse as Log(10)(x+1) of the mean settlement per under surface of Fibro strip (n=6) at site S1 and S2 per 100 sq cm per day. Oyster larval abundances are expressed as Log(10)(x+1) mean larval abundance of vertical plankton hauls (n=5) taken at site L2. Temperature and salinity (D) are expressed as the mean vertical profile temperature and salinity on each sampling occasion.

maximum of 24.6°C in February 1991 during period 2. Site L2 was generally characterised by higher summer and lower winter temperatures than site L1 during both periods. At site L2 mean salinities ranged from $21.6gL^{-1}$ to $36.8gL^{-1}$ in period 1 and from $10.8gL^{-1}$ to $38.1gL^{-1}$ in period 2, while at site L1 mean salinities ranged from $30.4gL^{-1}$ to $35.9gL^{-1}$ in period 1 and from $23.4gL^{-1}$ to $35.6gL^{-1}$ in period 2. During period 1 mean salinities were generally high (above $33.0gL^{-1}$) with salinity quickly recovering from periodic depressions of salinity associated with local rainfall events. During period 2 prolonged periods of depressed salinity were associated with run off from a series of rain events that caused major flooding along the NSW coast during 1990 (appendix 1). During this period mean salinity at both site L2 and L1 remained below $33.0gL^{-1}$ for extended periods. The depressions of mean salinity associated with rainfall events were larger a site L2 than at site L1, while during dry periods mean salinities recorded at site L2 exceeded those recorded at site L1 and in a number of instances exceeded $35.0gL^{-1}$.

2.2.4.2 Oyster larval abundance

Oyster larvae were present in plankton samples in all months other than September 1986 period 1 and August 1990 period 2. In 1985, 1986, 1989 and 1990 the number of late stage Sydney rock oyster larvae in the plankton increased rapidly at both sites L1 and L2 from October to December, after which major peaks in abundance occurred between November and May, declining to low or undetectable between the months of July and October. Late stage larvae were more abundant at site L1 than at L2, while site L2 was characterised by large numbers of earlier stage larvae.

Late stage Pacific oyster larvae were not detected in plankton samples at site L1 during period 1. However, over the same period, small numbers of larvae were detected at site L2 in December 1985 and between late November and late December 1986. During period 2 late stage Pacific oyster larvae were present in plankton samples taken at both sites L1 and L2 from November until May, with larger numbers of larvae observed at site L2.

2.2.4.3 Oyster settlement

Larvae of the Sydney rock oyster settled at monitoring site in the outer port between the months of November and July in P1.1, between November and mid May P1.2, between October and July P2.1 and between mid December and June P2.2. Minor settlement was also detected between mid September and mid October 1990. During P1.1 settlement began in early December and increased steadily through a series of peaks to a maximum occurring between late February and early March. Settlement then declining through a series of peaks to be barely detectable during May with a further minor peak occurring during early to mid June 1986. Settlement was not detected again until December 1986. During P1.2 settlement was first detected in December 1986 and was characterised by a single major peak occurring in February 1987 followed by a series of small peaks until settlement ceased in mid May 1987. During P2.1 settlement began in early November 1989 and increased steadily with a major peak occurring in March 1990 followed by a smaller peak during May 1990 with settlement ceasing in mid June 1990. During P2.2 settlement began in mid December 1990 and remained low with peaks in settlement between mid January 1991 and mid February 1991 and early April 1991 and late May 1991 after which settlement ceased. Settlement at monitoring sites in the inner port, although consistently much lower than that observed in the outer port, tended to coincide with the settlement trends in the outer port.

During period 1 settlement of the Pacific oyster was not observed in the outer port, however, during this period settlement of Pacific oyster larvae was observed at monitoring sites during early and mid December 1985 and from mid November 1986 to mid January 1987. During period 2 Pacific oyster settlement occurred in the outer port with a minor settlement observed between mid December 1989 and mid January 1990 followed by a larger settlement between mid February 1990 and early April 1990 with a peak during March 1990. Settlement was also observed from mid January 1991 to mid February 1991 and during late March 1991. Settlement in the inner port during period 2 occurred between mid November 1989 and mid April 1990, between mid December 1990 and late February 1991 with minor settlement occurring during early April 1991. Apart for March 1990, settlement of Pacific oyster larvae was observed to be higher in the inner port than the outer port.

2.2.4.4 Oyster larval abundance, settlement and hydrology

During periods of increasing and decreasing seasonal water temperature (Fig. 2.7), early stage oyster larvae were present in the plankton at mean water temperatures above 13.0 °C. Late stage larvae of the Sydney rock oyster (Fig. 2.8) were also present at mean water temperatures as low as 13.7°C during both increasing and decreasing mean water temperatures. However, during periods of increasing seasonal temperatures (Fig. 2.8) the number of late stage larvae began to increased rapidly once mean water temperatures exceeded 19.0°C, while during periods of falling seasonal temperatures larval tended to decline more gradually. During periods of both increasing and decreasing seasonal temperatures (Fig. 2.9) eyed larvae of the Pacific oyster were only present at temperatures above 21.0°C.

2.2.5 DISCUSSION

The occurrence in Port Stephens of the larvae and subsequent settlement of Sydney rock oyster during all but the coldest months of the year indicates that the Sydney rock oyster is capable of spawning and undergoing successful larval development and settlement over a wide range of water temperatures, particularly towards the end of its reproductive period. This, in conjunction with the ability of the Sydney rock oyster to partially spawn a number of times during it's reproductive period (Roughley,1933; Nell and Mason,1991) and the variation in hydrological

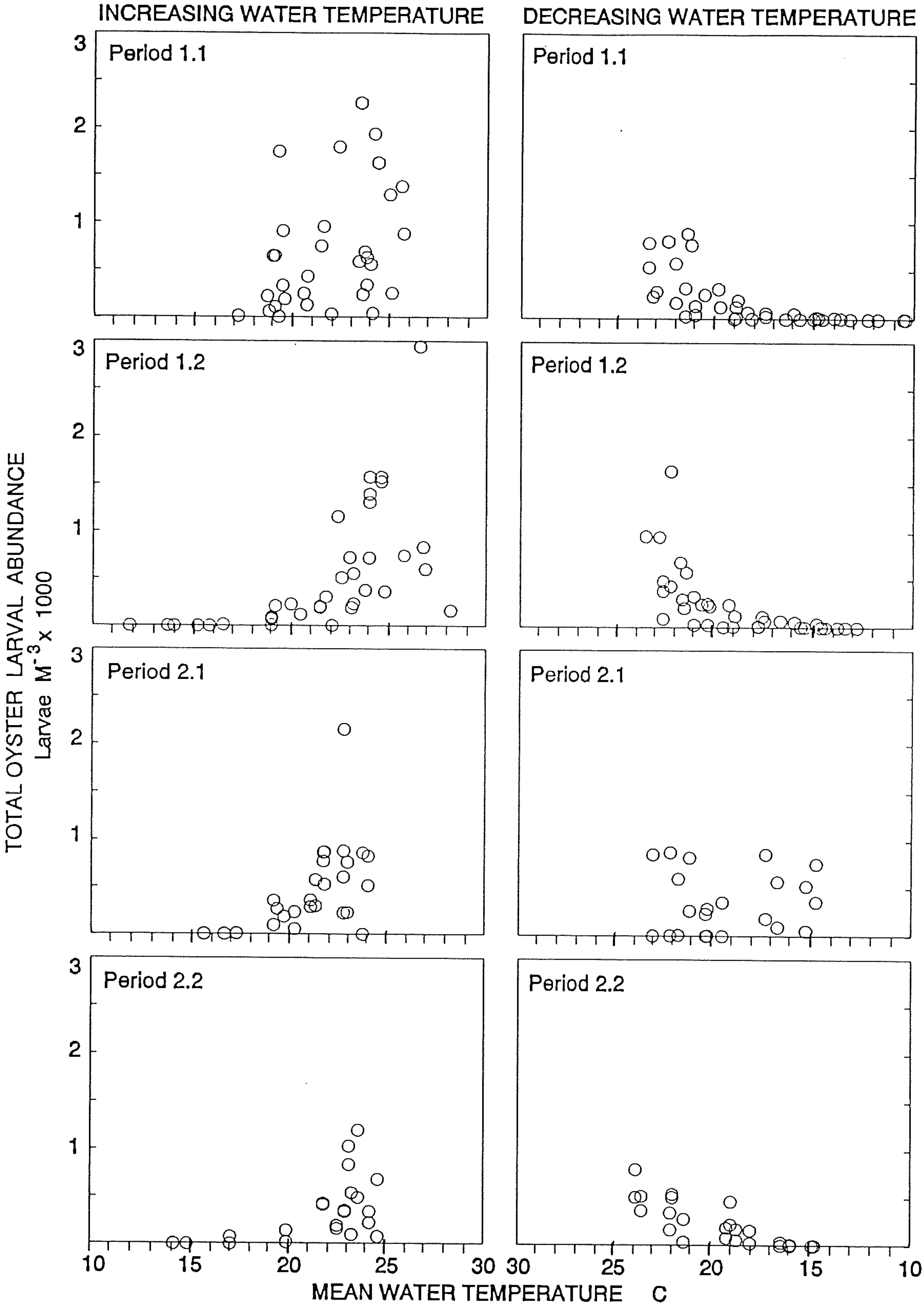


Figure 2.7 The relationship between total oyster larval abundance and increasing and decreasing mean seasonal water temperatures over four oyster reproductive periods at Port Stephens NSW. Data points represent the pooled larval abundance data (sites L1 & L2) with individual larval abundance means plotted against their corresponding mean profile temperature.

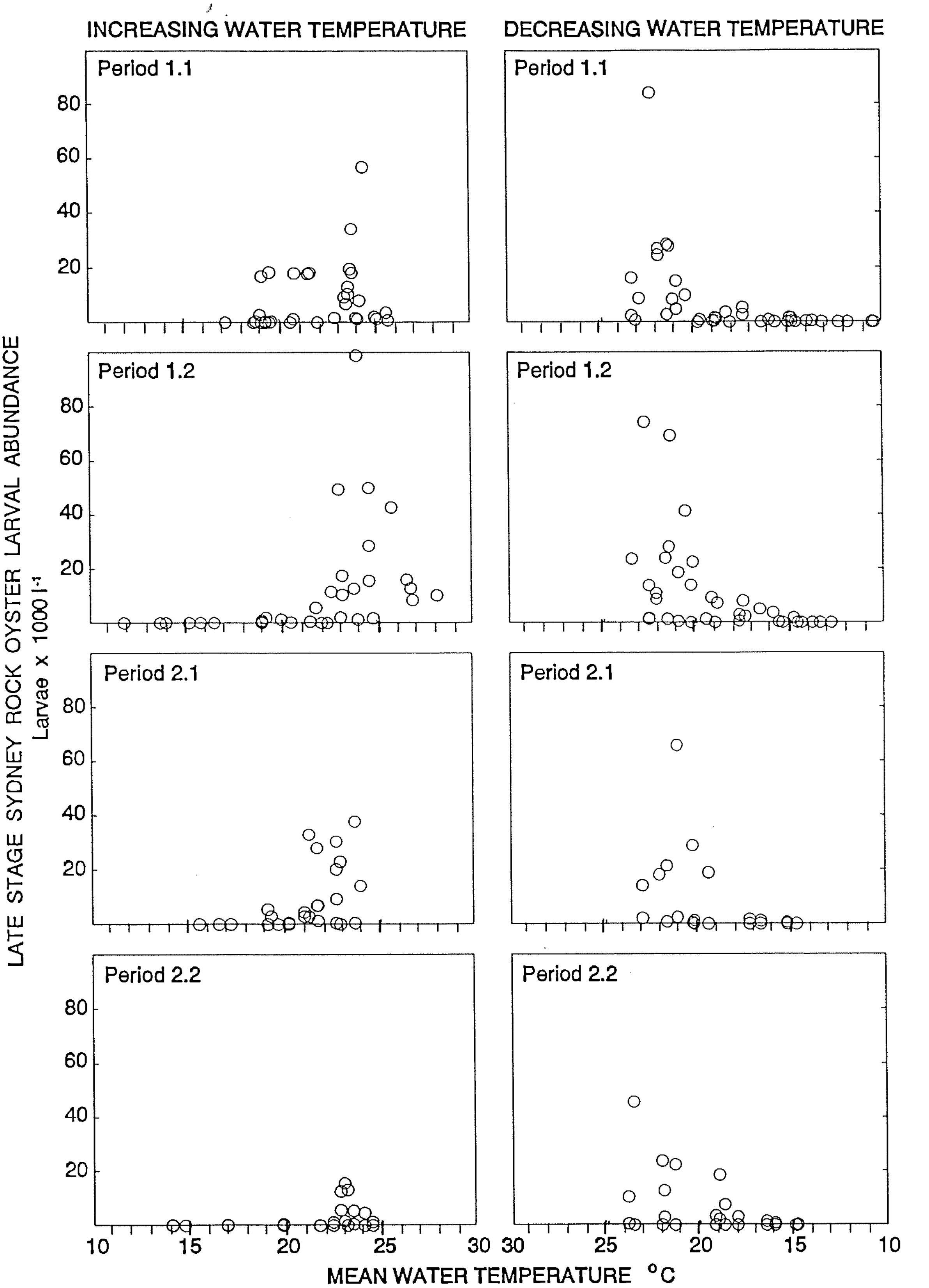


Figure 2.8 The relationship between Late Stage Sydney rock oyster larval abundance and increasing and decreasing mean seasonal water temperatures over four oyster reproductive periods at Port Stephens NSW. Data points represent the pooled larval abundance data (sites L1 & L2) with individual larval abundance means plotted against their corresponding mean profile temperature.

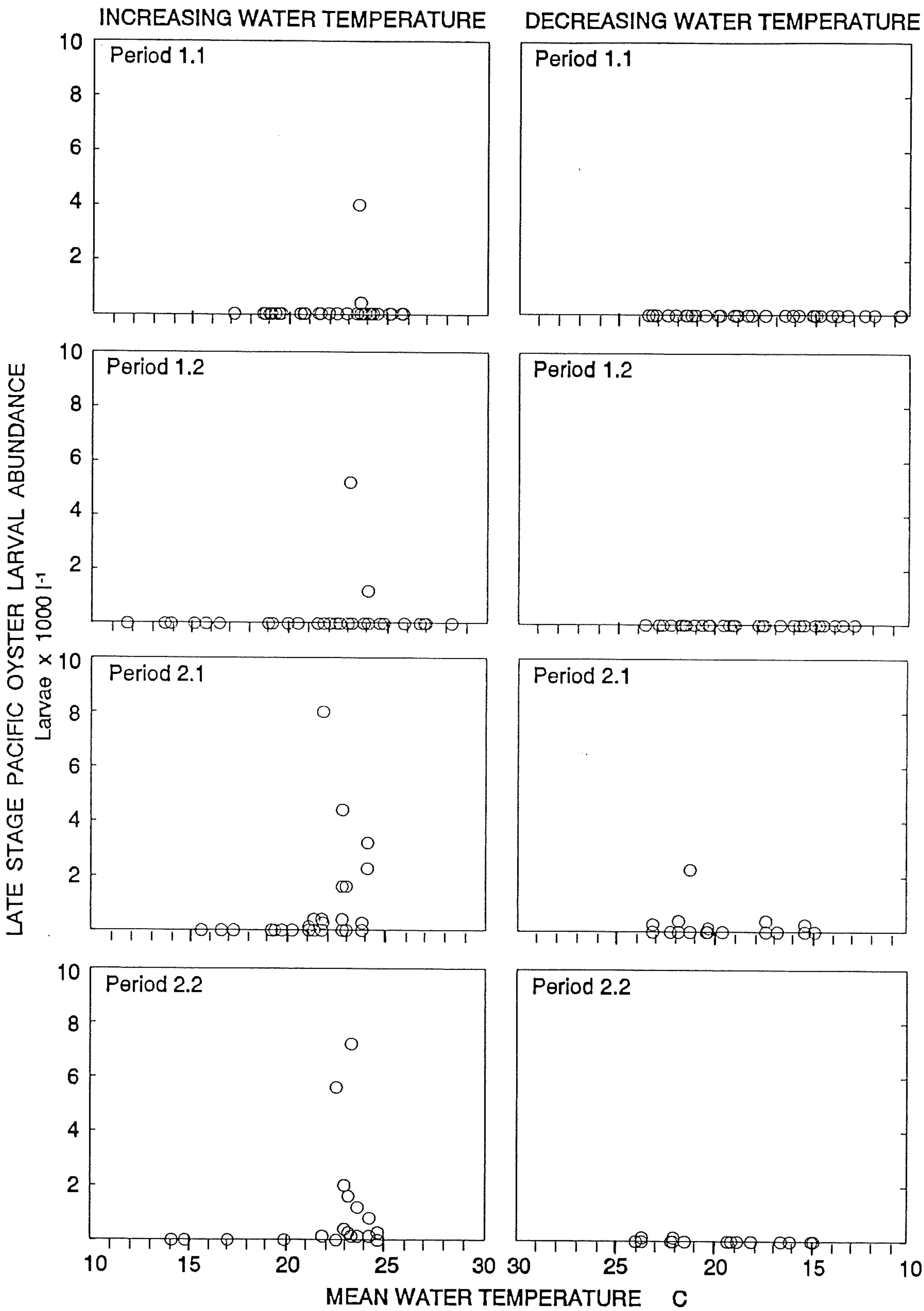


Figure 2.9 The relationship between Late Stage Pacific oyster larval abundance and increasing and decreasing mean seasonal water temperatures over four oyster reproductive periods at Port Stephens NSW. Data points represent the pooled larval abundance data (sites L1 & L2) with individual larval abundance means plotted against their corresponding mean profile temperature.

conditions that can exist simultaneously in Port Stephens (M^cOrrie,1984; Richardson,1991) appears to cause oysters to spawn at different locations at different times (Mason & Nell,1991; R.Moffat, personal communication,1991) and may explain the maintenance of the long period of high larval abundance and settlement observed at Port Stephens. Although late stage larvae of the Sydney rock oyster were present in the plankton at mean water temperatures as low 13.7°C, the large increase in the number of both early stage oyster larvae and late stage Sydney rock oyster larvae once mean water temperatures exceeded 19°C suggests a strong spawning threshold occurring at approximately 19°C for this species in Port Stephens. This threshold was evident in rising seasonal water temperatures in both periods 1 and 2. In contrast the lack of a well defined associated between temperature and a marked drop in the observed number of total oyster larvae in the plankton during falling seasonal temperatures is indicative of other factors such as spring tides triggering spawning (Roughley,1933) once reproductive condition has been reached. The occurrence of the late stage larvae of the Pacific oyster at temperatures above 21°C in Port Stephens is consistent with reports in the literature (Quale,1988; Chew,1991) suggesting that successful larval development and settlement of this species only occurs at temperatures above approximately 21°C.

In 1990 the heavy rainfall and widespread coastal flooding that occurred in early January (NSW Bureau of Meterology; Appendix 1) and intermittent heavy rain over the following months resulted in a prolonged period of depressed salinity in Port Stephens. The initial rainfall in January corresponded with major spawning of both Sydney Rock oyster and the Pacific oyster throughout Port Stephens (R.Bailey, R. Moffat, personal communications). Subsequently a synchronous period of larval development and settlement of both species in the outer Port was observed. The depressed salinities observed in the outer Port during this period were within the range for optimal larval development reported for the Pacific oyster (Nell and Holliday,1988) and may to some extent explain the large settlement of Pacific oysters that occurred on catching leases in Salamander bay that year (Reid,1991).

The data indicates that for maximum exposure to the available spatfall of the Sydney rock oyster catching materials should be deployed in early January. The data also indicates that some scope exists for oyster farmers to significantly reduce the catch of Pacific oysters in their Sydney rock oyster catch by delaying the deployment of their catching material until late February. However, it is also evident that a degree of risk is involved in delaying the deployment of commercial collectors for the Sydney rock oyster later than February. During 1987 many farmers deployed their catching sticks in late February and March in a attempt to avoid a catch of Pacific oysters on their sticks. It is generally accepted that tarred sticks require a period of soaking on the lease before oyster settlement will occur. This in conjunction with the occurrence of the major peak in oyster settlement in early February of that year and the cessation of settlement by mid may resulted in many farmer's sticks being exposed to a greatly reduced amount of the available spatfall in that year. This was undoubtedly a major factor in the poor if not non-commercial catch that occurred at a number of commercial catching leases, particularly those leases which had a history of light or patchy settlement.

The data indicates that those farmers wishing to exploit the settlement of the Pacific oyster to provide stock for on-growing should deploy their catching material at catching sites prior to mean water temperatures reaching 21°C (approximately November) to take full advantage of the settlement of the Pacific oyster. Sites in the inner port would appear to provide a consistent catch potential, particularly at site S3, as opposed to those located in the outer port.

2.2.6 CONCLUSIONS

(1) At Port Stephens, spawning and larval development of the Sydney rock oyster occurs over a wide range of temperatures, with the major reproductive period occurring at mean water temperatures above approximately 19°C.

(2) At Port Stephens, spawning and larval development of the Pacific oyster does not appear to occur over a wide range of temperatures and is confined to the period in which increasing seasonal mean water temperatures exceed approximately 21°C.

(3) During the major reproductive period of the Sydney rock oyster a large population of Sydney rock oyster larvae are maintained in Port Stephens, resulting in prolonged periods of settlement of the oyster.

(4) The settling stage larvae of the Sydney rock oyster are more abundant at site L1 in the outer basin of Port Stephens than at site L2 in the inner basin, while conversely, settling stage larvae of the Pacific oyster are generally more abundant at site L2 in the inner basin than at site L1 in the outer basin.

(5) Settlement of the Sydney rock oyster is more abundant at sites in the outer basin of Port Stephens than at sites in the inner basin, while conversely, settlement of the Pacific oyster is more abundant at sites in the inner basin.

(6) For maximum exposure to the available natural spatfall of the Sydney rock oyster, catching substrate should be deployed on leases in the outer Port in early January.

(7) By delaying the deployment of catching substrate until after February a significant reduction in the number of Pacific oysters settling on substrates may be achieved, however this may increase the risk of a reduced Sydney rock oyster catch.

(8) For those farmers wishing to obtain a catch of Pacific oysters, catching substrates should be deployed on leases in the inner basin no later than the beginning of November.

3 THE SETTLEMENT AND COMMERCIAL RECRUITMENT OF THE SYDNEY ROCK OYSTER *Saccostrea commercialis* IN NSW ESTUARIES

3.1 INTRODUCTION

As a result of the reliable and widespread spatfall of the Sydney rock oyster *Saccostrea commercialis* that occurs at Port Stephens NSW, this estuary had evolved as a major source of oyster spat for the Sydney rock oyster industry. In recent years this estuary has produced in excess of 75% of the Sydney rock oyster industry's annual spat requirements (Anon,1976).

Currently oysters are grown commercially in 31 estuaries in NSW as well as in a small number of estuaries in southern Queensland. The commercial cultivation of oysters in many of these estuaries has developed largely as a result of the reliable supplies of spat available from Port Stephens. Subsequently, the recent events at Port Stephens affecting the supplies of spat available have had a dramatic impact on the Sydney rock oyster industry. Oyster farmers in many estuaries have now been forced to investigate alternative sources of oyster spat to that previously available from Port Stephens to be on-grown on their leases. Although a number of spat catching areas exist in other estuaries, at present only limited information is available as to both their reliability and the extent to which they may be expanded to increase the amount of spat available to the Sydney rock oyster industry.

The objective of this study is to conduct a preliminary assessment of the commercial viability of estuaries outside Port Stephens for the supply of oyster spat to the Sydney rock oyster industry.

3.2 METHODS

The settlement and commercial recruitment of the Sydney rock oyster *S.commercialis* were monitored between January 1990 and January 1992 at 24 estuaries in NSW (Fig. 3.1). In each estuary 3 monitoring sites were selected at random on existing commercial oyster leases at increasing distances from the sea. To monitor both monthly settlement and commercial recruitment 230mm x 230mm x 5mm plates were prepared from smooth 230mm Fibro Cladding (James Hardy Ind.). This proven settlement substrate was chosen to provide a uniform surface characteristic in order to minimise the variation in settlement and subsequent recruitment that may have been due to variation in surface characteristics of the monitoring substrate. At each site plates were deployed, smooth side down, at normal local oyster rack height (approximately 1/3 the local indian spring tidal range above the indian spring low water mark). Plates were enclosed in plastic mesh cages to minimise losses that may have occurred due to fish predation or accidental damage.

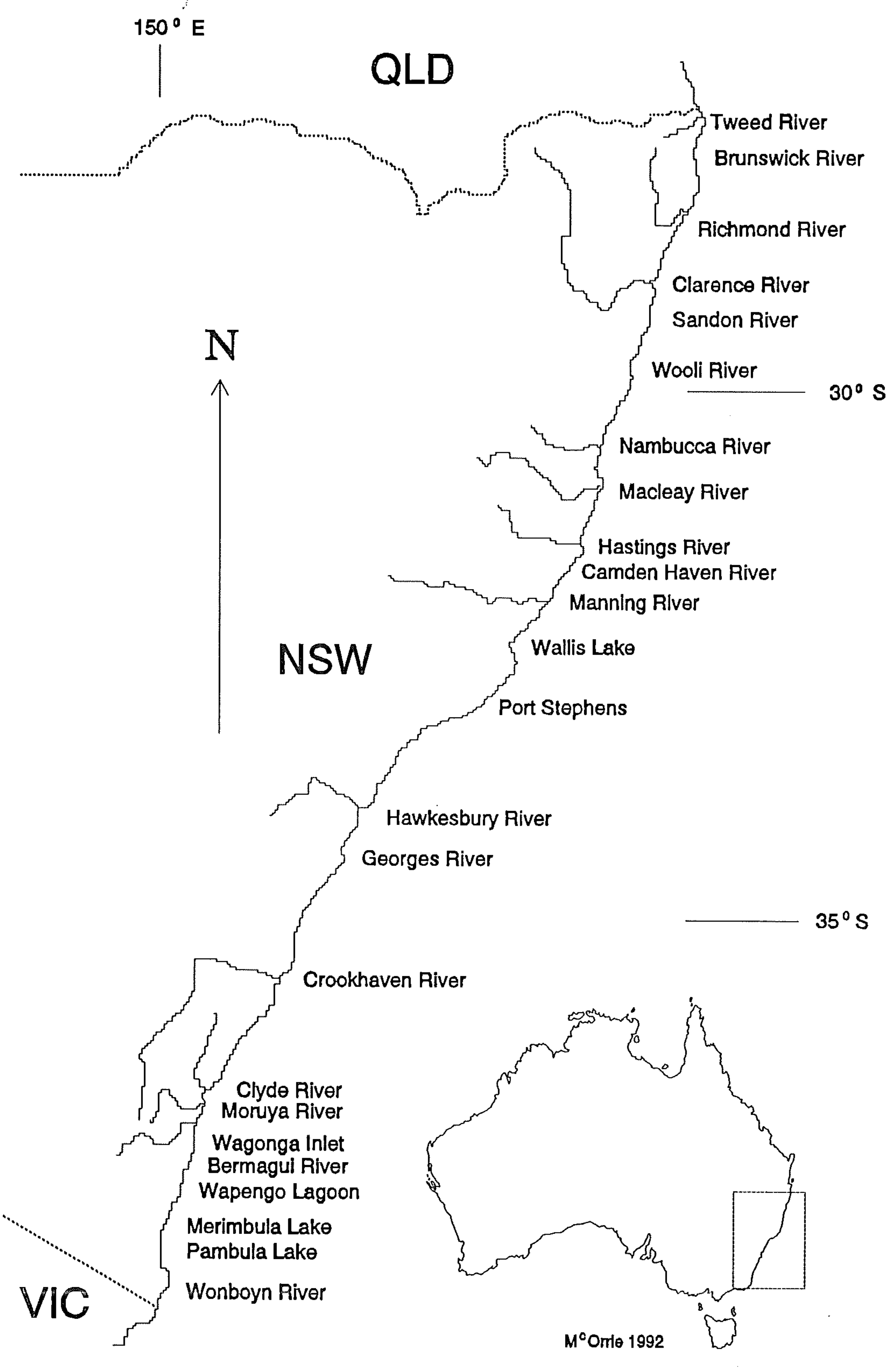


Figure 3.1. The geographic location of estuaries monitored for the settlement and commercial recruitment of the Sydney rock oyster in New South Wales.

3.2.1 SETTLEMENT

Settlement is defined as the number of Sydney rock oyster larvae attached (alive or dead) on the under surface of monitoring plates. The deployment and retrieval of settlement plates required the cooperation of local oyster farmers negotiations revealed that it was only possible for farmers to replace plates on a monthly basis at two sites. Monthly settlement monitoring plates were therefore maintained at sites 1 and 2 in each estuary. The exposed plates were collected regularly and the number of Sydney rock oysters settled on each plate were determined in the laboratory using a dissecting microscope. On each plate the number of Sydney rock oysters settled in two strips 40mm x 230mm were counted and the sum extrapolated to settlement per 100 cm^2. As it was not always possible for local oyster farmers to replace plates on the date required, seasonal data was converted to settlement per $100cm^2 \times day^{-1}$ to compensate for any differences in the deployment periods. The data was expressed graphically as $\log_{10}(x+1)$.

3.2.2 COMMERCIAL RECRUITMENT

Commercial recruitment is defined as the number of live oysters attached to the under side of monitoring plates at the end of the deployment period. In both 1990 and 1991 4 tarred and 4 untarred monitoring plates were placed at random on leases at each site in early January and removed at the beginning of October (the commercial catching stick deployment period) in both 1990 and 1991. Tarred plates were prepared by coating fibro plates with 2 coats of commercial oyster tar (Koppers "Oyster Tar" KC-700). Plates were removed to the laboratory where counts were made of the number of Sydney rock oysters on each plate. As little or no settlement was observed on the upper surfaces of plates counts refer to the total count of Sydney rock oysters on the under surface of plates. To determine the mean size of oysters at each site at the end of the commercial recruitment period, measurements were made of 50 randomly selected oysters on both tarred and untarred plates. Where total recruitment was below 50 oysters, measurements of all oysters present were made. Size of spat refers to its greatest width measured in mm (Thomson,1969)

3.3.2.1 Minium commercial recruitment

To facilitate the assessment of the commercial viability of recruitment it was necessary to determine a level that constituted a minimum commercial recruitment. To date no attempt has been made to define a minimum commercial catch in regard to the commercial stick deployment period (January to October). Potter (1984) attempted to assess site commercial viability at a number of sites in Morton Bay Queensland, in terms of the initial settlement of the Sydney rock oyster. Potter set a level of 100 spat per scallop shell or approximately 64 spat per $100cm^2$. A number of authors have reported commercial Sydney rock oyster recruitment at varying intervals after initial substrate deployment (Thomson,1950; Holliday et al.,1993).

Thomson (1950) reported a mean recruitment of 96 oysters per fibro-cement oyster slat (1200mm x 25mm x 6mm) approximately 12 months after deployment at Port Hacking NSW. He also reported that 86% of the recruitment occurred on the under surface, this equates to a recruitment at approximately 12 months to the under surface of collectors of 28 oysters per $100cm^2$. Dinamani and Lenz (1977) working on the New Zealand rock oyster *Saccostrea glomerata* a closely related species to the Sydney rock oyster (Buroker *et al.*, 1979) reported a mean recruitment to flat fibro slats 4 months after deployment (January to May) of 22.5 spat per $100cm^2$. Salamander Bay, Port Stephens as long been regarded as one of the best commercial settling areas in NSW. Holliday *et al.* (1993) reported recruitment of Sydney rock oysters to tarred sticks in Salamander Bay 127 days after deployment of 145 spat per $100cm^2$. An assessment of the commercial recruitment to tarred sticks at 11 sites (n=275) in Salamander Bay in October 1986 (M^{c}Orrie, unpublished data) recorded a mean site recruitment to the under surface of sticks of 36 oysters per $100cm^2$, with site means ranging from 2 to 70 oysters per $100cm^2$. Mr G. Diemar, for many years a major commercial supplier of Port Stephens caught sticks to the industry, suggests that a minimum commercial recruitment of Sydney rock oysters on caught sticks at the end of the catching season to be approximately 2 or 3 spat to every 100mm on the under surface of a commercial oyster stick. This equates to a catch of between 8 and 12 oysters per $100cm^2$, or between 36 and 54 oysters per stick under surface. In Tasmania Sumner (1979) reported that a catch of 3 Pacific oyster *Crassostrea gigas* spat per $100cm^2$ of scallop shell collector could be regarded as economically viable, at the end of the commercial recruitment period. To assess commercial viability of oyster recruitment in this study a level of 15 spat per $100cm^2$ was chosen as a conservative level of minimum commercial recruitment for an oyster stick at the end of the commercial deployment period (October).

3.3.3 STATISTICAL ANALYSIS

To ensure a conservative assessment of commercial recruitment viability, recruitment data were compared against the minimum commercial recruitment (15 oysters x $100cm^{-2}$) using a procedure described by Sokal and Rolf (1981) to test a mean against a prescribed standard.

$$t_{calc} = (\text{Mean}_{rec} - \text{MCR}) / \text{S.E.Mean}_{rec}$$

Where; t_{calc} = calculated t value to be compared with the tabulated t value.
Mean_{rec} = mean site recruitment per $100cm^{-2}$.
S.E.Mean_{rec} = Standard error of the site mean.

Mean site recruitment was classified as non-commercial if it were not significantly higher (P<0.05) than the 15 oysters per $100cm^2$ minimum. As Salamander Bay is regarded by the industry as an excellent oyster catching area, a further comparison of mean site recruitment at all sites in each estuary were made against the recruitment to tarred and untarred plates deployed at Salamander Bay over the same period using a *t*-test (Sokal and Rolf, 1981). As such, in each year, site means in each estuary were further classified as; significantly higher (P<0.05) than

15 spat per $100cm^2$ and significantly lower ($P<0.05$; *t*-test, one tailed) than Salamander Bay; not significantly different ($P<0.05$) from Salamander Bay; and significantly higher ($P<0.05$; *t*-test, one tailed) than Salamander Bay.

3.3 RESULTS

3.3.1 TWEED RIVER

3.3.1.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Tweed River (Fig. 3.3) estuary during 17 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Fig. 3.3) of 56 and 29 oysters per $100cm^2$ respectively (Table 3.4). Minor peaks in settlement occurred during 1990 from initial deployment until February (0.45 oysters x $100cm^{-2}$ x day^{-1}) and during April and May (0.34 oysters x $100cm^{-2}$ x day^{-1}). During 1991 minor peaks in settlement occurred between January and March (0.30 oysters x $100cm^{-2}$ x day^{-1}), with further minor settlement during September and (0.60 oysters x $100cm^{-2}$ x day^{-1}) December.

3.3.1.2 Commercial Recruitment

During 1990 mean commercial recruitment was classified as non commercial ($P<0.05$) to both tarred (9.3 oysters x $100cm^{-2}$) and untarred plates (6.3 oysters x $100cm^{-2}$) at site 1, to both tarred (13.3 oysters x $100cm^{-2}$) and untarred plates (13.6 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (9.4 oysters x $100cm^{-2}$)and untarred plates (6.0 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 the mean commercial recruitment to untarred plates (25.4 oysters x $100cm^{-2}$) at site 1 was significantly higher ($P<0.05$) than the recruitment to untarred plates at Salamander Bay, while recruitment to tarred plates (32.8 oysters x $100cm^{-2}$) at site 1 and untarred plates (17.25 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to recruitment to tarred and untarred plates respectively at Salamander Bay Port Stephens (Table 3.1). Recruitment was classified as non commercial ($P<0.05$) to both tarred (9.6 oysters x $100cm^{-2}$) and untarred (6.7 oysters x $100cm^{-2}$) plates at site 2, as well as to tarred plates (12.2 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 27.9mm, 26.4mm and 28.7mm respectively, while the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 29.4mm, 29.6mm and 35.1mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 17.2mm, 36.4mm and 34.3mm respectively, and the mean size of recruits to untarred plates at sites 1, 2 and 3 were 18.8mm, 30.5mm and 32.6mm respectively (Table 3.3).

ESTUARY	YEAR 1990						YEAR 1991					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	Tar	Fib	Tar	Fib	Tar	Fib	Tar	Fib	Tar	Fib	Tar	Fib
TWEED RIVER	u	u	u	u	u	u	▨	■	u	u	u	▨
BRUNSWICK RIVER	▨	▨	▨	u	⬚	u	■	■	▨	■	▨	u
RICHMOND RIVER	⬚	u	u	u	u	u	u	u	u	u	u	u
CLARENCE RIVER	⬚	u	u	u	⬚	u	■	▨	u	u	▨	■
SANDON RIVER	⬚	⬚	▨	▨	▨	u	▨	■	▨	▨	▨	u
WOOLI RIVER	▨	▨	u	u	u	u	■	■	▨	■	▨	▨
NAMBUCCA RIVER	u	u	u	u	u	u	u	u	■	■	▨	u
MACLEAY RIVER	u	u	u	u	u	u	■	u	▨	▨	▨	u
HASTINGS RIVER	u	u	u	u	u	u	■	■	▨	u	▨	▨
CAMDEN HAVEN RIVER	▨	▨	▨	u	▨	u	▨	▨	u	u	▨	▨
MANNING RIVER	u	u	⬚	u	u	u	■	▨	■	■	▨	u
WALLIS LAKE	▨	▨	▨	▨	■	■	▨	u	■	■	■	■
PORT STEPHENS	▨	▨	▨	▨	u	u	▨	▨	u	u	u	u
HAWKESBURY RIVER	▨	u	▨	u	u	u	u	u	▨	▨	u	u
GEORGES RIVER	▨	u	u	u	⬚	u	u	▨	u	u	u	u
SHOALHAVEN/CROOKHAVEN	■	▨	▨	▨	▨	u	■	■	⬚	u	u	u
CLYDE RIVER	▨	u	⬚	u	⬚	u	▨	▨	u	u	u	u
MORUYA RIVER	⬚	⬚	■	▨	u	u	▨	u	■	■	u	u
WAGONGA INLET	u	⬚	u	u	⬚	u	u	▨	u	u	u	u
BERMAGUI RIVER	▨	▨	■	▨	▨	u	▨	■	u	■	▨	■
WAPENGO LAGOON	▨	u	▨	▨	▨	⬚	■	▨	■	■	u	■
MERIMBULA LAKE	u	u	u	u	u	u	▨	■	u	u	u	u
PAMBULA LAKE	▨	▨	■	▨	u	u	■	■	■	■	▨	■
WONBOYN LAKE	▨	⬚	▨	⬚	⬚	u	▨	■	▨	u	u	u

Table 3.1 The commercial recruitment of the Sydney rock oyster to tarred [Tar] (n=4) and and untarred [Fib] (n=4) fibro-cement plates at 3 sites in each of 24 estuaries in NSW. Plates were deployed over the commercial recruitment period (January to October) during 1990 and 1991. Individual site recruitment is compared to the recruitment that occured at commercial Sydney rock oyster catching leases at Salamaner Bay NSW, monitored using the same technique over the same period (January to October) during 1990 and 1991. Site substrate recruitment is represented as significantly higher ($p<0.05$) than Salamander Bay ■ ; not significantly different ($p>0.05$) than Salamander Bay ▨ or significantly lower ($p<0.05$) than Salamander Bay ⬚ . Site substrate recruitment was classified as non-commercial "u" if it was not significantly higher ($p<0.05$) than 15 oysters per 100 sq cm of substrate.

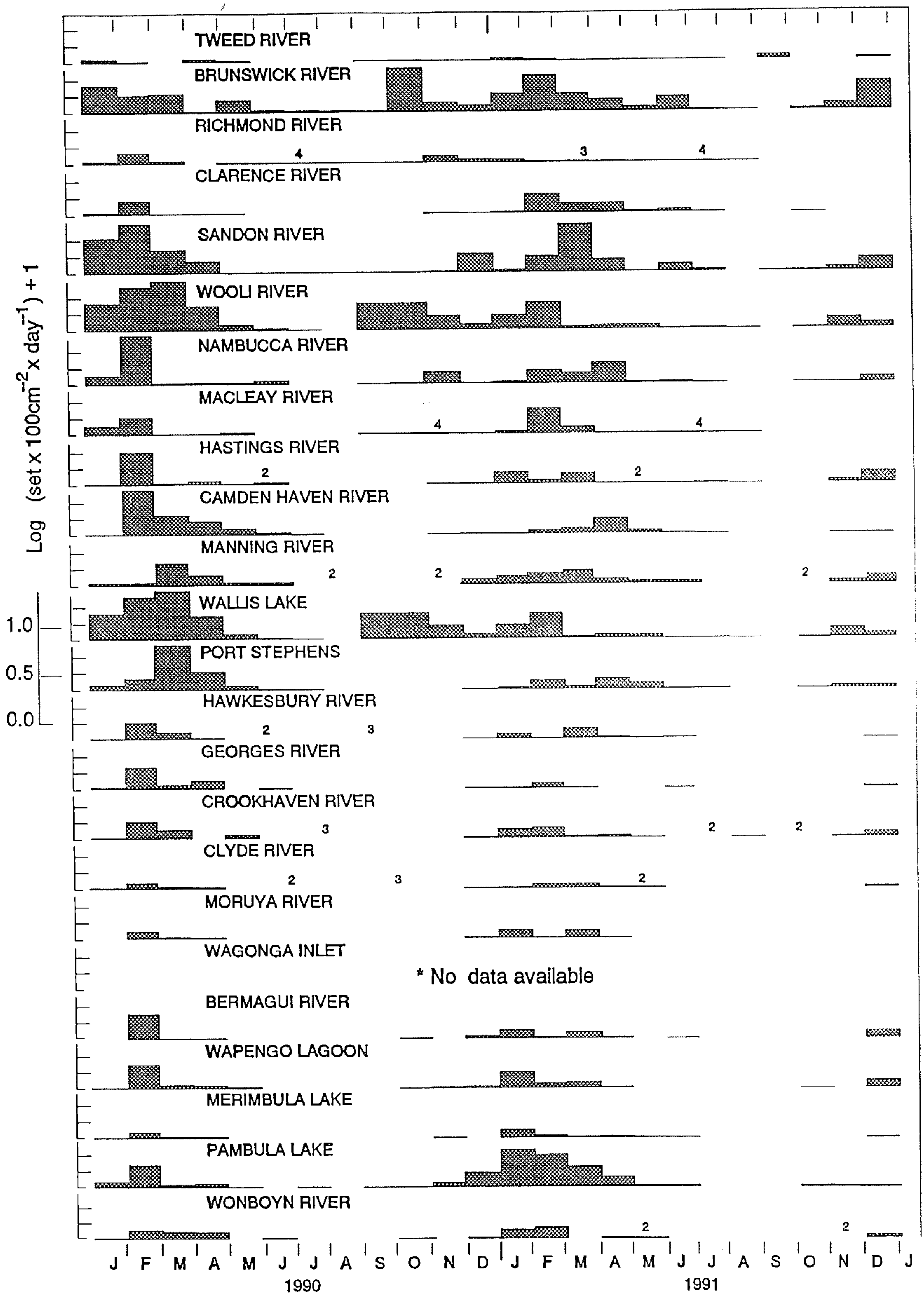
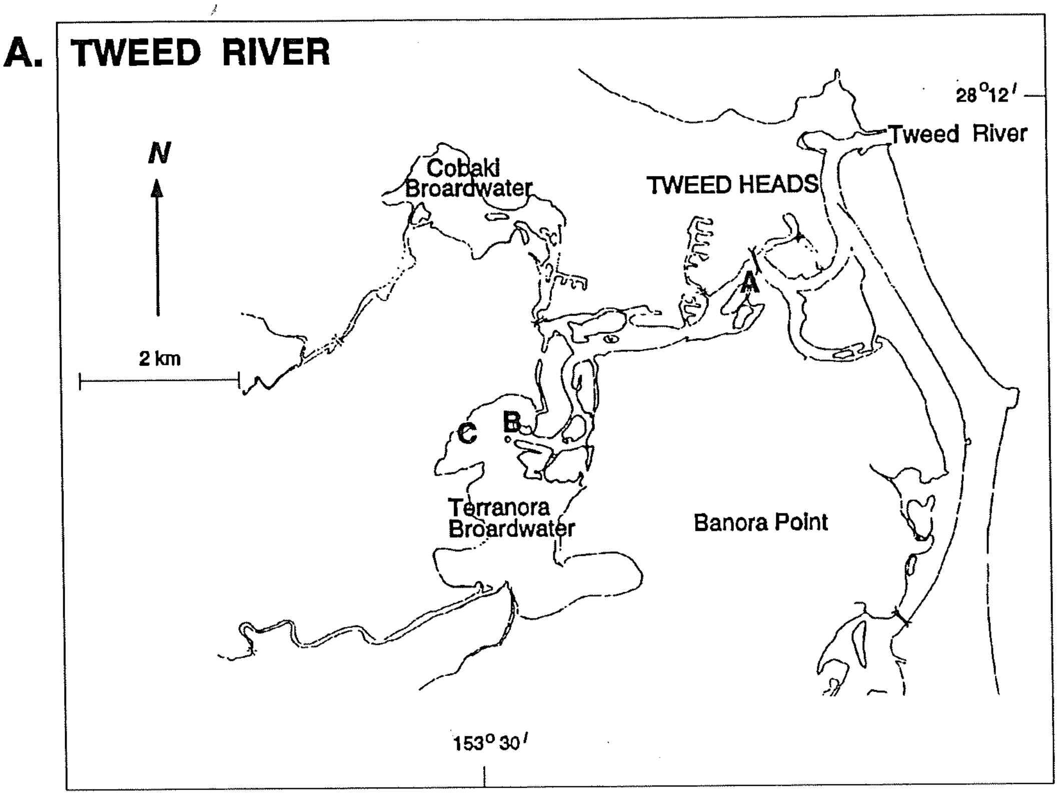


Figure 3.2 Settlement of the Sydney rock oyster in NSW estuaries from January 1990 untill January 1992. Settlement data is represented as Log (set x 100cm^{-2} x day^{-1}) + 1 The numeric superscript indicates periods of plate exposure (months) greater than 1 month.

ESTUARY	SITE 1		SITE 2		CUMULATIVE RANK
	SET	RANK	SET	RANK	
TWEED RIVER	56	20	29	20	21
BRUNSWICK RIVER	787	5	2602	2	3
RICHMOND RIVER	n.d.	-	n.d.	-	-
CLARENCE RIVER	253	11	105	14	13
SANDON RIVER	1291	3	3281	1	2
WOOLI RIVER	4789	1	701	6	1
NAMBUCCA RIVER	487	8	1811	4	4
MACLEAY RIVER	n.d.	-	n.d.	-	-
HASTINGS RIVER	704	6	48	18	9
CAMDEN HAVEN RIVER	228	12	1464	3	7
MANNING RIVER	91	15	251	10	14
WALLIS LAKE	788	4	381	7	8
PORT STEPHENS	1415	2	378	8	6
HAWKESBURY RIVER	87	16	164	11	15
GEORGES RIVER	210	13	67	16	17
SHOALHAVEN/CROOKHAVEN	285	9	60	17	12
CLYDE RIVER	71	18	24	20	20
MORUYA RIVER	53	21	81	15	18
WAGONGA INLET	n.d.	-	n.d.	-	-
BERMAGUI RIVER	275	10	119	13	11
WAPENGO LAGOON	91	15	359	9	10
MERIMBULA LAKE	71	18	30	19	19
PAMBULA LAKE	589	7	1306	5	5
WONBOYN LAKE	94	14	138	12	16

Table 3.4 The ranking of cumulative settlement in NSW estuaries. Set = total cumulative monthly settlement (n=24) of oysters per 100 cm^2 on fibro plates deployed at sites 1 and 2 in each estuary. Cumulative rank = ranking by decreasing combined cumulative settlement of both sites 1 and 2 in each estuary. n.d. = insufficient data to rank.



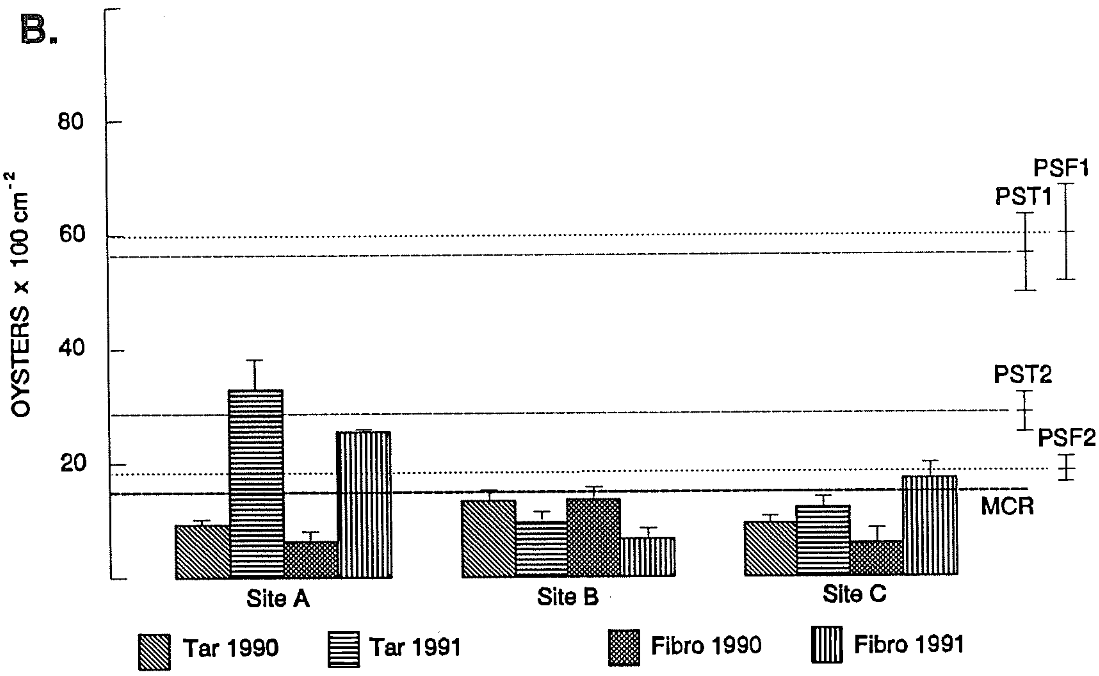


Figure 3.3 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.
B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

ESTUARY	YEAR 1990						YEAR 1991					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	Tar $\bar{x}$	S.E.	Tar $\bar{x}$	S.E.	Tar $\bar{x}$	S.E.	Tar $\bar{x}$	S.E.	Tar $\bar{x}$	S.E.	Tar $\bar{x}$	S.E.
Tweed River	27.9	1.79	26.4	1.62	28.7	2.51	17.2	1.14	36.4	2.84	34.3	1.47
Brunswick River	19.4	1.54	18.4	1.44	21.4	0.96	19.5	1.20	25.6	1.68	32.4	1.17
Richmond River	16.8	0.77	26.2	1.39	24.3	1.38	14.2	1.08	24.5	1.26	35.1	3.39
Clarence River	15.8	1.27	6.8	0.71	18.7	1.32	15.7	1.02	10.2	0.82	5.0	0.23
Sandon River	19.9	1.55	19.1	1.39	18.1	1.22	13.3	1.36	11.5	1.21	8.6	1.08
Wooli River	15.0	1.57	21.4	1.30	17.9	1.57	13.9	0.84	17.5	1.68	11.3	0.86
Nambucca River	30.8	1.40	24.0	1.56	13.8	3.92	20.0	1.95	21.1	1.68	27.7	1.27
Macleay River	18.8	1.17	19.2	0.98	18.3	0.81	17.6	1.55	16.0	1.44	15.5	1.89
Hastings River	5.7	0.99	10.0	6.00	12.4	1.82	14.1	0.90	26.3	1.42	27.6	1.65
Camden Haven River	12.3	2.22	7.6	1.38	19.2	1.20	14.3	1.22	22.0	2.60	19.8	1.79
Manning River	27.5	1.73	15.7	1.39	-	-	15.4	1.23	18.5	1.03	16.0	1.36
Wallis Lake	10.3	1.18	12.8	1.65	13.1	0.96	10.1	0.86	11.9	1.02	16.0	1.26
Port Stephens	12.0	0.85	10.5	1.27	7.4	0.91	14.4	1.24	25.5	1.75	13.3	1.91
Hawkesbury River	15.5	1.23	11.9	1.52	7.4	0.68	18.0	1.49	13.6	0.89	16.6	1.36
Georges River	17.9	1.20	12.2	1.12	10.2	0.99	23.9	1.49	13.3	0.52	6.4	0.42
Shoalhaven/Crookhaven	10.0	0.88	9.2	0.61	9.6	0.39	18.5	1.38	22.8	1.61	16.5	1.42
Clyde River	6.9	0.45	9.3	0.83	7.4	0.71	11.6	0.64	14.6	0.93	16.0	0.82
Moruya River	10.7	1.42	11.2	1.13	7.8	0.72	16.5	1.05	13.2	0.58	22.1	0.89
Wagonga Inlet	13.5	1.52	9.1	0.72	14.3	1.01	18.1	1.51	18.4	1.34	23.4	1.71
Bermagui River	12.6	1.20	7.2	0.58	9.0	1.26	18.9	1.42	14.0	0.95	13.1	0.69
Wapengo Lagoon	9.6	1.05	10.9	1.37	12.6	0.68	18.6	1.48	11.6	0.87	15.5	1.23
Merimbula Lake	17.8	1.20	12.5	1.66	13.1	0.87	17.7	1.13	17.4	1.40	16.5	0.87
Pambula Lake	15.9	1.13	17.8	1.40	11.6	1.05	12.5	1.22	10.9	0.93	26.8	1.91
Wonboyn River	7.6	0.48	8.3	0.58	10.0	1.06	16.6	1.01	14.0	0.86	12.1	0.71

Table 3.2 The mean size (± S.E.) of Sydney rock oyster recruitment on tarred fibro-cement substrate at the end of the commercial deployment period (January to October) at recruitment monitoring sites in 24 estuaries in NSW during 1990 and 1991. Measurements refer to the greatest width of oyster spat in mm.

ESTUARY	YEAR 1990						YEAR 1991					
	Site 1		Site 2		Site 3		Site 1		Site 2		Site 3	
	Fib $\bar{x}$	S.E.	Fib $\bar{x}$	S.E.	Fib $\bar{x}$	S.E.	Fib $\bar{x}$	S.E.	Fib $\bar{x}$	S.E.	Fib $\bar{x}$	S.E.
Tweed River	29.4	2.38	29.6	2.50	35.1	2.03	18.8	1.2	30.5	2.11	32.6	1.26
Brunswick River	16.4	1.39	18.9	1.26	16.5	2.11	21.2	1.25	20.1	1.19	29.9	1.16
Richmond River	16.3	1.73	4.4	0.86	4.3	0.34	22.0	3.37	31.4	1.21	17.1	3.29
Clarence River	18.6	1.15	7.6	0.44	24.0	1.50	15.8	1.31	11.0	1.32	7.5	0.87
Sandon River	14.5	1.19	15.1	1.00	15.3	0.61	12.5	1.35	17.6	1.80	22.7	2.14
Wooli River	14.5	1.79	23.1	1.79	17.4	1.16	14.3	0.90	12.8	0.99	13.3	1.03
Nambucca River	31.8	2.13	27.1	3.36	12.0	0.75	24.7	2.78	17.1	1.80	24.4	1.08
Macleay River	10.2	2.07	29.2	1.34	26.2	1.43	12.7	1.50	13.6	1.21	19.3	1.89
Hastings River	13.2	2.06	14.2	0.87	3.0	0.19	14.3	0.80	22.5	1.31	25.9	1.63
Camden Haven River	14.7	0.99	10.6	1.37	13.4	1.70	8.5	1.02	23.5	3.01	20.2	1.26
Manning River	22.7	2.16	16.9	1.81	-	-	17.0	1.50	19.4	1.27	12.4	0.87
Wallis Lake	15.4	1.95	13.9	1.81	12.9	1.07	12.3	0.87	13.2	1.01	13.5	1.00
Port Stephens	11.8	1.20	11.6	1.32	9.2	0.91	12.0	0.75	22.8	1.81	8.7	0.88
Hawkesbury River	16.0	1.42	14.6	1.01	14.2	1.11	18.2	2.10	11.0	0.91	14.5	1.29
Georges River	14.8	1.22	12.6	1.12	8.2	0.86	17.6	1.09	9.0	0.69	5.2	0.38
Shoalhaven/Crookhaven	10.8	1.30	12.5	0.92	10.7	0.83	17.6	1.17	23.2	1.32	17.3	1.29
Clyde River	9.2	0.62	11.8	1.14	13.1	1.09	10.2	0.74	8.1	0.64	10.0	0.70
Moruya River	9.3	0.84	12.4	1.53	14.9	1.68	17.7	1.03	11.3	0.61	18.5	0.88
Wagonga Inlet	15.0	1.71	11.4	1.58	14.3	1.33	16.0	0.75	15.6	0.95	16.1	1.18
Bermagui River	17.0	1.67	8.8	0.69	12.4	1.43	20.3	1.22	10.5	0.64	15.6	0.84
Wapengo Lagoon	12.3	1.06	10.0	0.79	16.3	1.02	15.8	1.13	13.9	0.94	10.0	0.75
Merimbula Lake	20.2	1.51	10.9	0.80	19.4	1.82	18.7	1.14	18.6	1.09	17.1	0.72
Pambula Lake	15.8	1.04	11.8	0.88	14.3	0.88	12.0	0.75	9.8	0.67	17.1	1.34
Wonboyn River	6.4	0.81	11.2	0.90	15.1	0.82	13.8	1.00	17.4	1.35	12.2	0.66

Table 3.3 The mean size (± S.E.) of Sydney rock oyster recruitment on untarred fibro-cement substrate at the end of the commercial deployment period (January to October) at recruitment monitoring sites in 24 estuaries in NSW during 1990 and 1991. Measurements refer to the greatest width of oyster spat in mm.

3.3.2 BRUNSWICK RIVER

3.3.2.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Brunswick River (Fig. 3.4) estuary during 23 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was considerable with total cumulative settlement at sites 1 and 2 (Fig. 3.4) of 787 and 2602 oysters per $100cm^2$ respectively (Table 3.4).

Substantial settlement was observed from initial deployment until June 1990 with a peak occurring between January and April (10.23 oysters x $100cm^{-2}$ x day^{-1}) and during May 1990 (2.45 oysters x $100cm^{-2}$ x day^{-1}). Major settlement commenced again during October 1990 and continued through until July 1991. Peaks in settlement occurring in October 1990 (37.68 oysters x $100cm^{-2}$ x day^{-1}) and February 1991, with a minor peak during June 1991. Settlement commenced again in October and climbed steadily during November 1991 to the termination of monitoring in early January 1992 (11.84 oysters x $100cm^{-2}$ x day^{-1}).

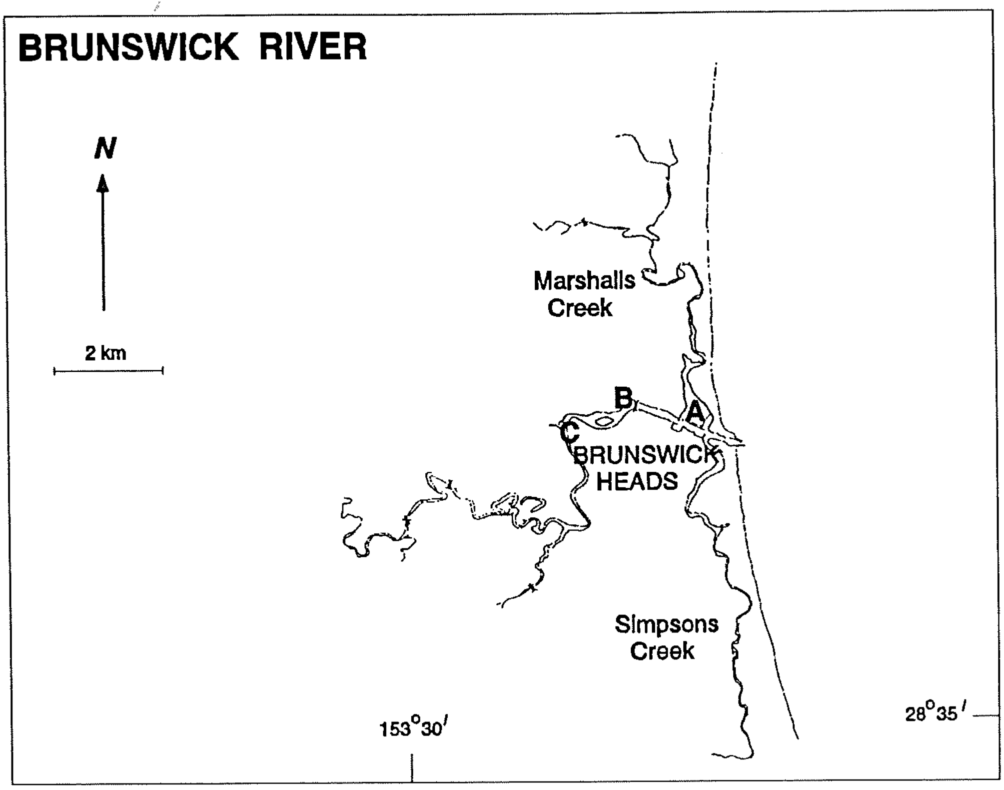
3.3.2.2 Commercial Recruitment

During 1990 the mean commercial recruitment to both tarred (57.7 oysters x $100cm^{-2}$) and untarred plates (42.0 oysters x $100cm^{-2}$) at site 1, as well as tarred plates (37.9 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to tarred (28.6 oysters x $100cm^{-2}$) plates at site 3 was commercial though significantly lower than that on plates at Salamander Bay. Recruitment to untarred plates (19.7 oysters x $100cm^{-2}$) at site 2 as well as to untarred plates (11.4 oysters x $100cm^{-2}$) and at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (51.9 oysters x $100cm^{-2}$) and untarred plates (46.4 oysters x $100cm^{-2}$) at site 1 as well as to untarred plates (36.15 oysters x $100cm^{-2}$) at site 2 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to tarred plates (23.1 oysters x $100cm^{-2}$) at site 2 and to tarred (15.5 oysters x $100cm^{-2}$) plates at site 3 were not significantly different ($P<0.05$) to the recruitment at Salamander Bay Port Stephens. Recruitment to untarred plates (14.1 oysters x $100cm^{-2}$) at site 3 was non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 19.4mm, 18.4mm and 18.8mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 16.4mm, 18.9mm and 16.5mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 19.5mm, 25.6mm and 32.4mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were

A.



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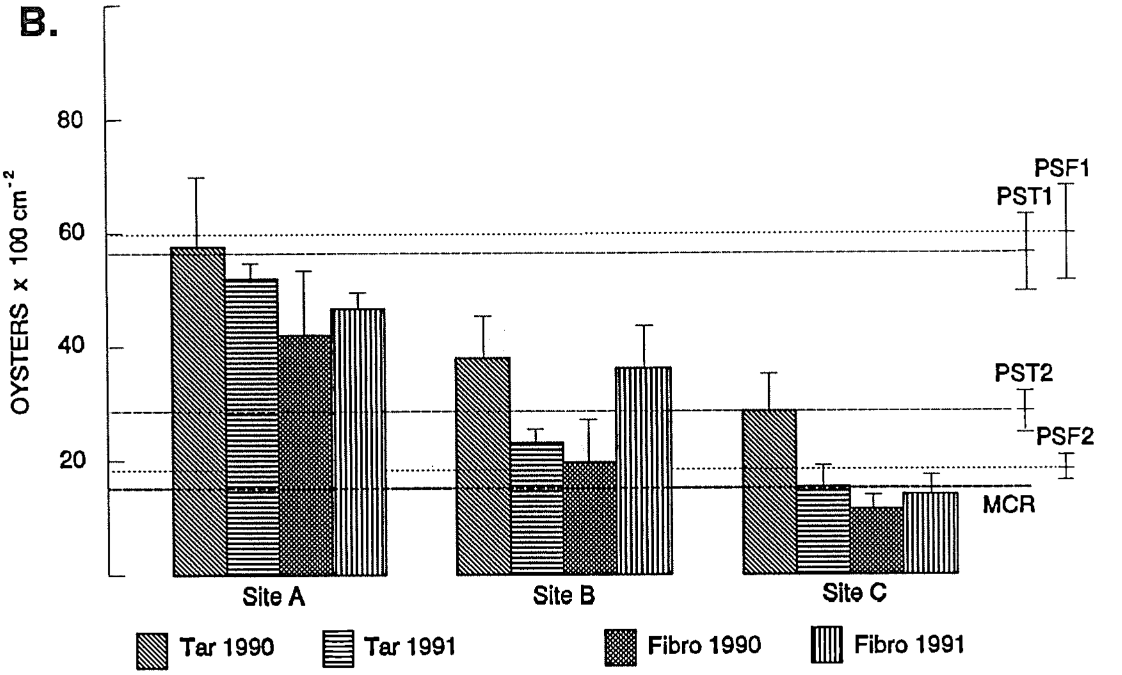


Figure 3.4 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.
B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

21.2mm, 20.1mm and 29.9mm respectively.

3.3.3 RICHMOND RIVER

3.3.3.1 Settlement

Due to the long periods of deployment of collectors on a number of occasions it was not possible to accurately isolate settlement on a monthly basis (Fig. 3.2). Settlement was generally light and appeared to have occurred during the summer months.

3.3.3.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred plates (27.4 oysters x $100cm^{-2}$) at site 1 (Fig. 3.5) was classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to tarred plates at Salamander Bay. Recruitment to untarred plates (12.2 oysters x $100cm^{-2}$) at site 1 to both tarred (1.3 oysters x $100cm^{-2}$) and untarred plates (0.1 oysters x $100cm^{-2}$), at site 2 to both tarred (0 oysters x $100cm^{-2}$) and untarred plates (13.6 oysters x $100cm^{-2}$) at site 3, were classified as non commercial ($P<0.05$) (Table 3.1).

During 1991 the mean commercial recruitment to tarred (23.0 oysters x $100cm^{-2}$) and untarred plates (0.6 oysters x $100cm^{-2}$) at site 1 to both tarred (5.3 oysters x $100cm^{-2}$) and untarred plates (6.4 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (0.6 oysters x $100cm^{-2}$) and untarred plates (0.9 oysters x $100cm^{-2}$) at site 3 were classified as non commercial ($P<0.05$) (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 16.8mm, 3.0mm and 21.2mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 16.3mm, 4.4mm and 4.3mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 14.2mm, 24.4mm and 35.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 22.0mm, 31.4mm and 17.1mm respectively.

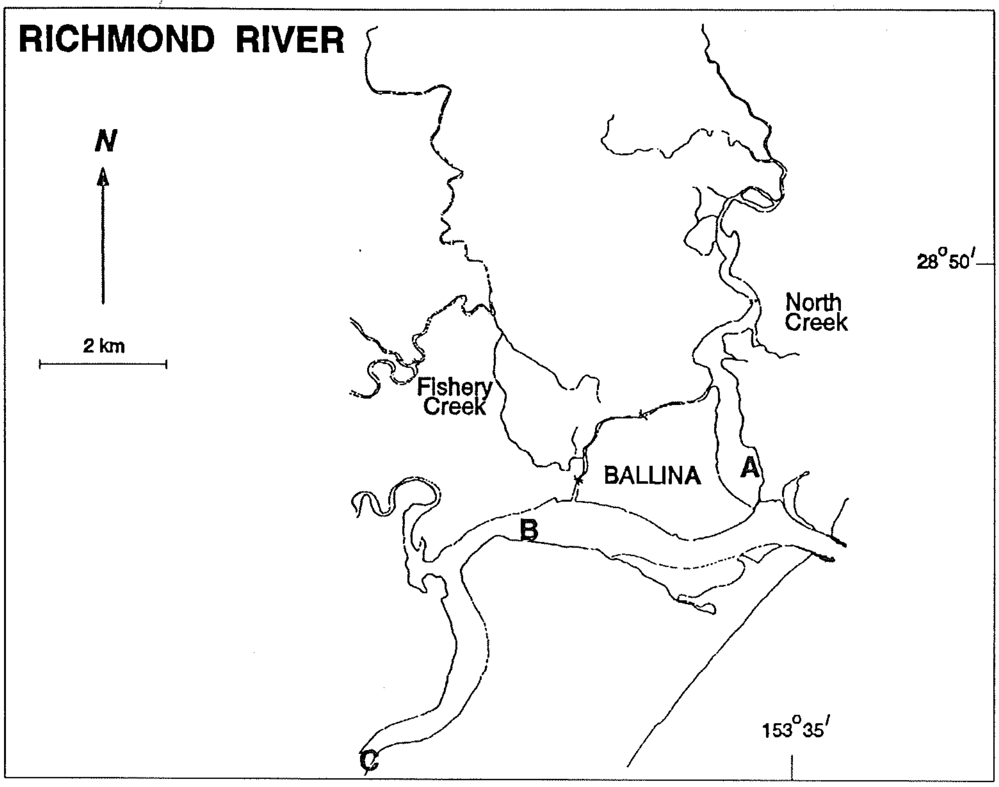
3.3.4 CLARENCE RIVER

3.3.4.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Clarence River estuary (Fig. 3.6) during 15 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was moderate with total cumulative settlement at sites 1 and 2 (Fig. 3.6) of 253 and 105 oysters per $100cm^2$ respectively (Table 3.4).

Settlement was observed from initial deployment through until June 1990 with a

A.



B.

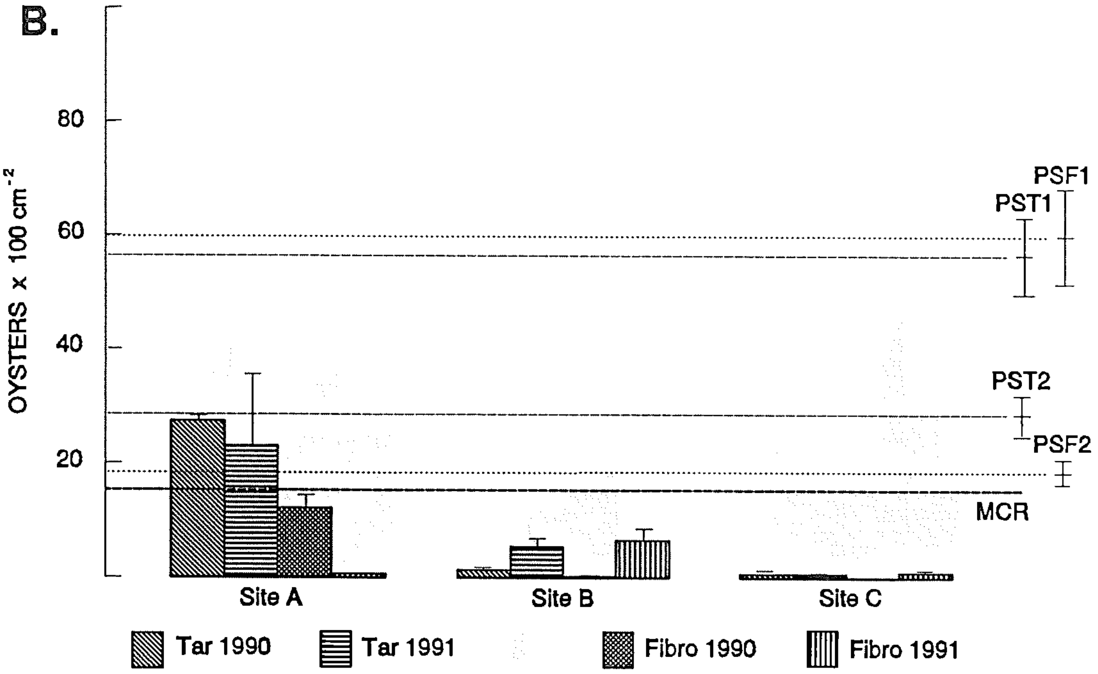


Figure 3.5 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

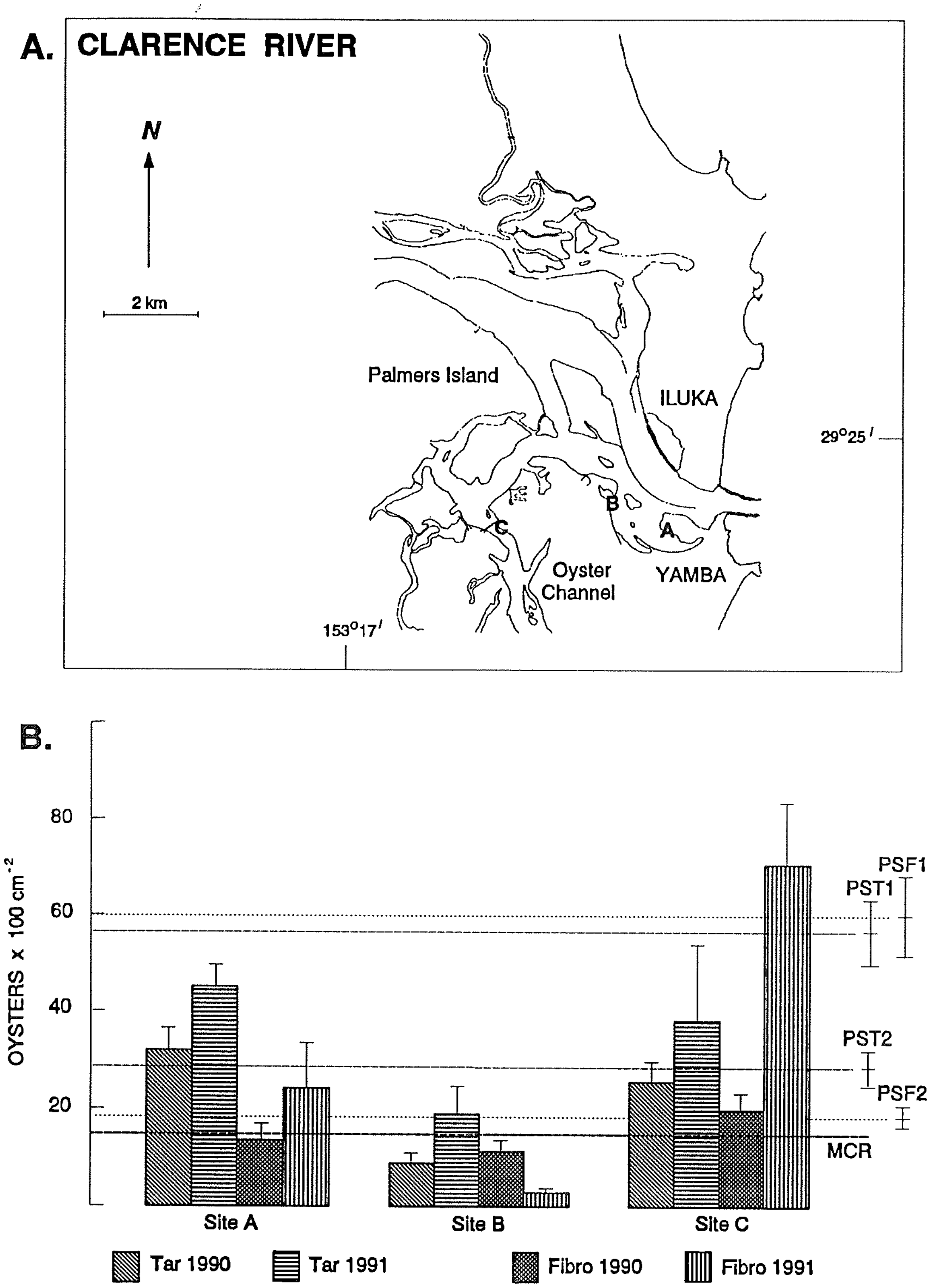


Figure 3.6 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

peak occurring during February (2.45 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during November 1990 and continued through until July 1991 with a peak in settlement occurring during February 1991 (4.52 oysters x $100cm^{-2}$ x day^{-1}). Minor settlement was observed in October 1991, with no further settlement detected prior to the termination of sampling.

3.3.4.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred plates (31.9 oysters x $100cm^{-2}$) at site 1 as well as tarred plates (25.7 oysters x $100cm^{-2}$) at site 3 were classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to tarred plates at Salamander Bay. Recruitment to untarred plates (13.5 oysters x $100cm^{-2}$) at site 1 to both tarred (8.84 oysters x $100cm^{-2}$) and untarred plates (11.3 oysters x $100cm^{-2}$) at site 2, as well as to untarred plates (19.9 oysters x $100cm^{-2}$) at site 3 were classified as non commercial ($P<0.05$) (Table 3.1).

During 1991 the mean commercial recruitment to tarred plates (44.9 oysters x $100cm^{-2}$) at site 1 and untarred plates (70.5 oysters x $100cm^{-2}$) at site 3 were significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay. Recruitment to untarred plates (24.2 oysters x $100cm^{-2}$) at site 1 and tarred plates (38.0 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to recruitment to tarred and untarred plates respectively at Salamander Bay Port Stephens (Table 3.1). Recruitment to tarred (19.1 oysters x $100cm^{-2}$) and untarred (2.8 oysters x $100cm^{-2}$) plates at site 2 was classified as non commercial ($P<0.05$) (Table 3.1).

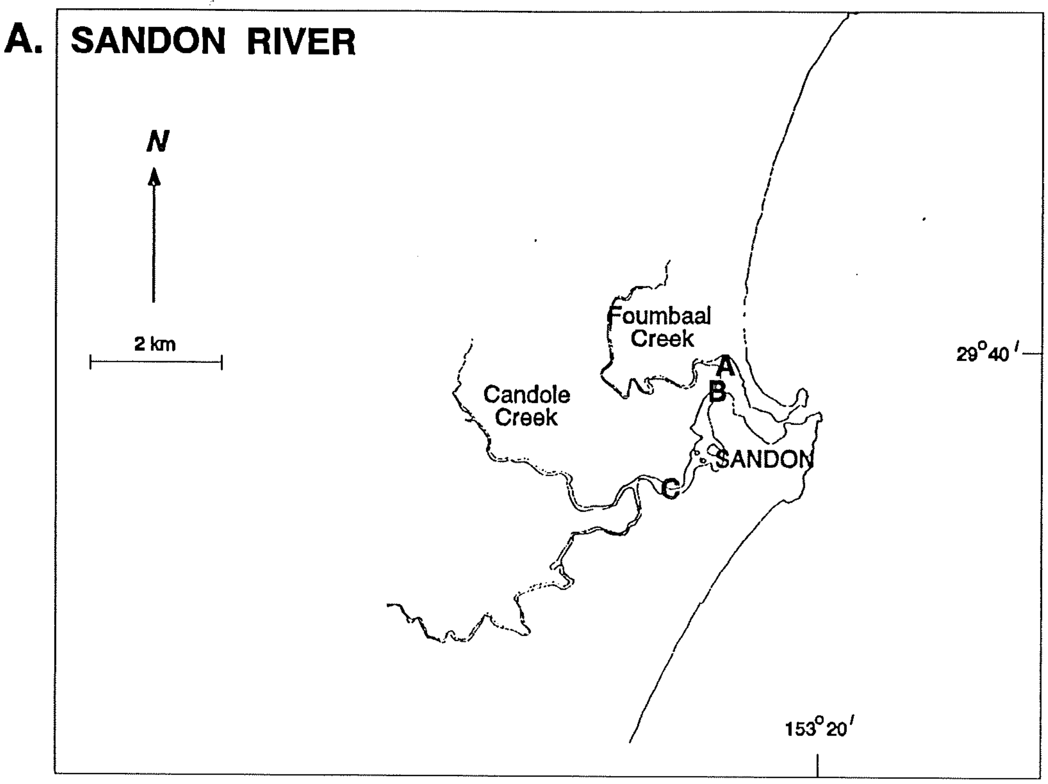
During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.8mm, 6.8mm and 18.7mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 18.6mm, 7.6mm and 24.0mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.7mm, 10.2mm and 5.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 15.8mm, 11.0mm and 7.5mm respectively.

3.3.5 SANDON RIVER

3.3.5.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Sandon River estuary (Fig. 3.7) during 23 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4) of 1291 and 3281 oysters per $100cm^2$ respectively.

Major settlement was observed from initial deployment until May 1990 with a major peak occurring during February (9.1 oysters x $100cm^{-2}$ x day^{-1}) (Fig. 3.2). Major settlement commenced again during December 1990 and continued through until



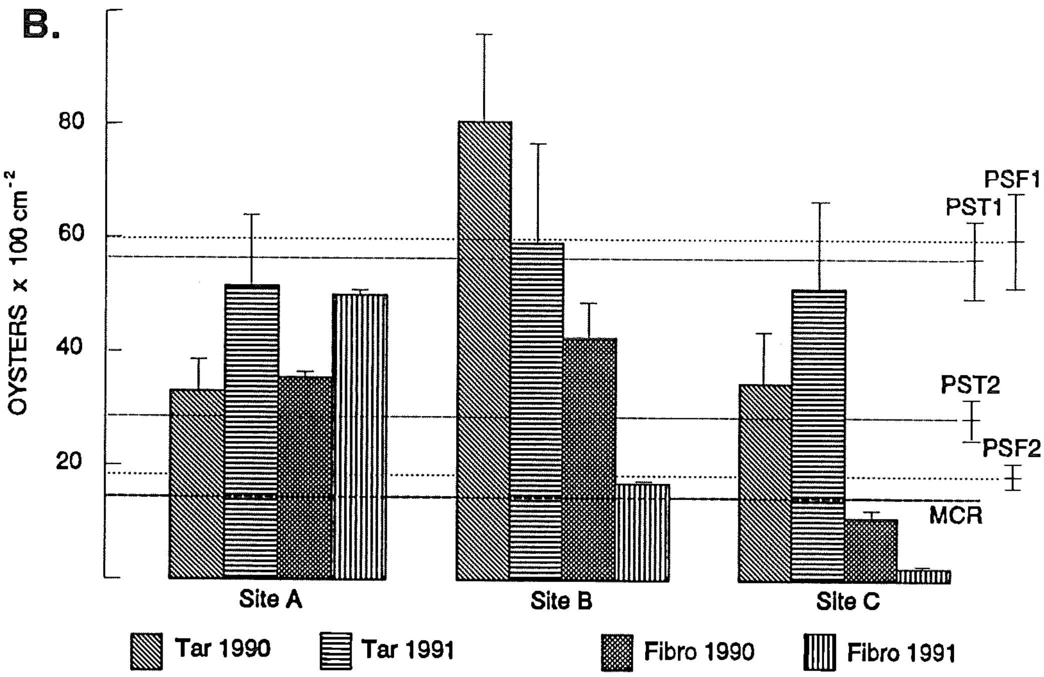


Figure 3.7 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

August 1991. Peaks in settlement occurring during December 1990 (4.57 oysters x $100cm^{-2}$ x day^{-1}) and March 1991 (4.57 oysters x $100cm^{-2}$ x day^{-1}), with a minor peak during June 1991. Settlement commenced again in September 1991 and climbed steadily until the termination of monitoring in early January 1992 (2.62 oysters x $100cm^{-2}$ x day^{-1}).

3.3.5.2 Commercial Recruitment

During 1990 mean commercial recruitment to both tarred (80.4 oysters x $100cm^{-2}$) and untarred plates (42.5 oysters x $100cm^{-2}$) at site 2 as well as to tarred plates at site 3 were not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 3.1). Recruitment to tarred (33.0 oysters x $100cm^{-2}$) and untarred plates (35.4 oysters x $100cm^{-2}$) at site 1 were classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment to untarred plates (11.0 oysters x $100cm^{-2}$) at site 3 were classified as non commercial ($P<0.05$) (Table 3.1).

During 1991 the mean commercial recruitment to untarred plates (49.9 oysters x $100cm^{-2}$) at site 1 was significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to tarred plates (51.5 oysters x $100cm^{-2}$) at site 1 and to both tarred (59.1 oysters x $100cm^{-2}$) and untarred plates (16.9 oysters x $100cm^{-2}$) at site 2 as well as to tarred plates (51.1 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 3.1). Recruitment to untarred (2.08 oysters x $100cm^{-2}$) plates at site 3 was classified as non commercial ($P<0.05$) (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 19.9mm, 19.1mm and 18.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.5mm, 15.1mm and 15.3mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 13.3mm, 11.5mm and 8.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.5mm, 17.6mm and 22.7mm respectively.

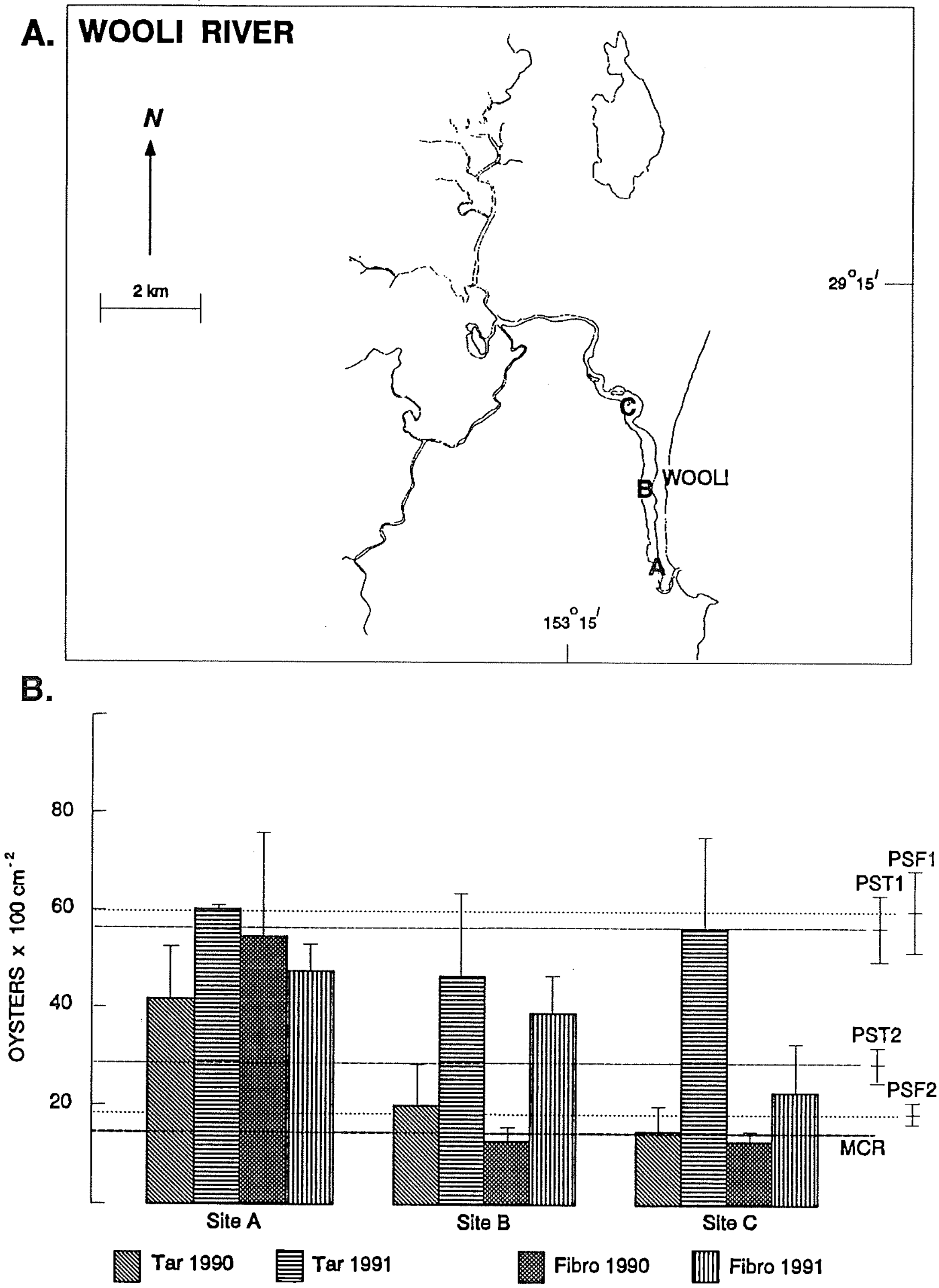
3.3.6 WOOLI RIVER

3.3.6.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Wooli River estuary (Fig. 3.8) during 22 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4) of 4789 and 701 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until August 1990 with a major peak occurring during March 1990 (85.61 oysters x $100cm^{-2}$ x day^{-1}). Major

A.



B.

Figure 3.8 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

settlement commenced again during September 1990 and continued through until August 1991. Peaks in settlement occurred during September and October 1990 (10.03 oysters x $100cm^{-2}$ x day^{-1}) and February 1991 (9.2 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again in September 1991 and continued at a low level until the termination of monitoring, with a minor peak occurring during November 1991 (1.8 oysters x $100cm^{-2}$ x day^{-1}).

3.3.6.2 Commercial Recruitment

During 1990 the mean commercial recruitment to both tarred (41.7 oysters x $100cm^{-2}$) and untarred plates (54.6 oysters x $100cm^{-2}$) at site 1 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to both tarred (20.0 oysters x $100cm^{-2}$) and untarred plates (12.8 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (14.8 oysters x $100cm^{-2}$) and untarred plates (12.8 oysters x $100cm^{-2}$) and at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (60.2 oysters x $100cm^{-2}$) and untarred plates (47.5 oysters x $100cm^{-2}$) at site 1 as well as to untarred plates (38.8 oysters x $100cm^{-2}$) at site 2 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to tarred plates (46.5 oysters x $100cm^{-2}$) at site 2 and to both tarred (56.4 oysters x $100cm^{-2}$) and untarred plates (22.7 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to the recruitment at Salamander Bay Port Stephens (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.0mm, 21.4mm and 17.9mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.5mm, 23.1mm and 17.4mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 13.9mm, 17.5mm and 11.3mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.3mm, 12.8mm and 13.3mm respectively.

3.3.7 NAMBUCCA RIVER

3.3.7.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Nambucca River estuary (Fig. 3.9) during 20 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was considerable with total cumulative settlement at sites 1 and 2 (Table 3.4) of 487 and 1811 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until July 1990 with a major peak occurring during February 1990 (57.7 oysters x $100cm^{-2}$ x day^{-1}). Settlement

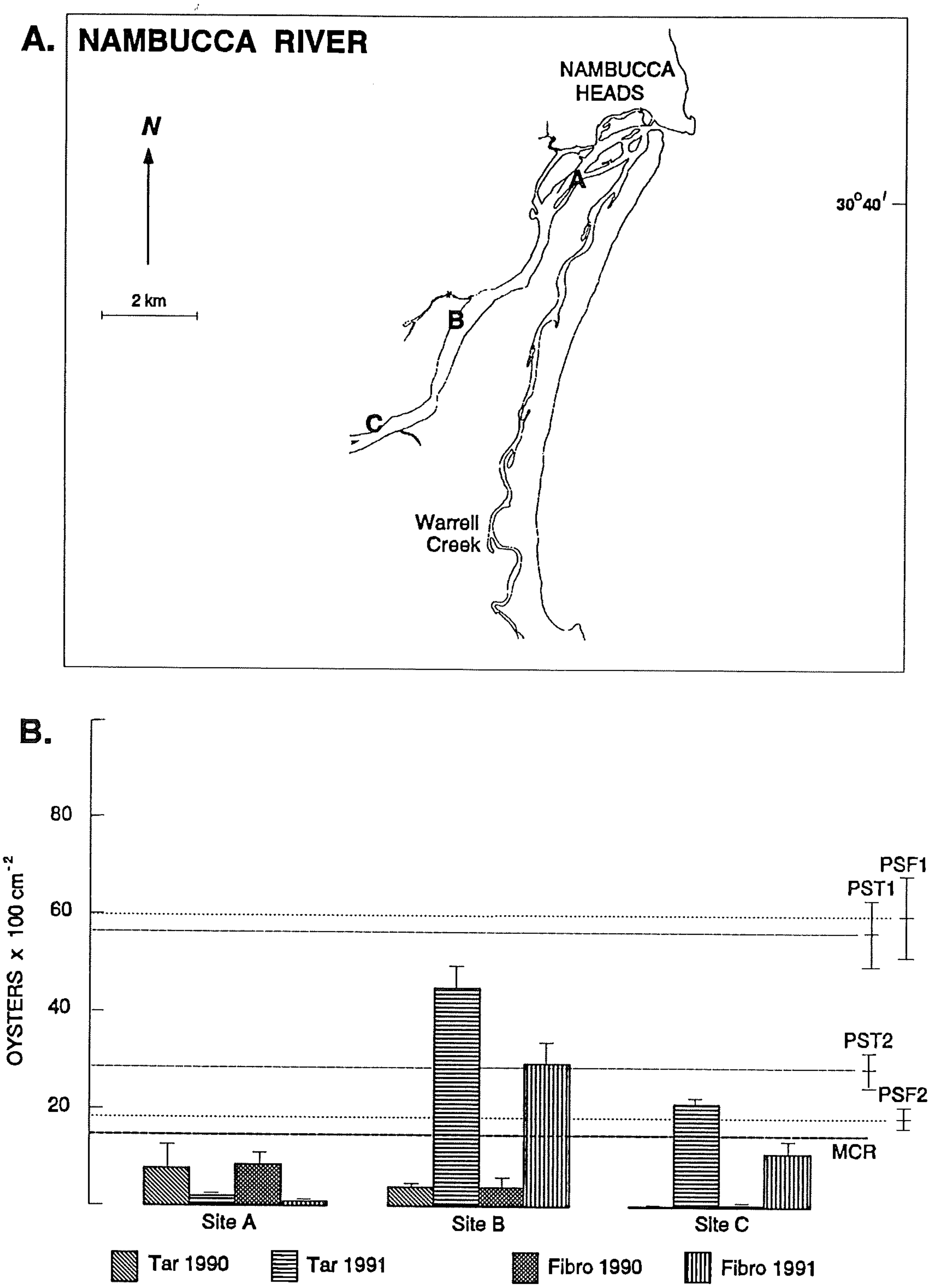


Figure 3.9 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

commenced again during September 1990 and continued through until August 1991. Peaks in settlement occurred during November 1990 (2.3 oysters x $100cm^{-2}$ x day^{-1}), February (2.6 oysters x $100cm^{-2}$ x day^{-1})and April 1991 (5.3 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during October 1991 and continued at a low level until the termination of monitoring.

3.3.7.2 Commercial Recruitment

During 1990 mean commercial recruitment was classified as non commercial ($P<0.05$) to both tarred (7.8 oysters x $100cm^{-2}$) and untarred plates (8.5 oysters x $100cm^{-2}$) at site 1, to both tarred (3.9 oysters x $100cm^{-2}$) and untarred plates (3.9 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (0.1 oysters x $100cm^{-2}$)and untarred plates (0.3 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 the mean commercial recruitment to both tarred (44.9 oysters x $100cm^{-2}$) and untarred plates (29.5 oysters x $100cm^{-2}$) at site 2 was significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to tarred plates (21.2 oysters x $100cm^{-2}$) at site 3 was not significantly different ($P<0.05$) to recruitment plates at Salamander Bay (Table 1). Recruitment was classified as non commercial ($P<0.05$) to both tarred (1.94 oysters x $100cm^{-2}$) and untarred (0.85 oysters x $100cm^{-2}$) plates at site 1, as well as to untarred plates (10.0 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

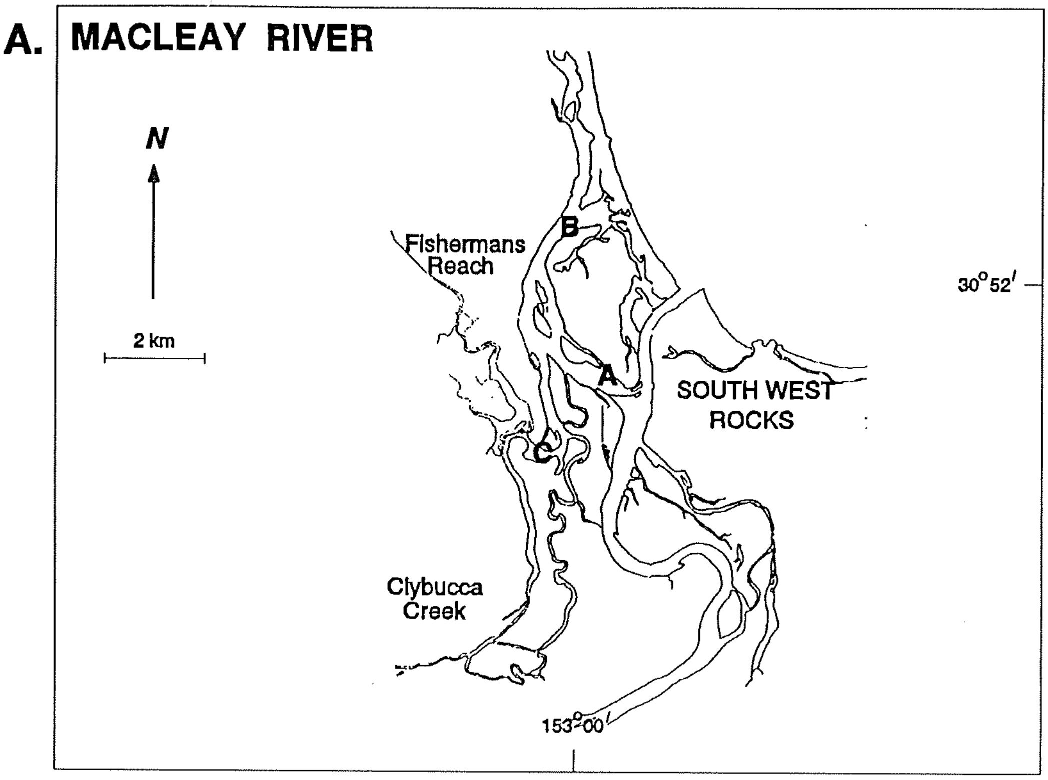
During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 30.8mm, 24.0mm and 13.8mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 31.8mm, 27.1mm and 12.0mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 20.0mm, 21.1mm and 27.7mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 24.7mm, 17.1mm and 24.4mm respectively.

3.3.8 MACLEAY RIVER

3.3.8.1 Settlement

Due to unforseen circumstances settlement monitoring plates in the Macleay River estuary (Fig. 3.10) were left deployed for a number of extended periods, therefore it was not possible to accurately isolate settlement on a monthly basis (Fig. 3.2). Settlement was generally light and appeared to have occurred during the summer months. However, peaks in settlement occurred during 1990 during January and February. During 1991 peaks in January and February.

3.3.8.2 Commercial Recruitment



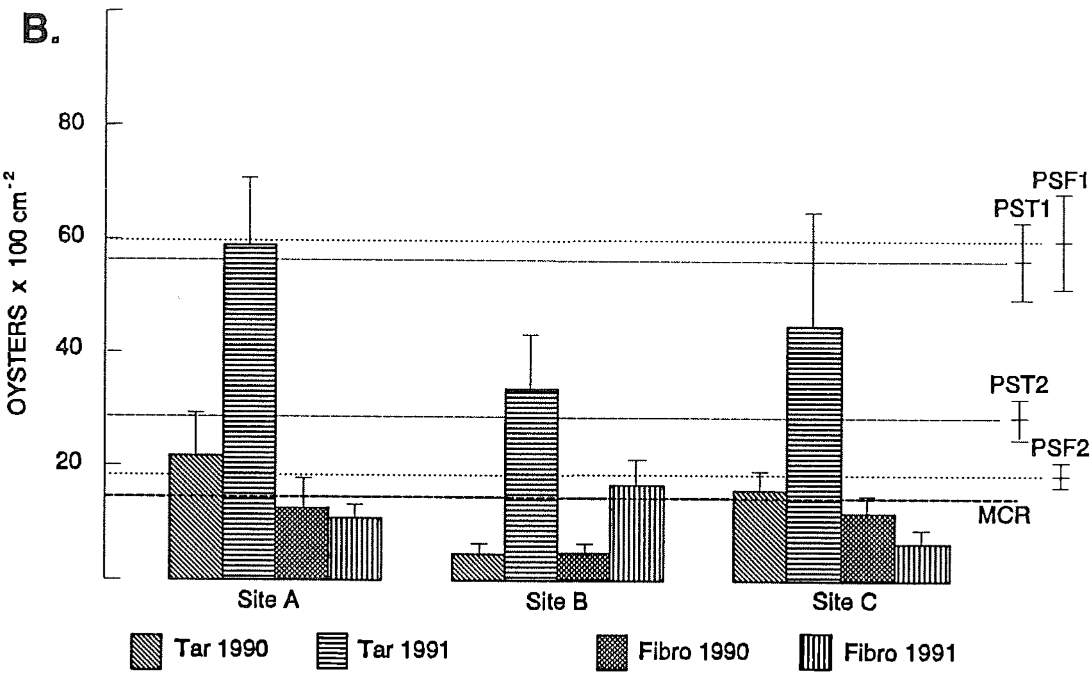


Figure 3.10 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

During 1990 mean commercial recruitment was classified as non commercial ($P<0.05$) to both tarred (21.7 oysters x $100cm^{-2}$) and untarred plates (12.6 oysters x $100cm^{-2}$) at site 1, to both tarred (4.6 oysters x $100cm^{-2}$) and untarred plates (4.8 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (15.7 oysters x $100cm^{-2}$)and untarred plates (11.8 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 the mean commercial recruitment to tarred plates (58.9 oysters x $100cm^{-2}$) at site 1 was significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to both tarred plates (33.6 oysters x $100cm^{-2}$) and untarred plates (16.6 oysters x $100cm^{-2}$) at site 2 and tarred plates (44.6 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 3.1). Recruitment was classified as non commercial ($P<0.05$) to untarred plates (10.7 oysters x $100cm^{-2}$) at site 1 and to untarred plates (6.5 oysters x $100cm^{-2}$) plates at site 3 (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.8mm, 19.2mm and 18.3mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 10.2mm, 29.2mm and 26.2mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 17.6mm, 16.0mm and 15.5mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.7mm, 13.6mm and 19.3mm respectively.

3.3.9 HASTINGS RIVER

3.3.9.1 Settlement

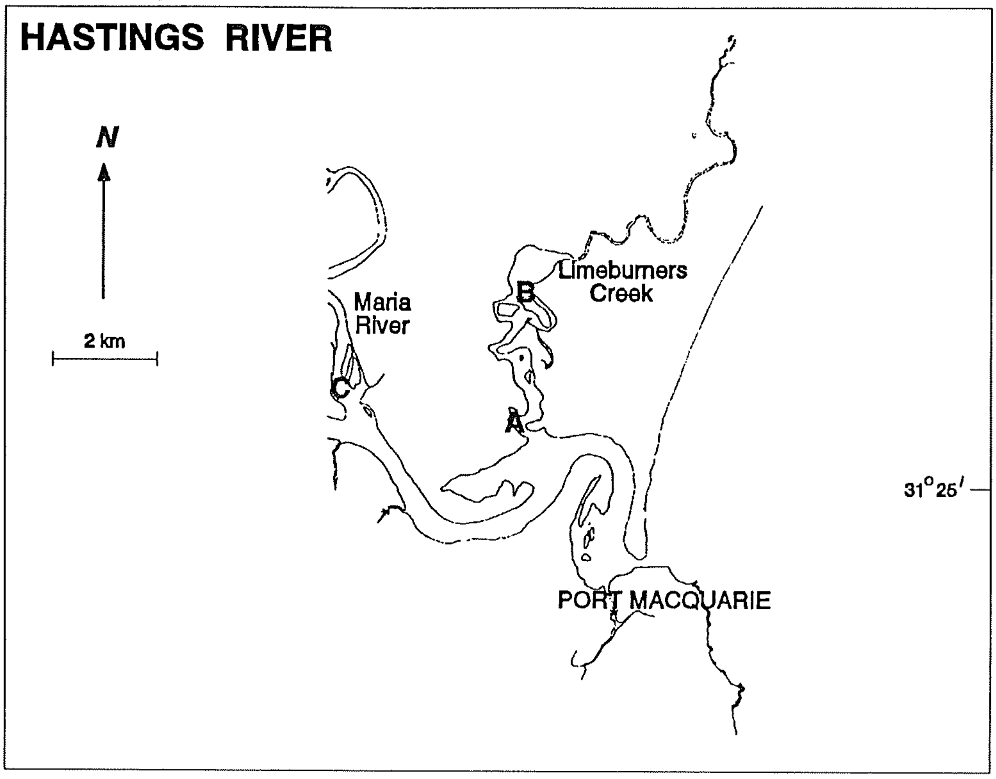
Settlement of the Sydney rock oyster was detected at monitoring sites in the Hastings River estuary (Fig. 3.11) during 18 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was moderate with total cumulative settlement at sites 1 and 2 (Table 3.4) of 704 and 48 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until July 1990 with a major peak occurring during February 1990 (15.0 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during November 1990 and continued through until September 1991. Peaks in settlement occurred during January 1990 (2.28 oysters x $100cm^{-2}$ x day^{-1}) and March 1991 (1.96 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during November 1991 and increased to the termination of monitoring (2.3 oysters x $100cm^{-2}$ x day^{-1}).

3.3.9.2 Commercial Recruitment

During 1990 mean commercial recruitment was classified as non commercial

A.



B.

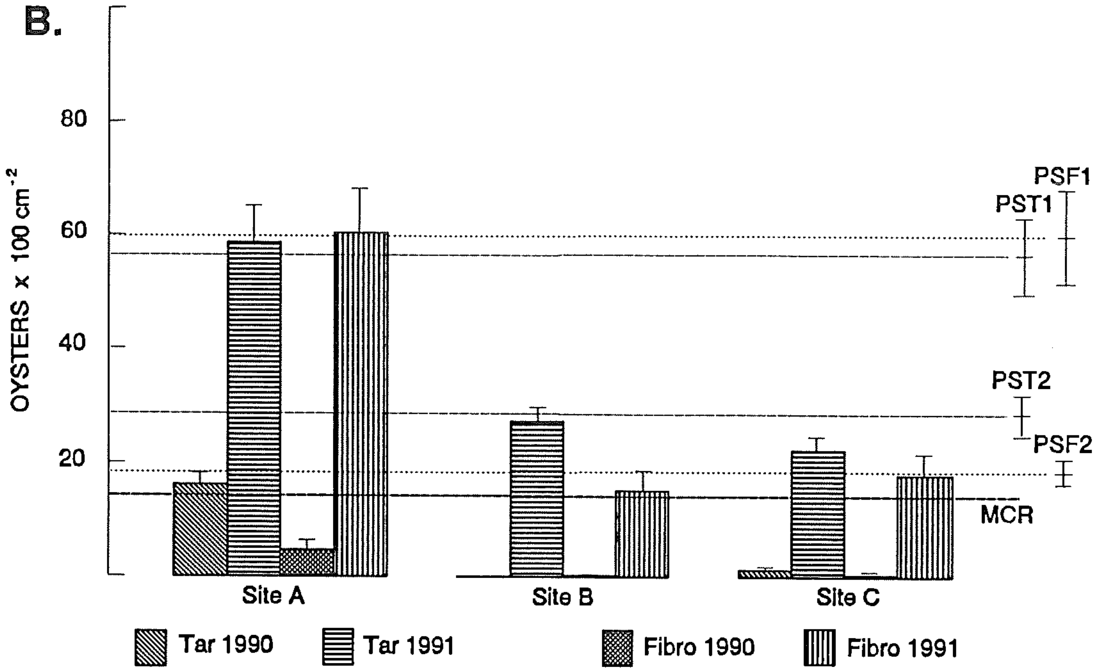


Figure 3.11 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

($P<0.05$) at site 1 to both tarred (16.2 oysters x $100cm^{-2}$) and untarred plates (4.6 oysters x $100cm^{-2}$), at site 2 to both tarred (0 oysters x $100cm^{-2}$) and untarred plates (0.1 oysters x $100cm^{-2}$) and at site 3 to both tarred (1.2 oysters x $100cm^{-2}$)and untarred plates (0.3 oysters x $100cm^{-2}$) (Table 3.1).

During 1991 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (58.6 oysters x $100cm^{-2}$) and untarred plates (60.3 oysters x $100cm^{-2}$) at site 1 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to tarred (27.3 oysters x $100cm^{-2}$) at site 2 as well as to both tarred (22.3 oysters x $100cm^{-2}$) and untarred plates (17.9 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to the recruitment at Salamander Bay. Recruitment to untarred (15.1 oysters x $100cm^{-2}$) plates at site 2 were non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1 and 2 were 5.7mm and 10.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 13.3mm, 18.3mm and 3.0mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 14.1mm, 26.3mm and 27.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.3mm, 22.5mm and 25.9mm respectively.

3.3.10 CAMDEN HAVEN RIVER

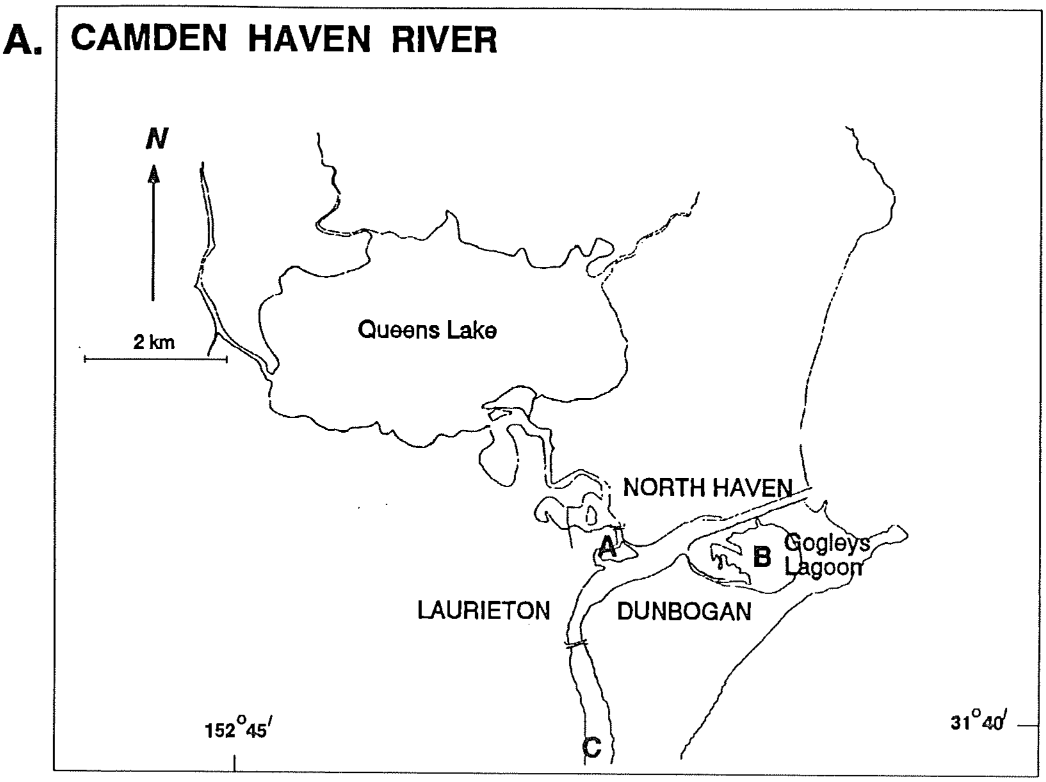
3.3.10.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Camden Haven River estuary (Fig. 3.12) during 18 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was considerable with total cumulative settlement at sites 1 and 2 (Table 3.4) of 228 and 1464 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until August 1990 with a major peak occurring during February 1990 (38.6 oysters x $100cm^{-2}$ x day^{-1}) declining steadily until August. Settlement commenced again during November 1990 and continued through until August 1991, with a peak in settlement occurring during April 1990 (3.47 oysters x $100cm^{-2}$ x day^{-1}). A low level of settlement commenced again during November 1991 and continued to the termination of monitoring.

3.3.10.2 Commercial Recruitment

During 1990 the mean commercial recruitment to both tarred (48.6 oysters x $100cm^{-2}$) and untarred plates (48.6 oysters x $100cm^{-2}$) at site 1, to tarred plates (54.5 oysters x $100cm^{-2}$) at site 2 as well as to tarred plates (42.3 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to that on plates at Salamander Bay.



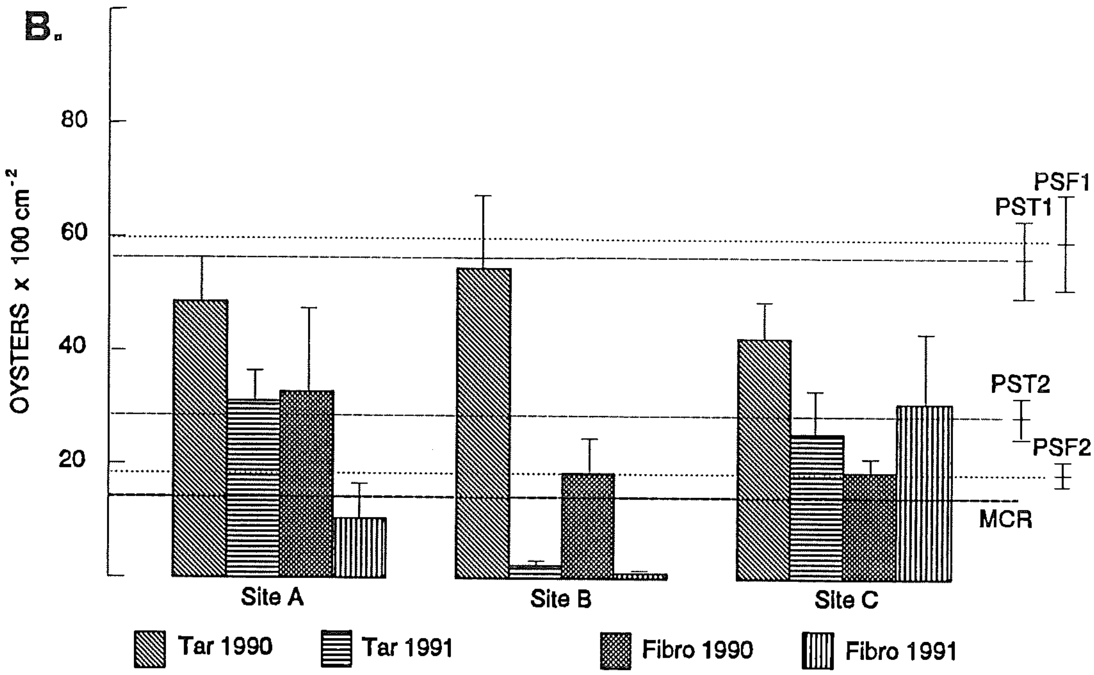


Figure 3.12 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

Recruitment to untarred plates (18.4 oysters x $100cm^{-2}$) at site 2 as well as to untarred plates (18.6 oysters x $100cm^{-2}$) at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to tarred (31.2 oysters x $100cm^{-2}$) plates at site 1, as well as to both tarred (25.6 oysters x $100cm^{-2}$) and untarred plates (30.8 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to the recruitment at Salamander Bay (Table 1). Recruitment to untarred (10.3 oysters x $100cm^{-2}$) plates at site 1, as well as to both tarred (2.2 oysters x $100cm^{-2}$) and untarred plates (0.9 oysters x $100cm^{-2}$) at site 2 were classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 12.3mm, 7.6mm and 19.2mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.7mm, 10.3mm and 13.4mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 14.3mm, 22.0mm and 19.8mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 8.5mm, 23.5mm and 20.2mm respectively.

3.3.11 MANNING RIVER

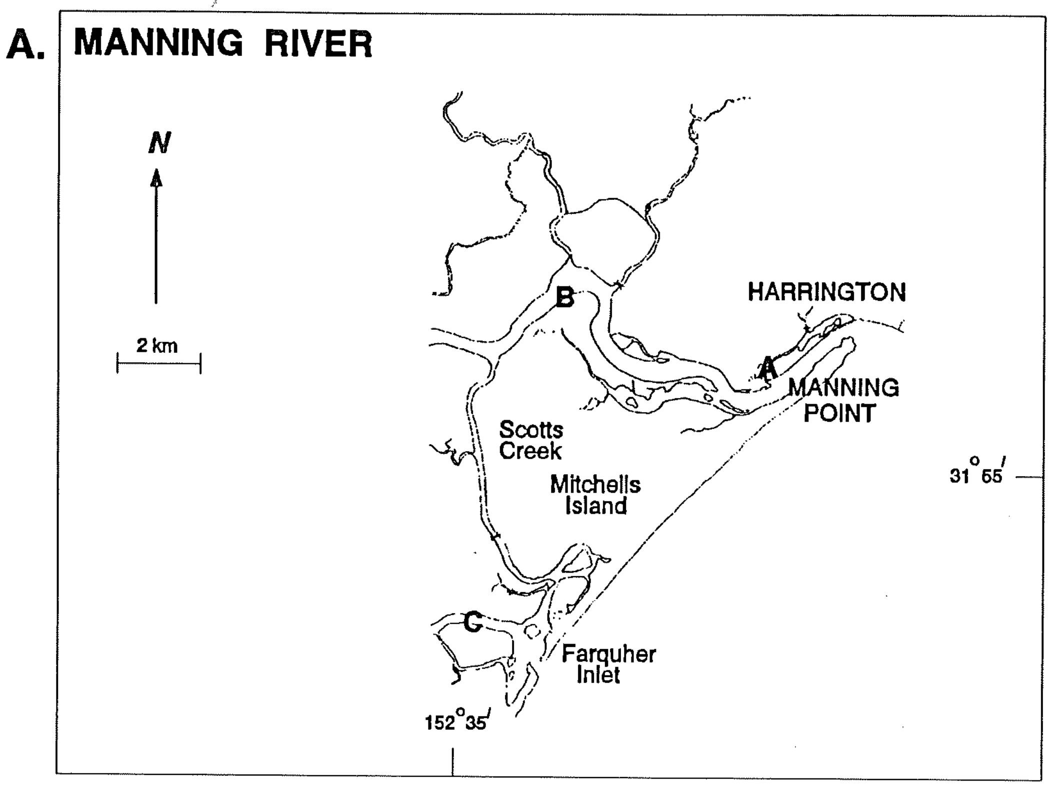
3.3.11.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Manning River estuary (Fig. 3.13) during 15 of the 22 deployments (Fig. 3.2). Settlement over the duration of the study was moderate with total cumulative settlement at sites 1 and 2 (Table 3.4) of 91 and 251 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until July 1990 with a peak in settlement occurring during March 1990 (3.1 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again in December 1990 and continued until July 1991. A peak in settlement occurring in March (1.9 oysters x $100cm^{-2}$ x day^{-1}) with further settlement beginning during November 1991.

3.3.11.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred (25.4 oysters x $100cm^{-2}$) at site 2 was classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment was classified as non commercial ($P<0.05$) at site 1 to both tarred 7.3 oysters x $100cm^{-2}$) and untarred plates (1.7 oysters x $100cm^{-2}$), at site 2 to untarred plates (13.2 oysters x $100cm^{-2}$) and to both tarred (0 oysters x $100cm^{-2}$)and untarred plates (0 oysters x $100cm^{-2}$) at site 3 (Table 3.1).



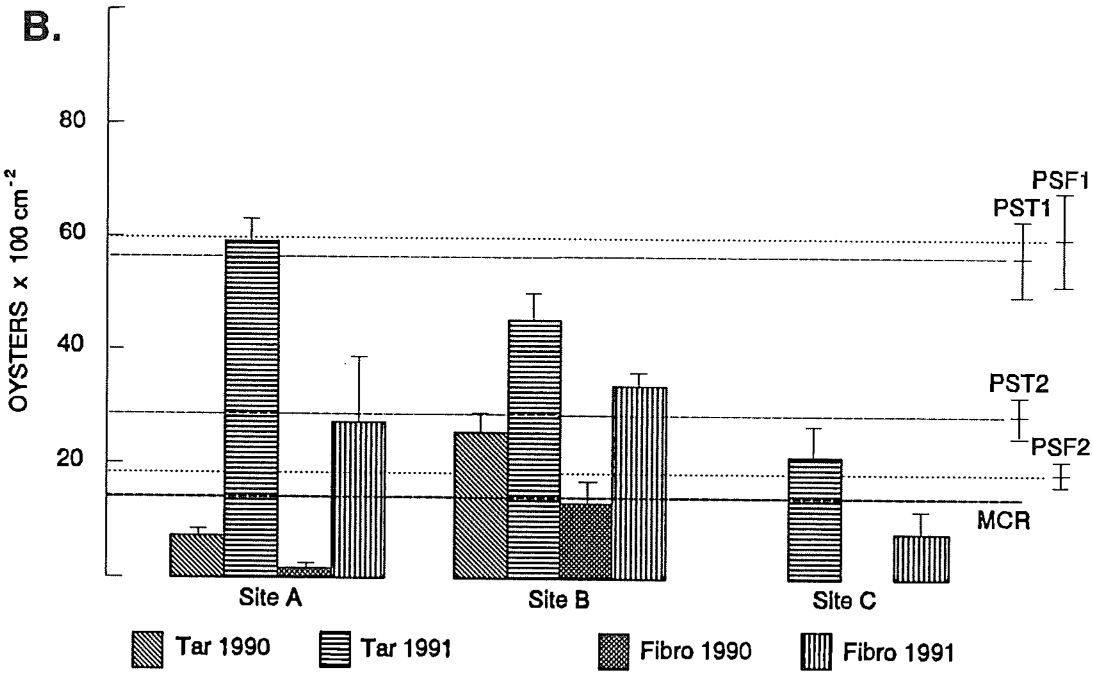


Figure 3.13 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

During 1991 the mean commercial recruitment to tarred plates (59 oysters x $100cm^{-2}$) at site 1 and to both tarred plates (45.1 oysters x $100cm^{-2}$) and untarred plates (33.7 oysters x $100cm^{-2}$) at site 2 were significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to untarred plates (27.3 oysters x $100cm^{-2}$) at site 1 and to tarred plates (21.2 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1). Recruitment to untarred plates (7.9 oysters x $100cm^{-2}$) at site 3 was classified as non commercial ($P<0.05$) (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1 and 2 were 27.5mm and 15.7mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 22.7mm, 16.9mm and 20.2mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.4mm, 18.5mm and 16.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 17.0mm, 19.4mm and 12.4mm respectively.

3.3.12 WALLIS LAKE

3.3.12.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in Wallis Lake (Fig. 3.14) during 18 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4) of 788 and 381 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until June 1990 with a major peak occurring during February 1990 (29.2 oysters x $100cm^{-2}$ x day^{-1}). Low level settlement was detected during both July and September 1990. Settlement commenced again during November 1990 and continued through until August 1991, with a peak in settlement occurring during March and April 1990 (5.4 oysters x $100cm^{-2}$ x day^{-1}). A low level of settlement commenced again during November 1991 and continued to the termination of monitoring.

3.3.12.2 Commercial Recruitment

During 1990 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (97.5 oysters x $100cm^{-2}$) and untarred plates (83.0 oysters x $100cm^{-2}$) at site 3 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to both tarred (71.1 oysters x $100cm^{-2}$) and untarred plates (38.0 oysters x $100cm^{-2}$) at site 1 as well as to both tarred (80.5 oysters x $100cm^{-2}$) and untarred plates (67.1 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to the recruitment at Salamander Bay (Table 3.1).

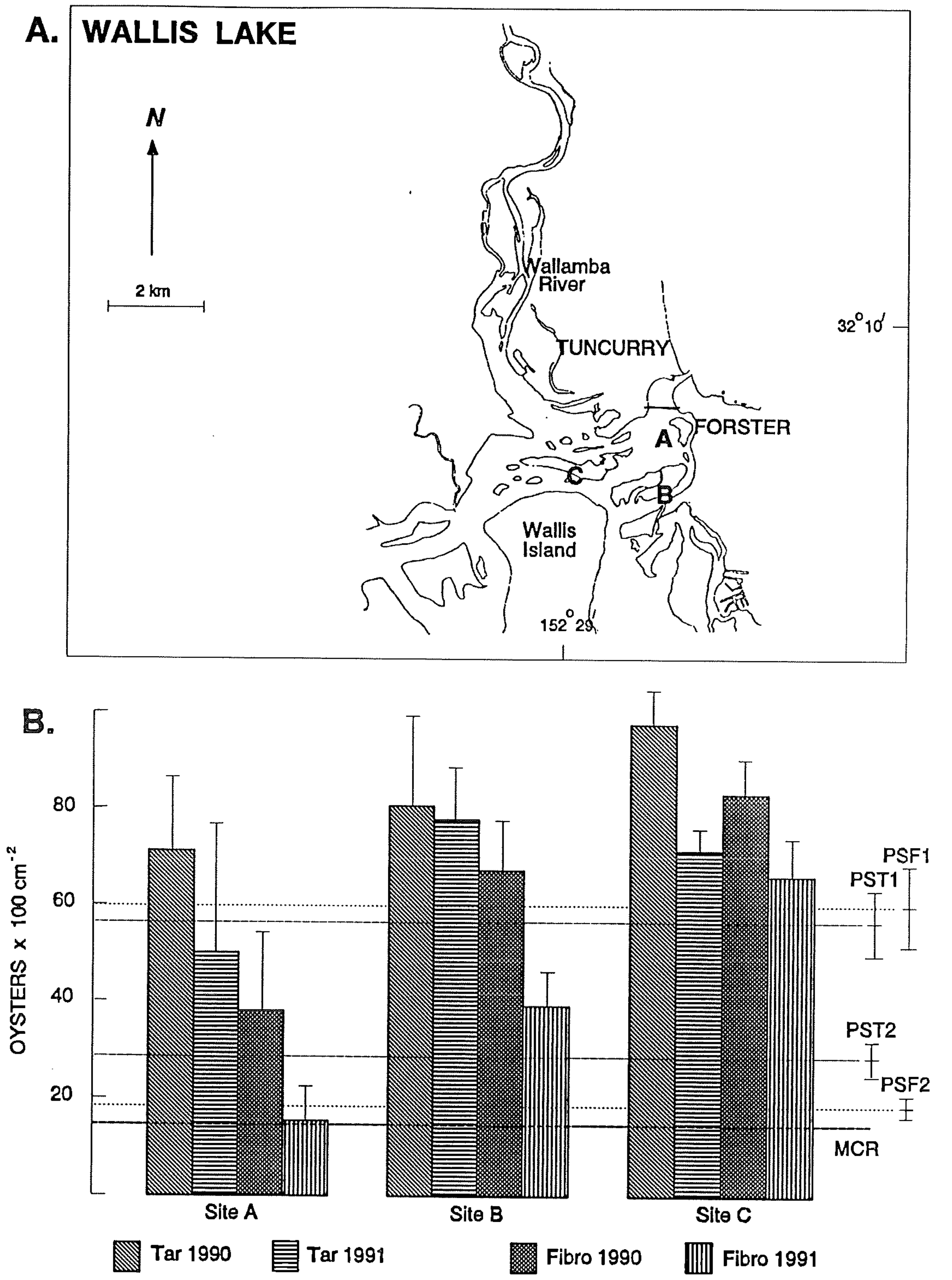


Figure 3.14 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

During 1991 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (77.7 oysters x $100cm^{-2}$) and untarred plates (39.1 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (71.3 oysters x $100cm^{-2}$) and untarred plates (66.0 oysters x $100cm^{-2}$) at site 3 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to tarred plates (50.0 oysters x $100cm^{-2}$) at site 1 was not significantly different ($P<0.05$) to the recruitment at Salamander Bay, while recruitment to untarred plates (15.5 oysters x $100cm^{-2}$) at site 1 was classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 10.3mm, 12.8mm and 13.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 15.4mm, 13.9mm and 12.9mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 10.1mm, 11.9mm and 16.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.3mm, 13.2mm and 13.5mm respectively.

3.3.13 PORT STEPHENS

3.3.13.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in Port Stephens (Fig. 3.15) during 18 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4(of 1415 and 374 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until August 1990 with a major peak occurring during February 1990 (43.7 oysters x $100cm^{-2}$ x day^{-1}) followed by a smaller peak during April (4.3 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during December 1990 and continued through until August 1991, with peaks in settlement occurring during February (1.4 oysters x $100cm^{-2}$ x day^{-1}) and April (1.9 oysters x $100cm^{-2}$ x day^{-1}) 1990. Settlement commenced again during October 1991 and increased slowly to the termination of monitoring.

3.3.13.2 Commercial Recruitment

During 1990 the mean commercial recruitment to both tarred (90.6 oysters x $100cm^{-2}$) and untarred plates (60.0 oysters x $100cm^{-2}$) at site 2 was not significantly different ($P<0.05$) to the recruitment at Salamander Bay (Table 3.1). Recruitment was classified as non commercial to both tarred (2.6 oysters x $100cm^{-2}$) and untarred plates (2.2 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 recruitment to both tarred (9.6 oysters x $100cm^{-2}$) and untarred plates (6.0 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (2.7 oysters x $100cm^{-2}$) and untarred plates (1.3 oysters x $100cm^{-2}$) at site 3 were classified as non

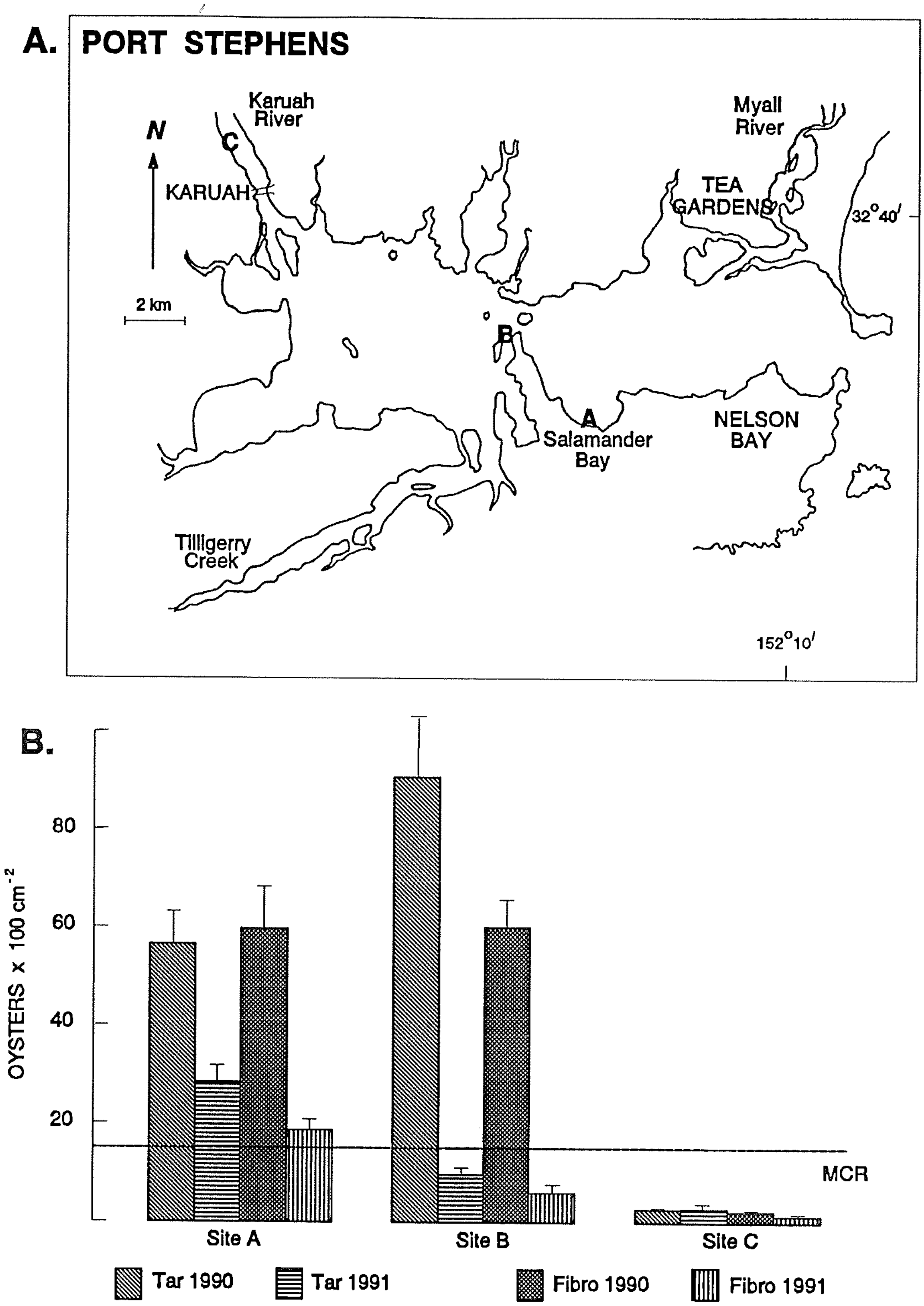


Figure 3.15 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 12.0mm, 10.5mm and 7.4mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 11.8mm, 11.6mm and 9.2mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 14.4mm, 25.5mm and 13.3mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.0mm, 22.8mm and 8.7mm respectively.

3.3.14 HAWKESBURY RIVER

3.3.14.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Hawkesbury River estuary (Fig. 3.16) during 12 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Table 3.4) of 87 and 164 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until May 1990 with a peak occurring during February 1990 (3.7 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during December 1990 and continued through until July 1991, with peaks in settlement occurring during January (0.7 oysters x $100cm^{-2}$ x day^{-1}) and March (1.8 oysters x $100cm^{-2}$ x day^{-1}) 1990. Settlement commenced again during December 1991.

3.3.14.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred plates (49.3 oysters x $100cm^{-2}$) at site 1 and tarred plates (63.3 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (4.8 oysters x $100cm^{-2}$) at site 1 and untarred plates (16.4 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (4.3 oysters x $100cm^{-2}$) and untarred plates (0.8 oysters x $100cm^{-2}$) and at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred (30.9 oysters x $100cm^{-2}$) and untarred plates (18.2 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to both tarred (5.6 oysters x $100cm^{-2}$) and untarred plates (0.5 oysters x $100cm^{-2}$) at site 1 as well as to both tarred (9.6 oysters x $100cm^{-2}$) and untarred plates (3.8 oysters x $100cm^{-2}$) and at site 3 were classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.4mm, 11.9mm and 7.4mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 16.0mm, 14.6mm and

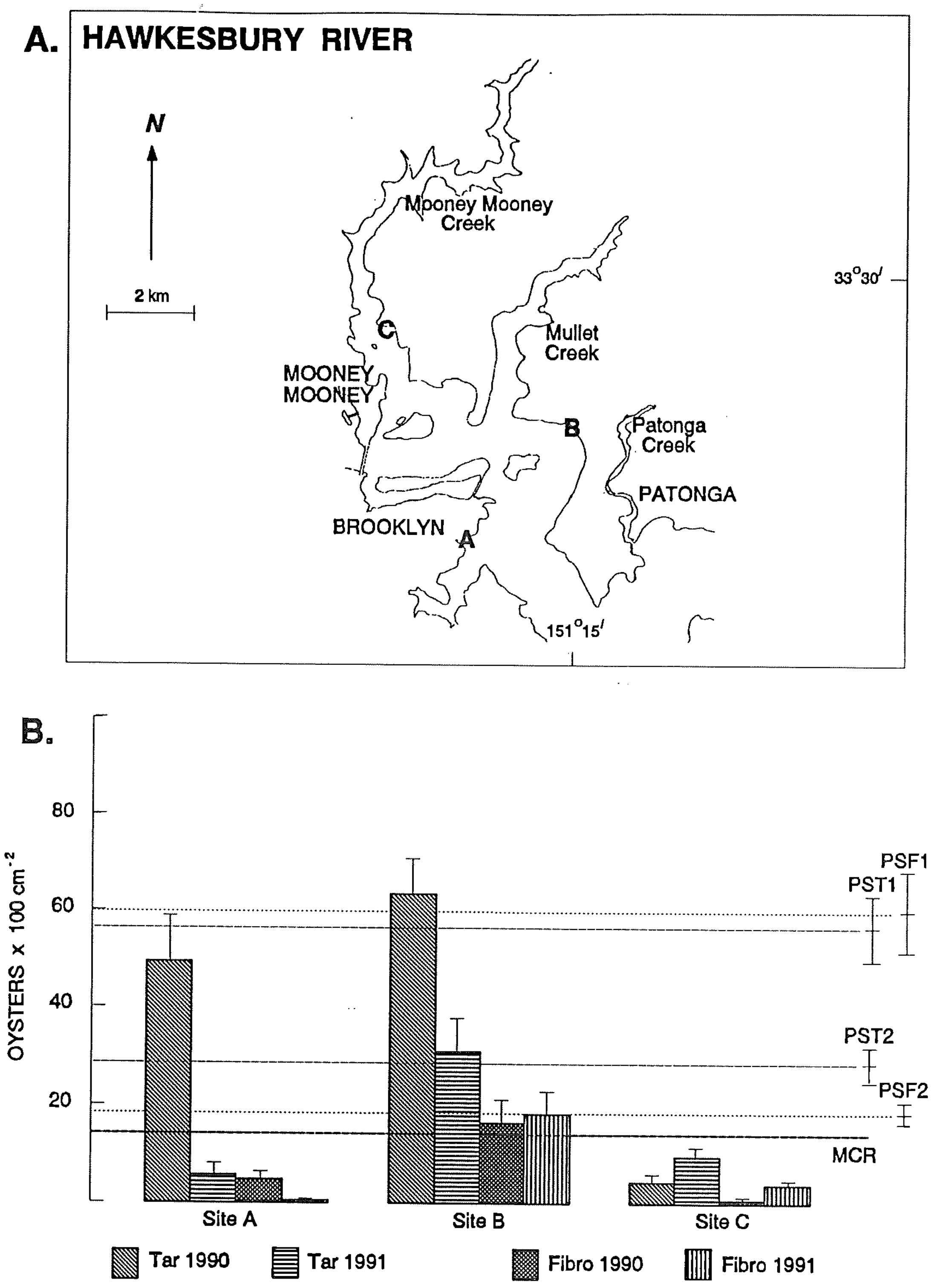


Figure 3.16 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

14.2mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.0mm, 13.6mm and 16.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 18.2mm, 11.0mm and 14.5mm respectively.

3.3.15 GEORGES RIVER

3.3.15.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Georges River estuary (Fig. 3.17) during 11 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Table 3.4) of 210 and 67 oysters per $100cm^2$ respectively.

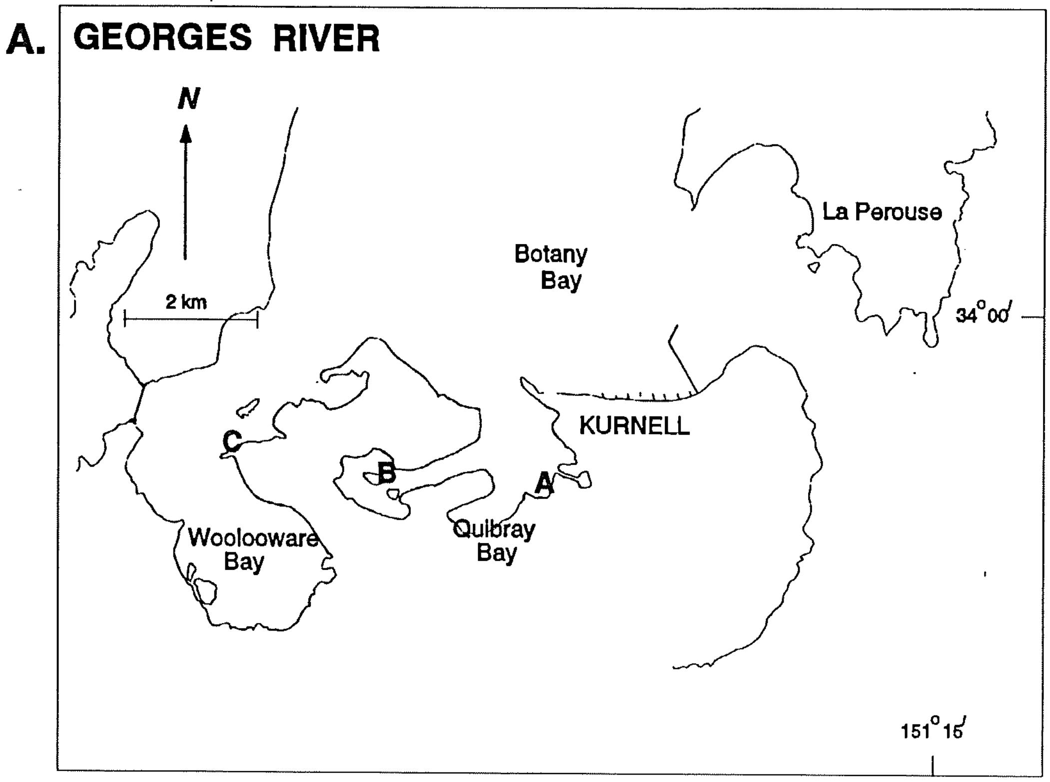
Settlement was observed from initial deployment until May 1990 with a peak occurring during February 1990 (5.9 oysters x $100cm^{-2}$ x day^{-1}). Further low level settlement was detected during June 1990. Settlement commenced again during December 1990 and continued through until April 1991, with a peak in settlement occurring during February (0.6 oysters x $100cm^{-2}$ x day^{-1}). Further low level settlement was detected during June 1991. Settlement commenced again during December 1991.

3.3.15.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred (50.3 oysters x $100cm^{-2}$) at site 1 was not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1). Recruitment to tarred plates (21.2 oysters x $100cm^{-2}$) at site 3 was classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment to untarred plates (19.4 oysters x $100cm^{-2}$) at site 1, to both tarred (10.3 oysters x $100cm^{-2}$) and untarred plates (3.9 oysters x $100cm^{-2}$) and at site 2 as well as to untarred plates (9.0 oysters x $100cm^{-2}$) at site 3 were classified as non commercial (Table 3.1).

During 1991 mean commercial recruitment to untarred (22.6 oysters x $100cm^{-2}$) at site 1 was not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1).
Recruitment to tarred plates (6.3 oysters x $100cm^{-2}$) at site 1, to both tarred (4.5 oysters x $100cm^{-2}$) and untarred plates (2.2 oysters x $100cm^{-2}$) and at site 2 as well as to tarred (2.6 oysters x $100cm^{-2}$) an untarred plates (9.1 oysters x $100cm^{-2}$) at site 3 were classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 17.9mm, 12.2mm and 10.2mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 14.8mm, 12.6mm and 8.8mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to



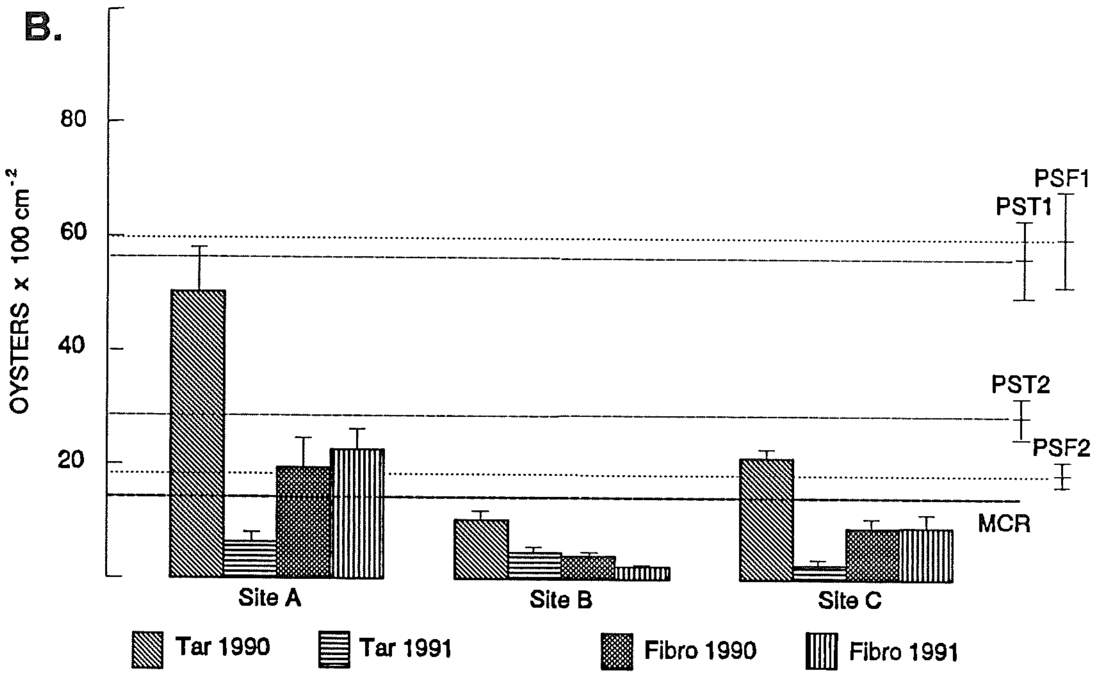


Figure 3.17 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

tarred plates at sites 1, 2 and 3 were 23.9mm, 13.3mm and 6.4mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 17.6mm, 41.0mm and 17.3mm respectively.

3.3.16 CROOKHAVEN RIVER

3.3.16.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Crookhaven River estuary (Fig. 3.19) during 13 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was considerable with total cumulative settlement at sites 1 and 2 (Table 3.4) of 285 and 60 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until April 1990 with a major peak occurring during February 1990 (3.8 oysters x $100cm^{-2}$ x day^{-1}). Further settlement was detected during May 1990 (0.5 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during December 1990 and continued through until June 1991, with peaks in settlement occurring during February (1.61 oysters x $100cm^{-2}$ x day^{-1}) 1990. Further low level settlement was detected during August 1990 (0.1 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during November 1991 and increased to the termination of monitoring (0.9 oysters x $100cm^{-2}$ x day^{-1}).

3.3.16.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred (110 oysters x $100cm^{-2}$) at site 1 was significantly higher than that at Salamander Bay. Recruitment to untarred plates (48.9 oysters x $100cm^{-2}$) at site 1, to tarred plates (62.1 oysters x $100cm^{-2}$) and untarred plates (43.3 oysters x $100cm^{-2}$) at site 2 as well as to tarred plates (37.7 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (6.2 oysters x $100cm^{-2}$) at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred (37.7 oysters x $100cm^{-2}$) and untarred plates (54.1 oysters x $100cm^{-2}$) at site 1 were significantly higher ($P<0.05$) than that on plates at Salamander Bay. Recruitment to tarred (17.9 oysters x $100cm^{-2}$) at site 2 was classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment to untarred plates (3.3 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (?? oysters x $100cm^{-2}$)and untarred plates (2.9 oysters x $100cm^{-2}$) at site 3 were classified as non commercial ($P<0.05$) (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 10.0mm, 9.2mm and 9.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 10.8mm, 12.5mm and 10.7mm

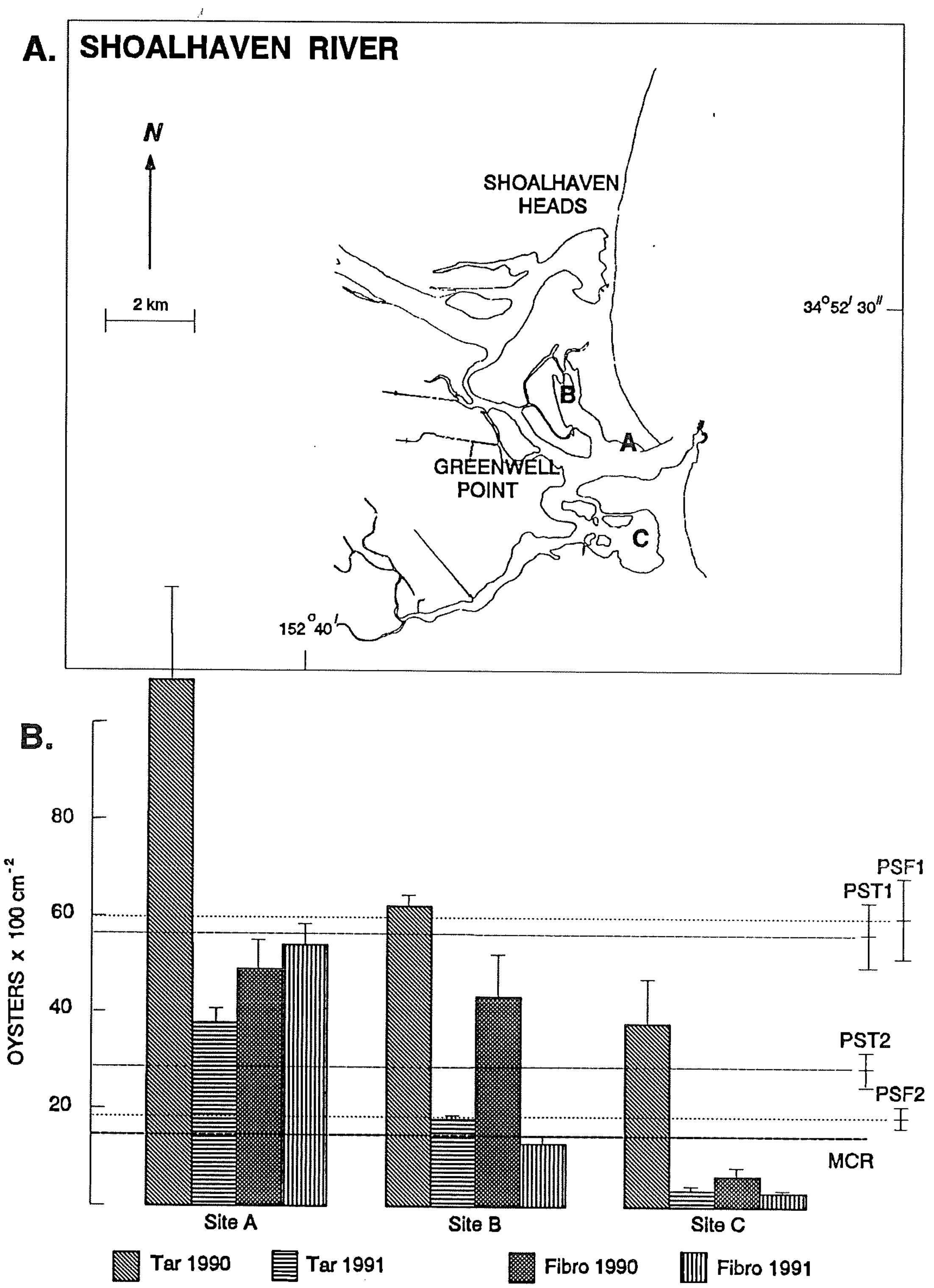


Figure 3.18 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.5mm, 22.8mm and 16.5mm respectively, and the mean size of recruits (table 3.3) to untarred plates at sites 1, 2 and 3 were 17.6mm, 41.0mm and 17.3mm respectively.

3.3.17 CLYDE RIVER

3.3.17.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Clyde River estuary (Fig. 3.20) during 11 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Table 3.4) of 71 and 24 oysters per 100cm^2 respectively.

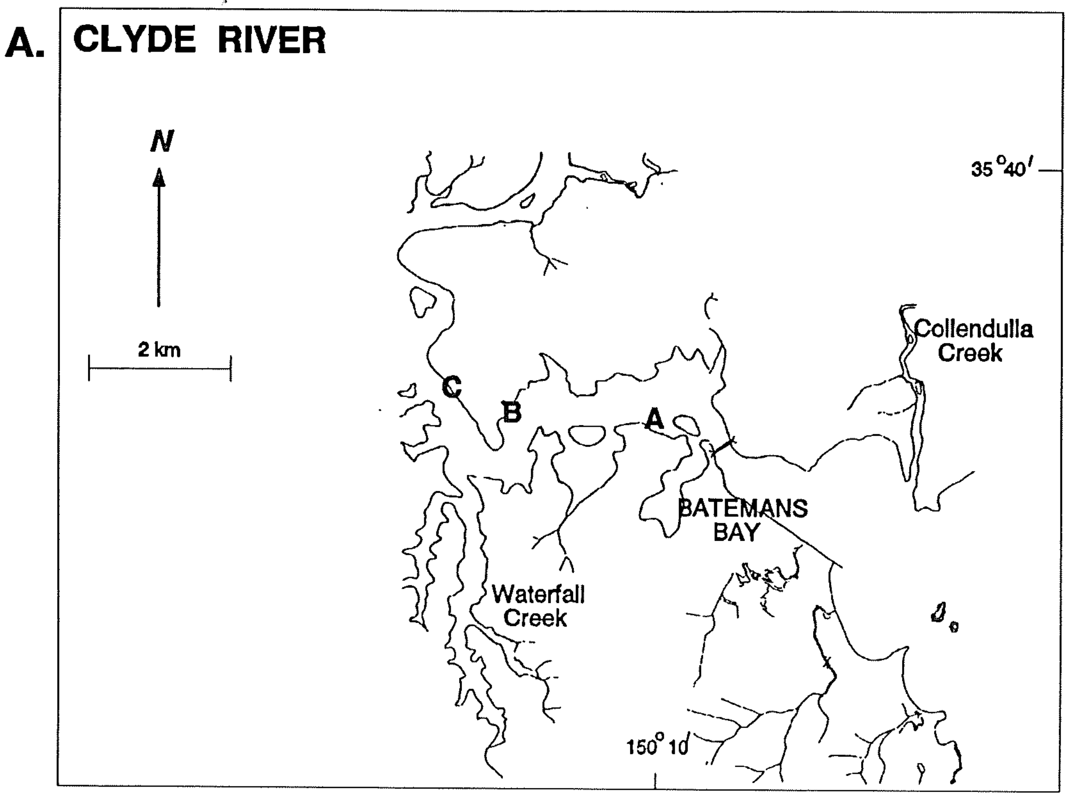
Settlement was observed from initial deployment until June 1990 with a peak occurring during February 1990 (0.8 oysters x 100cm^{-2} x day^{-1}). Settlement commenced again during December 1990 and continued through until June 1991, with a peak in settlement occurring during February (0.6 oysters x 100cm^{-2} x day^{-1}) 1991. Settlement was not detected again until December 1991.

3.3.17.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred (52.9 oysters x 100cm^{-2}) at site 1 was not significantly different (P<0.05) to recruitment to plates at Salamander Bay (Table 1). Recruitment to tarred plates (31.4 oysters x 100cm^{-2}) at site 2 was classified as commercial (P<0.05) though significantly lower (P<0.05) than recruitment to plates at Salamander Bay. Recruitment to untarred plates (18.3 oysters x 100cm^{-2}) at site 1 and untarred plates (15.6 oysters x 100cm^{-2}) at site 2, as well as to bot tarred (21.3 oysters x 100cm^{-2}) and untarred plates (3.5 oysters x 100cm^{-2}) at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred (21.0 oysters x 100cm^{-2}) and untarred plates (23.2 oysters x 100cm^{-2}) at site 1 were not significantly different (P<0.05) to that on plates at Salamander Bay. Recruitment to both tarred (2.4 oysters x 100cm^{-2}) and untarred plates (2.6 oysters x 100cm^{-2}) at site 2 as well as to both tarred (6.0 oysters x 100cm^{-2}) and untarred plates (4.7 oysters x 100cm^{-2}) and at site 3 were classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 6.9mm, 9.3mm and 7.4mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 9.2mm, 11.8mm and 13.1mm respectively. During 1991 the mean size of oysters recruits (table 3.2) to tarred plates at sites 1, 2 and 3 were 11.6mm, 14.6mm and 16.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 10.2mm, 8.1mm and 10.0mm respectively.



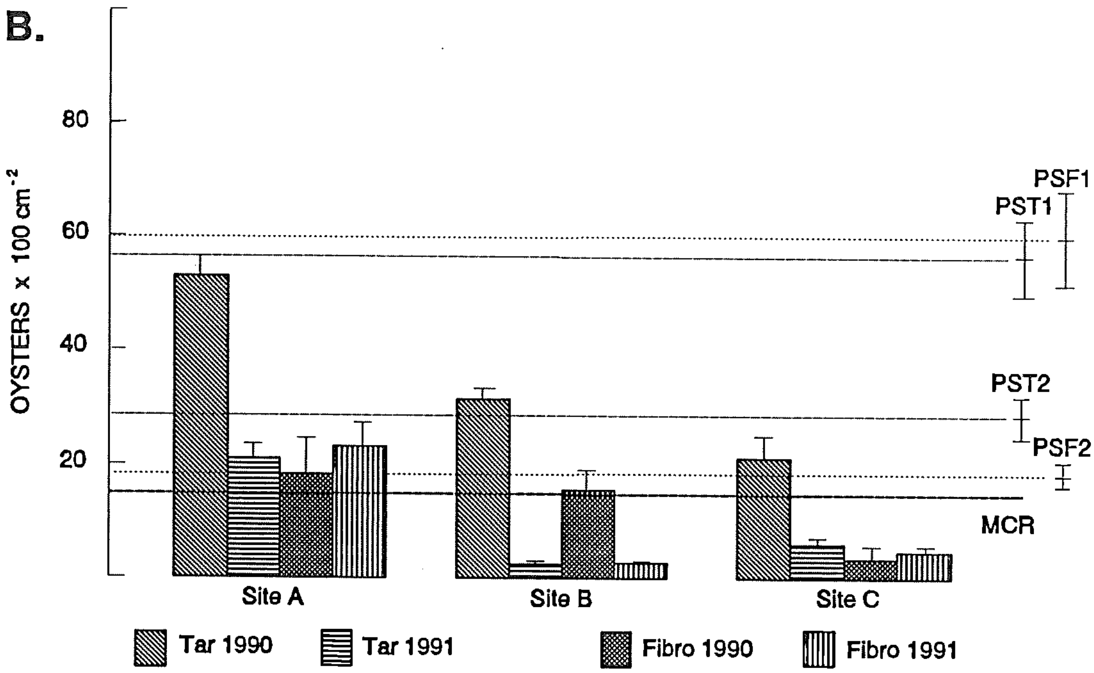


Figure 3.19 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

3.3.18 MORUYA RIVER

3.3.18.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Moruya River estuary (Fig. 3.21) during 8 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was light with total cumulative settlement at sites 1 and 2 (Table 3.4) of 53 and 81 oysters per $100cm^2$ respectively.

Settlement was observed from February until June 1990 with a peak occurring during February 1990 (1.06 oysters x $100cm^{-2}$ x day^{-1}). Settlement was not detected again until December 1990 and continued through until May 1991, with a peak in settlement occurring during January (1.4 oysters x $100cm^{-2}$ x day^{-1}). No further settlement was detected prior to the termination of monitoring.

3.3.18.2 Commercial Recruitment

During 1990 mean commercial recruitment to tarred (105 oysters x $100cm^{-2}$) at site 2 was significantly higher ($P<0.05$) than that to plates at Salamander Bay (Table 1). Recruitment to untarred plates (64.9 oysters x $100cm^{-2}$) at site 2 was not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1). Recruitment to both tarred (29.0 oysters x $100cm^{-2}$) and untarred plates (26.8 oysters x $100cm^{-2}$) at site 1 were classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment to both tarred (21.6 oysters x $100cm^{-2}$) and untarred plates (3.9 oysters x $100cm^{-2}$) at site 3 were classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to both tarred (38.5 oysters x $100cm^{-2}$) and untarred plates (36.1 oysters x $100cm^{-2}$) at site 2 were significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to tarred (23.8 oysters x $100cm^{-2}$) was not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1). Recruitment was classified as non commercial ($P<0.05$) to untarred plates (14.1 oysters x $100cm^{-2}$) at site 1,as well as to both tarred (15.5 oysters x $100cm^{-2}$) and untarred plates (11.4 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 10.7mm, 11.2mm and 7.8mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 9.3mm, 12.4mm and 14.9mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 16.5mm, 13.2mm and 22.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 17.7mm, 11.3mm and 18.5mm respectively.

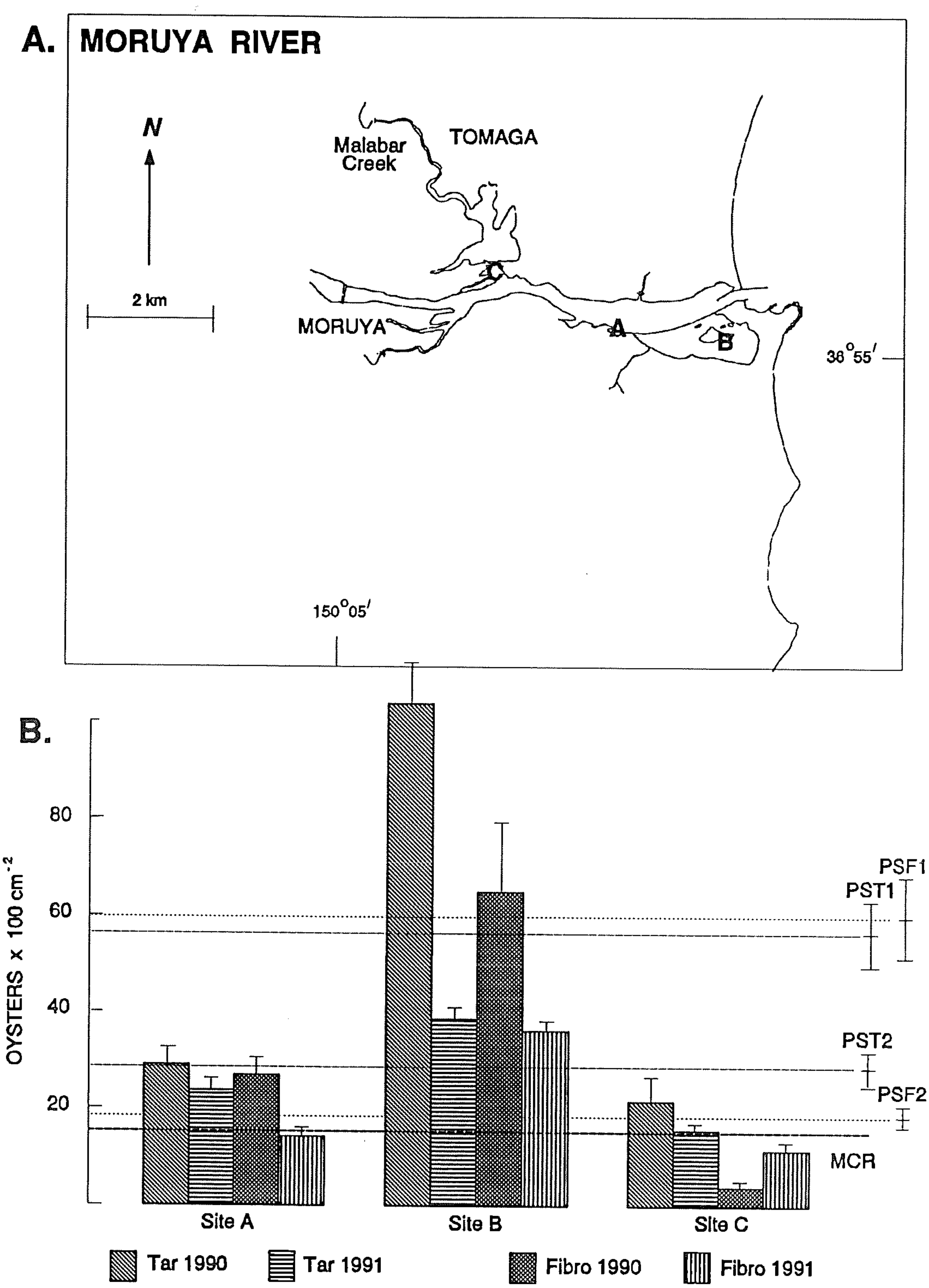


Figure 3.20 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

3.3.19 WAGONGA INLET

3.3.19.1 Settlement

Due to unforseen circumstances reliable settlement data was not available for Wagonga Inlet.

3.3.19.2 Commercial Recruitment

During 1990 mean commercial recruitment to untarred plates (28.3 oysters x $100cm^{-2}$) at site 1 (Fig. 3.21) and to tarred (25.2 oysters x $100cm^{-2}$) plates at site 3 were classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment was classified as non commercial ($P<0.05$) to tarred plates (16.8 oysters x $100cm^{-2}$) at site 1, to both tarred (12.9 oysters x $100cm^{-2}$) and untarred plates (7.1 oysters x $100cm^{-2}$) and at site 2, as well as to untarred plates (14.5 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 mean commercial recruitment to untarred plates (24.2 oysters x $100cm^{-2}$) at site 1 was not significantly different to the recruitment to untarred plates at Salamander Bay. Recruitment was classified as non commercial ($P<0.05$) to tarred plates (8.2 oysters x $100cm^{-2}$) at site 1, to both tarred (3.5 oysters x $100cm^{-2}$) and untarred plates (6.9 oysters x $100cm^{-2}$) and at site 2, as well as to both tarred (1.7 oysters x $100cm^{-2}$) and untarred plates (3.9 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

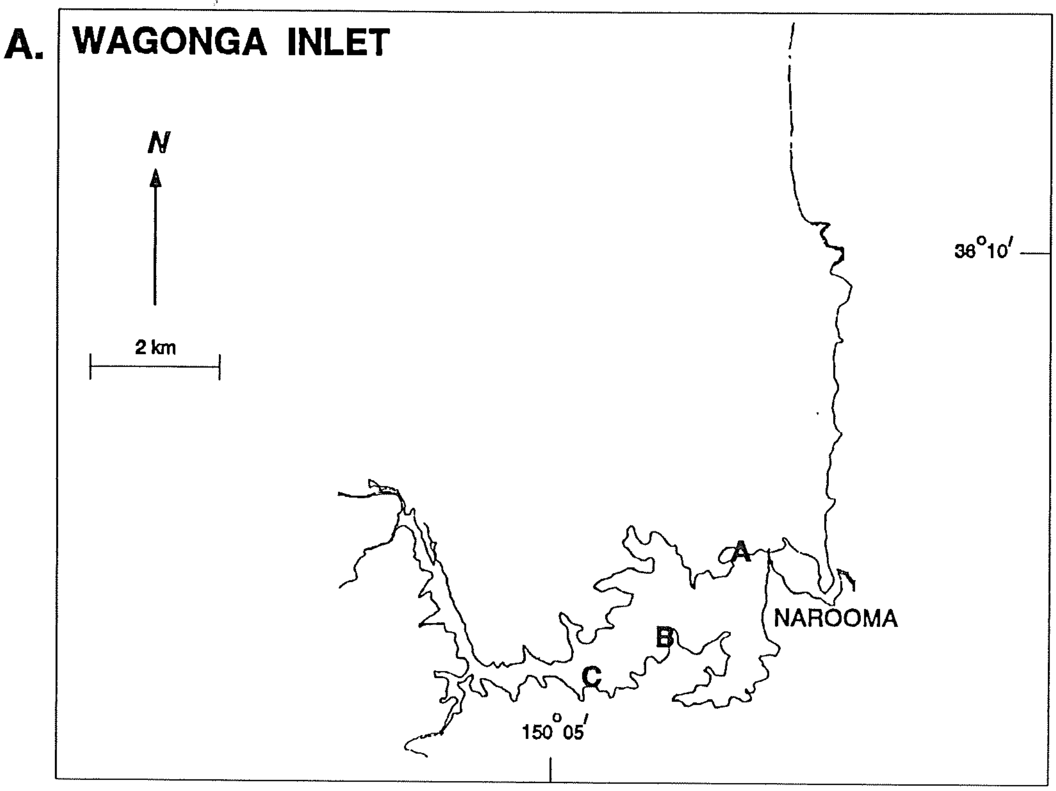
During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 13.5mm, 9.1mm and 14.3mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 15.0mm, 11.4mm and 14.3mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.1mm, 18.4mm and 23.4mm respectively, and the mean size of recruits (Table 2.3) to untarred plates at sites 1, 2 and 3 were 16.0mm, 15.6mm and 16.1mm respectively.

3.3.20 BERMAGUI RIVER

3.3.20.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Bermagui River estuary (Fig. 3.22) during 11 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was considerable with total cumulative settlement at sites 1 and 2 (Table 3.4) of 275 and 119 oysters per $100cm^2$ respectively.

Settlement was observed from January until April 1990 with a peak occurring during February 1990 (7.9 oysters x $100cm^{-2}$ x day^{-1}). Further settlement was detected during October 1990 (0.1 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again



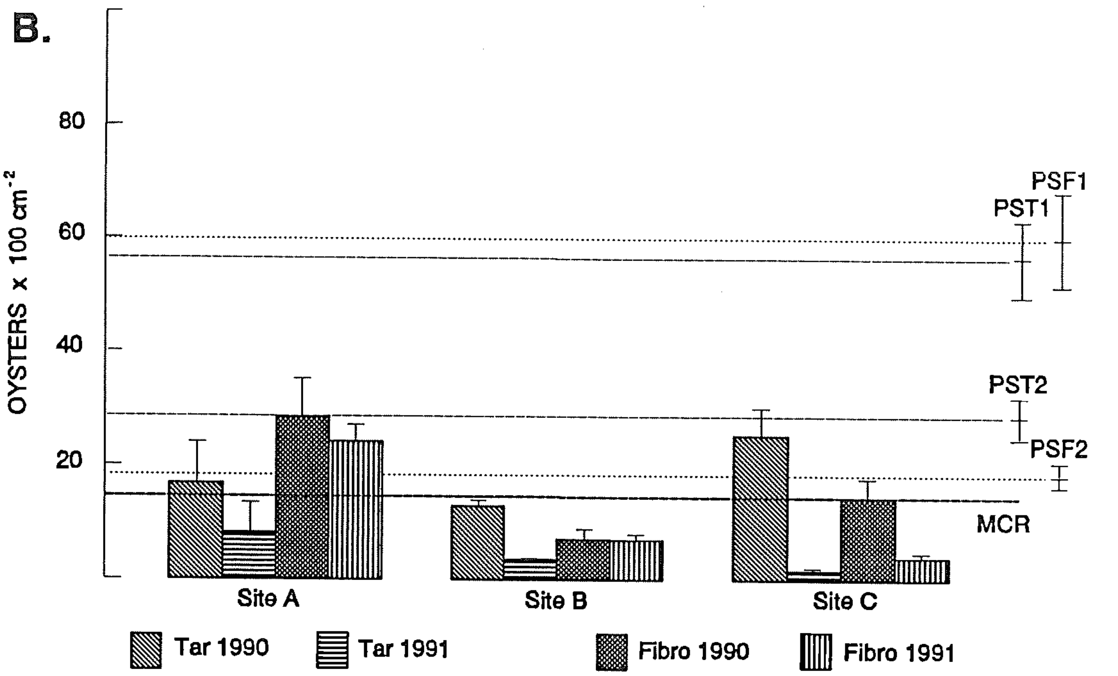
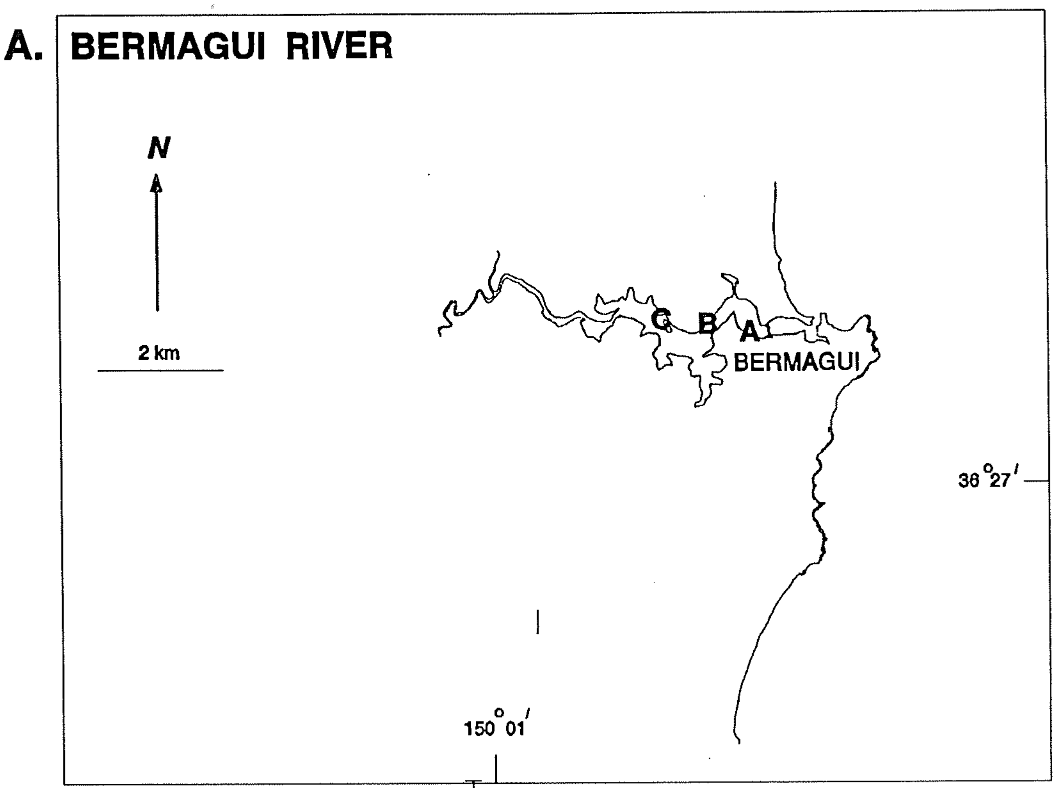


Figure 3.21 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.



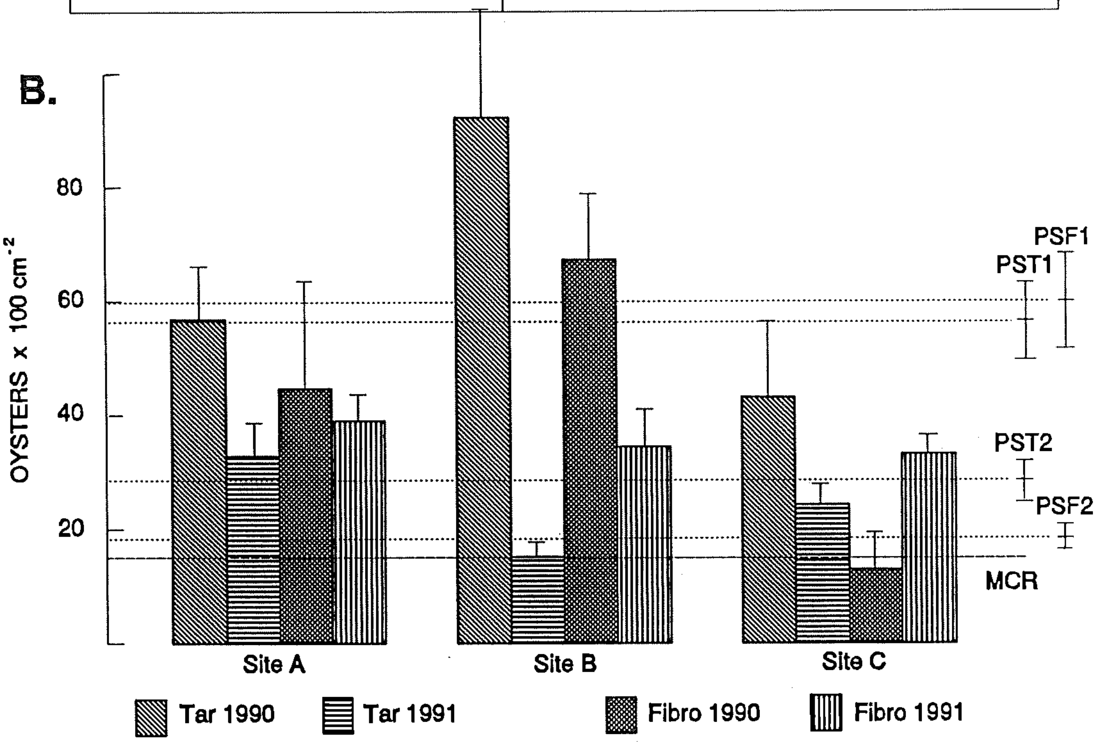


Figure 3.22 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

during December 1990 and continued through until May 1991, with peaks in settlement occurring during January (1.6 oysters x $100cm^{-2}$ x day^{-1}) and May (1.1 oysters x $100cm^{-2}$ x day^{-1}) 1991. Further low level settlement was detected during July 1991. Settlement commenced again during December 1991 prior to the cessation of monitoring.

3.3.20.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred (56.8 oysters x $100cm^{-2}$) at site 1 was significantly higher than settlement to tarred plates at Salamander Bay. Recruitment to untarred plates (44.6 oysters x $100cm^{-2}$) at site 1, to both tarred (92.3 oysters x $100cm^{-2}$) and untarred plates (67.2 oysters x $100cm^{-2}$) at site 2 as well as to tarred plates (43.0 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (12.9 oysters x $100cm^{-2}$) at site 3 was classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to untarred plates (38.9 oysters x $100cm^{-2}$) at site 1, untarred plates (34.5 oysters x $100cm^{-2}$) at site 2 and to untarred plates (33.2 oysters x $100cm^{-2}$) at site 3 were significantly higher ($P<0.05$) to that on plates at Salamander Bay. Recruitment to tarred plates (32.9 oysters x $100cm^{-2}$) at site 1 and to tarred plates (24.3 oysters x $100cm^{-2}$) at site 3 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to tarred plates (15.3 oysters x $100cm^{-2}$) at site 2 was classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 12.6mm, 7.2mm and 9.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 17.0mm, 8.8mm and 12.4mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.9mm, 14.0mm and 13.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 20.3mm, 10.5mm and 15.6mm respectively.

3.3.21 WAPENGO LAGOON

3.3.21.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Wapengo Lagoon (Fig. 3.23) during 14 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4) of 91 and 359 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until June 1990 with a peak occurring during February 1990 (7.2 oysters x $100cm^{-2}$ x day^{-1}). Settlement commenced again during October 1990 and continued through until May 1991, with a peak in settlement occurring during January (4.0 oysters x $100cm^{-2}$ x day^{-1}) and

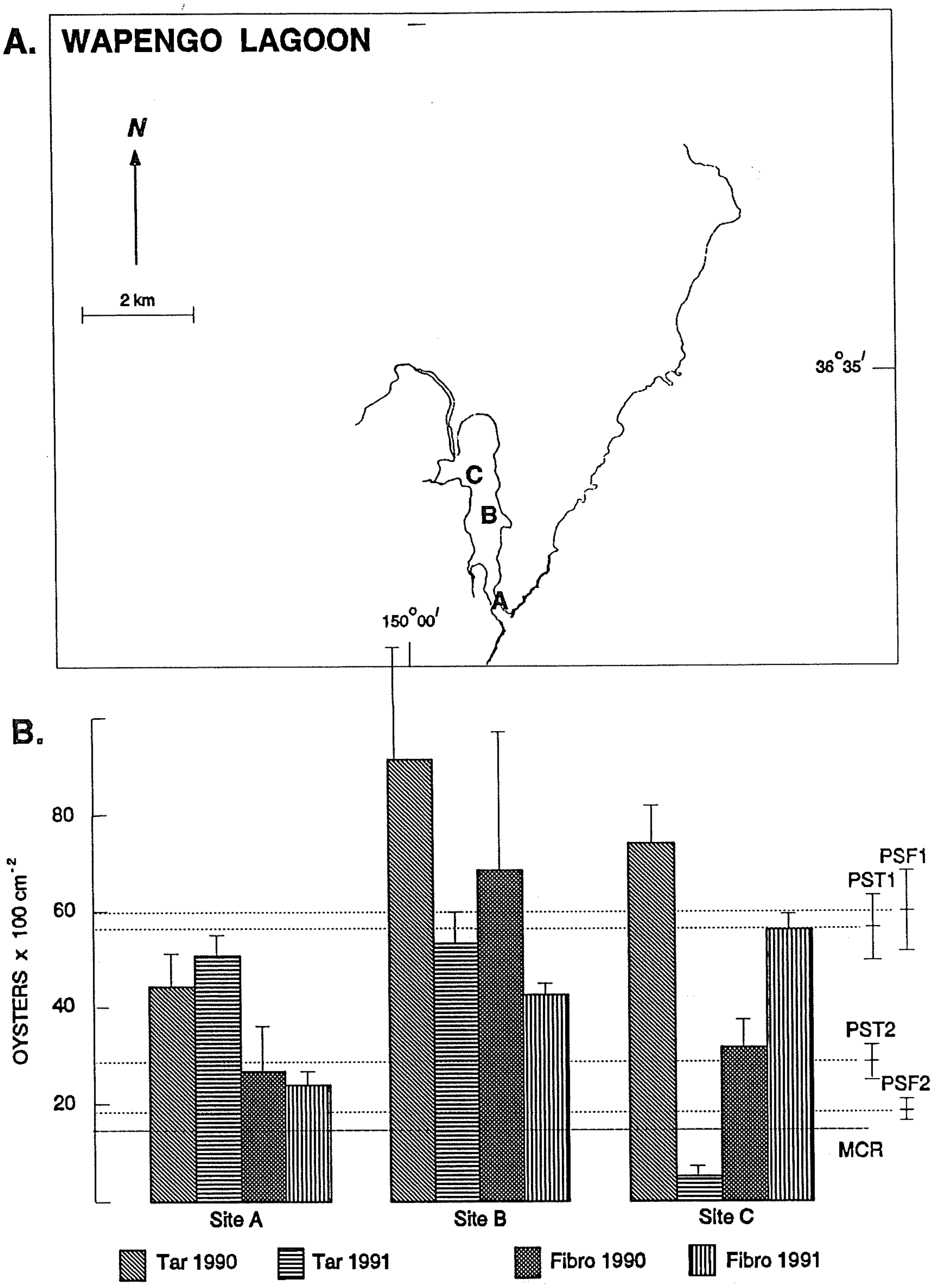


Figure 3.23 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.
B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

March (1.0 oysters x 100cm^{-2} x day^{-1}) 1991. Further low level settlement was detected during October 1991. Settlement commenced again during December 1991 prior to the cessation of monitoring.

3.3.21.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred plates (44.3 oysters x 100cm^{-2}) at site 1, to both tarred (91.3 oysters x 100cm^{-2}) and untarred plates (68.4 oysters x 100cm^{-2}) at site 2, as well as to tarred plates (73.9 oysters x 100cm^{-2}) at site 3 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (26.7 oysters x 100cm^{-2}) at site 1 ant to untarred plates (31.5 oysters x 100cm^{-2}) at site 3 was classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay (Table 3.1).

During 1991 the mean commercial recruitment to tarred plates (50.7 oysters x 100cm^{-2}) at site 1, to both tarred (53.2 oysters x 100cm^{-2}) and untarred plates (42.4 oysters x 100cm^{-2}) at site 2, as well as to untarred plates (56.0 oysters x 100cm^{-2}) at site 3 were significantly higher ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (23.9 oysters x 100cm^{-2}) at site 1 was not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to tarred plates (5.1 oysters x 100cm^{-2}) at site 3 was classified as non commercial (Table 3.1).

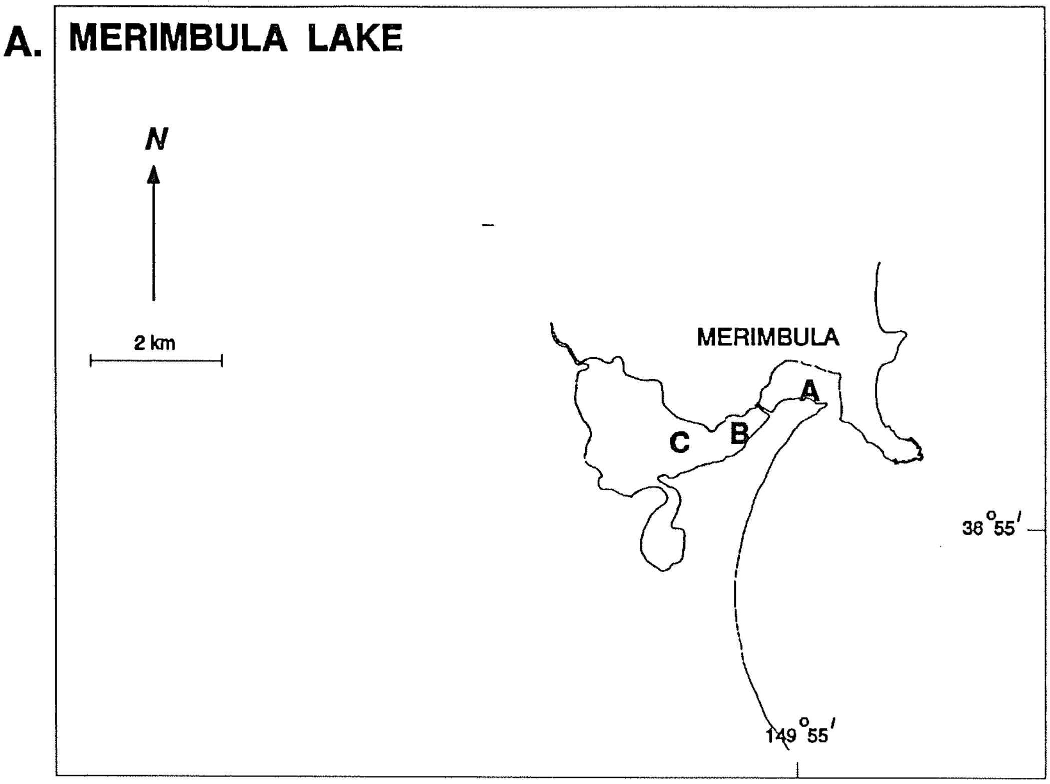
During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 9.6mm, 10.9mm and 12.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.3mm, 10.0mm and 16.3mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 18.6mm, 11.6mm and 15.5mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 15.8mm, 13.9mm and 10.0mm respectively.

3.3.22 MERIMBULA LAKE

3.3.22.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in Merimbula Lake (Fig. 3.24) during 12 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Table 3.4) of 71 and 30 oysters per 100cm^2 respectively.

Settlement was observed from initial deployment until May 1990 with a peak occurring during February 1990 (0.9 oysters x 100cm^{-2} x day^{-1}). Settlement was not observed again until November 1990. Settlement commenced again during January 1991 and continued through until July 1991, with a peak in settlement occurring



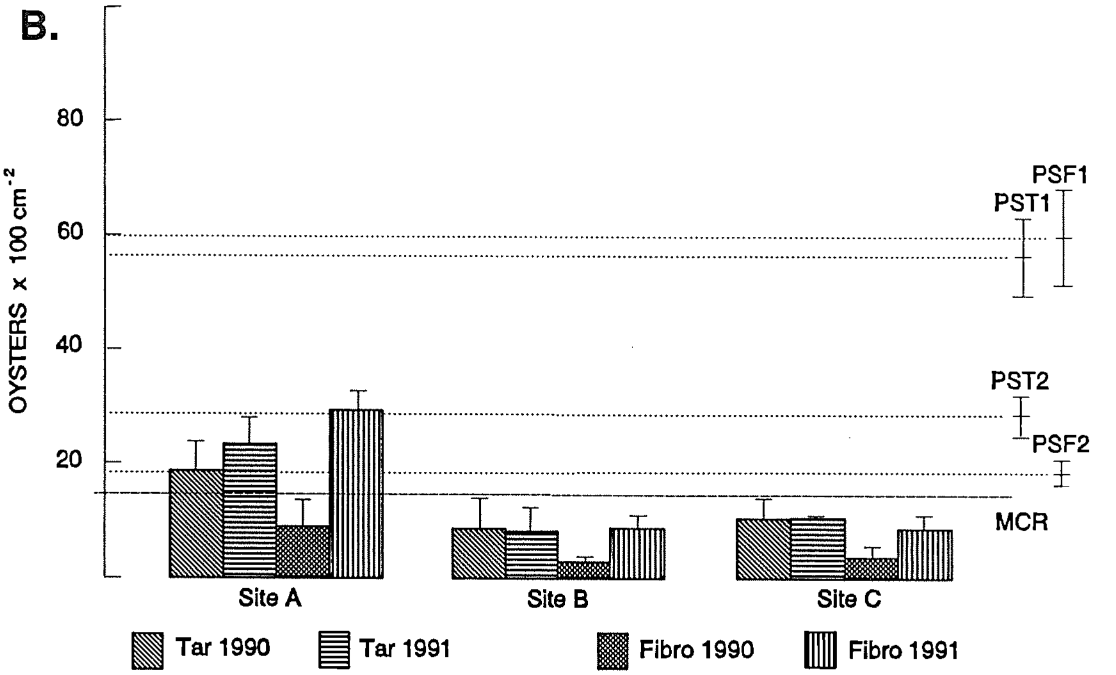


Figure 3.24 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

during January (1.3 oysters x $100cm^{-2}$ x day^{-1}) 1991. Low level settlement commenced again during December 1991 prior to the cessation of monitoring.

3.3.22.2 Commercial Recruitment

During 1990 mean commercial recruitment was classified as non commercial ($P<0.05$) at site 1 to both tarred (18.6 oysters x $100cm^{-2}$) and untarred plates (9.0 oysters x $100cm^{-2}$), at site 2 to both tarred (8.6 oysters x $100cm^{-2}$) and untarred plates (2.9 oysters x $100cm^{-2}$) and at site 3 to both tarred (10.4 oysters x $100cm^{-2}$)and untarred (10.4 oysters x $100cm^{-2}$) plates (Table 3.1).

During 1991 the mean commercial recruitment untarred plates (29.3 oysters x $100cm^{-2}$) at site 1 was significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to tarred plates (23.3 oysters x $100cm^{-2}$) at site 1 was not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 1). Recruitment was classified as non commercial ($P<0.05$) to both tarred (8.2 oysters x $100cm^{-2}$) and untarred plates (8.8 oysters x $100cm^{-2}$) at site 2, as well as to both tarred (10.5 oysters x $100cm^{-2}$) and untarred plates (8.6 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 17.8mm, 12.5mm and 13.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 20.2mm, 10.9mm and 19.4mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 17.7mm, 17.4mm and 16.5mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 18.7mm, 18.6mm and 17.1mm respectively.

3.3.23 PAMBULA LAKE

3.3.23.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in Pambula Lake 9Fig. 3.25) during 19 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was high with total cumulative settlement at sites 1 and 2 (Table 3.4) of 589 and 1306 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until June 1990 with a major peak occurring during February 1990 (6.3 oysters x $100cm^{-2}$ x day^{-1}). Minor settlement was also detected during July 1990. Settlement commenced again during September 1990 and increased to a peak during January 1991 (25.0 oysters x $100cm^{-2}$ x day^{-1}) after which it steadily declined until July 1991. Settlement was detected again during October 1991 and continued at a low level until the cessation of monitoring.

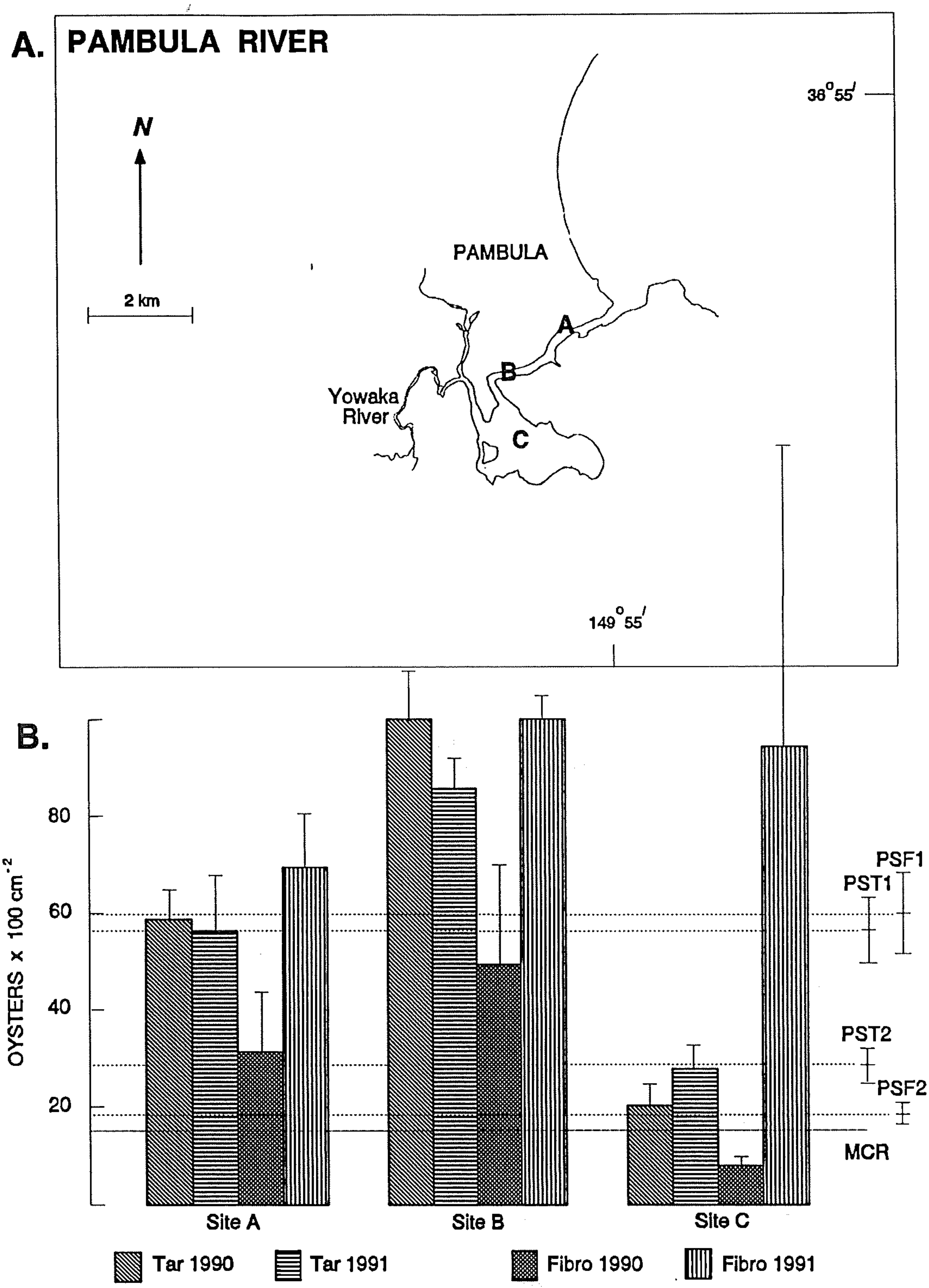


Figure 3.25 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.
B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

3.3.23.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred plates (101.3 oysters x $100cm^{-2}$) at site 2 was significantly higher ($P<0.05$) than the recruitment to plates at Salamander Bay, while recruitment to both tarred (58.7 oysters x $100cm^{-2}$) and untarred plates (31.3 oysters x $100cm^{-2}$) at site 1, as well as to untarred plates (49.4 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to recruitment to plates at Salamander Bay (Table 3.1). Recruitment was classified as non commercial ($P<0.05$) to both tarred (20.3 oysters x $100cm^{-2}$) and untarred plates (7.9 oysters x $100cm^{-2}$) at site 3 (Table 3.1).

During 1991 the mean commercial recruitment to both tarred and untarred plates at all sites were commercial. Recruitment to both tarred (56.4 oysters x $100cm^{-2}$) and untarred plates (69.4 oysters x $100cm^{-2}$) at site 1 and to both tarred (85.7 oysters x $100cm^{-2}$) and untarred plates (103.7 oysters x $100cm^{-2}$) at site 2, as well as to untarred plates (94.2 oysters x $100cm^{-2}$) at site 3 were significantly higher ($P<0.05$) than the recruitment at Salamander Bay. Recruitment to tarred plates (27.8 oysters x $100cm^{-2}$) at site 3 was not significantly different ($P<0.05$) to the recruitment at Salamander Bay (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 15.9mm, 17.8mm and 11.6mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 15.8mm, 11.8mm and 14.3mm respectively. During 1991 the mean size of oysters recruits (table 3.2) to tarred plates at sites 1, 2 and 3 were 12.5mm, 10.9mm and 26.8mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 12.0mm, 9.8mm and 18.1mm respectively.

3.3.24 WONBOYN RIVER

3.3.24.1 Settlement

Settlement of the Sydney rock oyster was detected at monitoring sites in the Wonboyn River estuary (Fig. 3.26) during 12 of the 24 deployments (Fig. 3.2). Settlement over the duration of the study was low with total cumulative settlement at sites 1 and 2 (Table 3.4) of 94 and 138 oysters per $100cm^2$ respectively.

Settlement was observed from initial deployment until May 1990 with a slight peak occurring during February 1990 (1.31 oysters x $100cm^{-2}$ x day^{-1}). Minor settlement was detected during June and October 1990. Settlement commenced again during December 1990 and was detected in consecutive months until March 1991, with a peak in settlement occurring during February (1.9 oysters x $100cm^{-2}$ x day^{-1}) 1991. Further low level settlement was detected during April and May. Settlement commenced again during December 1991 (0.5 oysters x $100cm^{-2}$ x day^{-1}) prior to the cessation of monitoring.

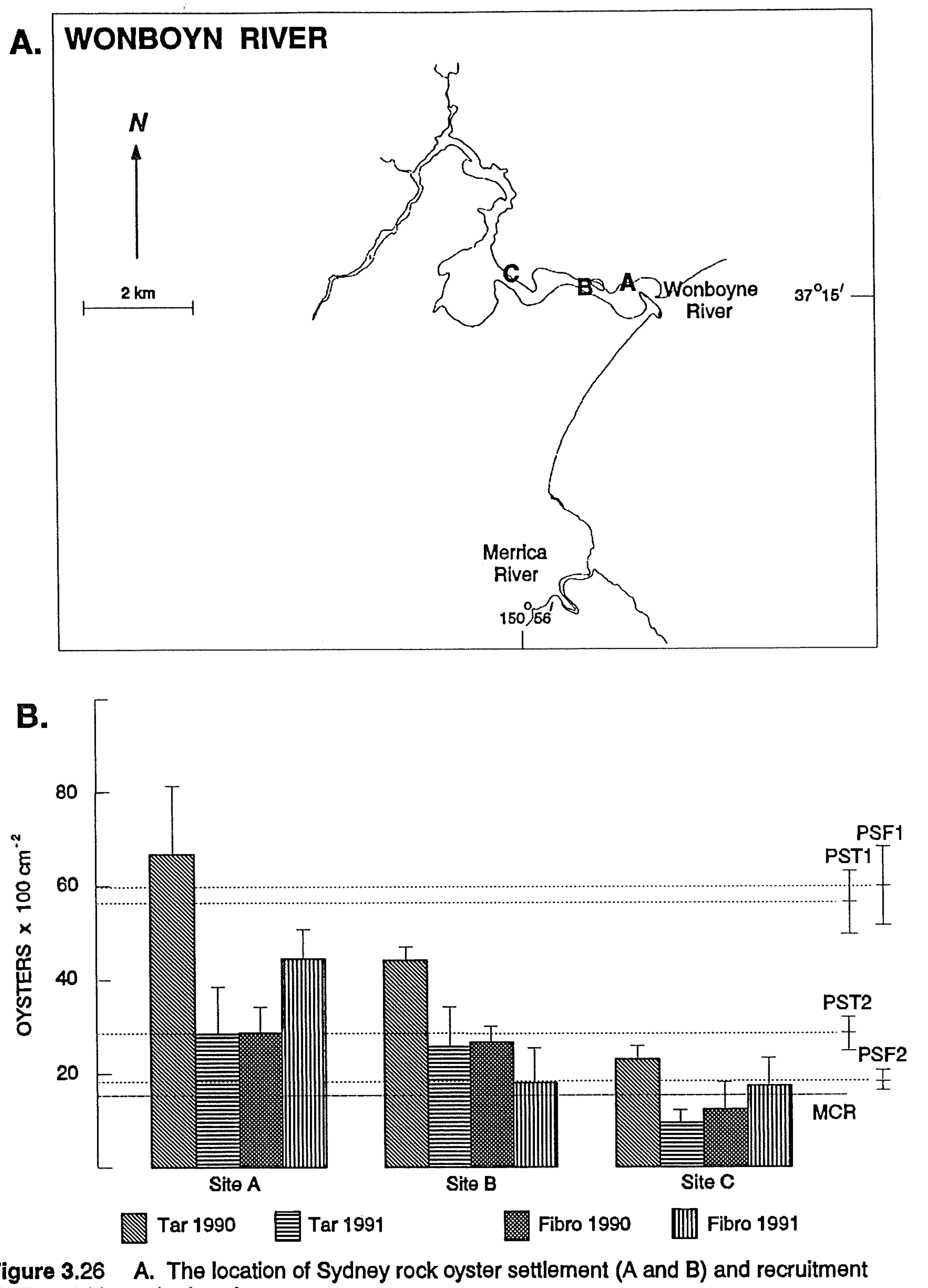


Figure 3.26 A. The location of Sydney rock oyster settlement (A and B) and recruitment (A, B and C) monitoring sites.

B. Sydney rock oyster recruitment (mean ± S.E.; n=4) to tarred and untarred fibro-cement plates at sites (A,B and C) during 1990 and 1991. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1990 at Salamander Bay Port Stephens are indicated by PST1 and PSF1 respectively. Recruitment to tarred and untarred fibro-cement plates (mean ± S.E.; n=4) deployed from January to October 1991 at Salamander Bay Port Stephens are indicated by PST2 and PSF2 respectively. The level of minimum commercial recruitment (15 spat per 100 sq cm) is indicated by MCR.

3.3.24.2 Commercial Recruitment

During 1990 the mean commercial recruitment to tarred plates (66.8 oysters x $100cm^{-2}$) at site 1 and to tarred (44.1 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (28.7 oysters x $100cm^{-2}$) at site 1 and untarred plates (26.8 oysters x $100cm^{-2}$) at site 2, as well as to tarred plates (23.0 oysters x $100cm^{-2}$) at site 3 were classified as commercial ($P<0.05$) though significantly lower ($P<0.05$) than recruitment to plates at Salamander Bay. Recruitment to untarred plates (12.4 oysters x $100cm^{-2}$) at site 3 was classified as non commercial (Table 3.1).

During 1991 the mean commercial recruitment to untarred plates (44.5 oysters x $100cm^{-2}$) at site 1 was significantly higher ($P<0.05$) to that on plates at Salamander Bay. Recruitment to tarred plates (28.5 oysters x $100cm^{-2}$) at site 1 and to tarred (25.8 oysters x $100cm^{-2}$) at site 2 were not significantly different ($P<0.05$) to that on plates at Salamander Bay. Recruitment to untarred plates (18.2 oysters x $100cm^{-2}$) at site 2, as well as to both untarred plates (17.4 oysters x $100cm^{-2}$) and tarred plates (9.6 oysters x $100cm^{-2}$) at site 3 was classified as non commercial (Table 3.1).

During 1990 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 7.6mm, 8.3mm and 10.0mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 6.4mm, 11.2mm and 15.1mm respectively. During 1991 the mean size of oysters recruits (Table 3.2) to tarred plates at sites 1, 2 and 3 were 16.6mm, 14.0mm and 12.1mm respectively, and the mean size of recruits (Table 3.3) to untarred plates at sites 1, 2 and 3 were 13.8mm, 17.4mm and 12.2mm respectively.

3.4 DISCUSSION

During this study, settlement of the Sydney rock oyster occurred in all 24 estuaries monitored and the data indicate that considerable variation may occur in both the timing and intensity of major settlement of the Sydney rock oyster in NSW. The duration of the period of major settlement of the Sydney rock oyster has been reported to extend from November until March in Morton Bay in southern QLD (26°50′S) (Potter,1984) as well as at Port Hacking in Sydney (33°55′S) (Thomson,1950) and from February until May in Port Stephens (32°43′S) (Wisely et al.,1979; Holliday,1985a; Holliday and Goard,1986). The data indicate that although major settlement of the Sydney rock oyster can generally be considered to occur in NSW during the summer and autumn months, major settlement may occurred as early as September/October and as late as June in estuaries in the northern half of the state. The data also suggest that individual estuaries may exhibit considerable variation in both the timing and intensity of settlement from year to year. The settlement period of the Sydney rock oyster was longest in northern NSW, occurring during 23 of the 24 deployment periods in the Brunswick and Sandon Rivers (Fig. 3.1) and declined gradually with increasing latitude along the NSW coast, to 12 of the 24 deployments at both Merimbula Lake and the Wonboyn River in southern NSW (Fig. 3.1). In the instigation and termination of reproductive activity in bivalve molluscs, temperature is widely recognised as an important exogenous factor in marine environments (Thorson,1950; Bayne,1976; Quayle,1988; Quayle and Newkirk,1989). The investigation of the relationship between the occurrence of the larvae of the Sydney rock oyster and water temperature at Port Stephens (Section 2.2) indicates that although minor spawning and larval development may take place during the colder months of the year, major reproductive activity does not occurred until mean water temperatures have exceeded approximately 19°C. In this study it was not logistically possible to generate the large number of water temperature measurements required to investigate the relationship between water temperature and settlement in each estuary. However, an analysis of previous long term measurements of water temperature conducted by Wolf and Collins (1973) in many of these estuaries, reveal that the number of months in which average water temperatures could be expected to exceeded 19°C ranged from approximately 18 out of 24 in northern NSW to approximately 8 out of 24 in southern NSW, supporting a hypothesis that water temperature is a major factor in the general regulation of the reproductive activity of the Sydney rock oyster along the NSW coast. The settlement data (Fig. 3.2) indicate an apparent synchronous settlement event occurring along much of the NSW coastline during February 1990. It has long been recognised that although temperature has a broad control over the reproductive activity of marine bivalve molluscs other factors, such as salinity, large tides or pH. change may be responsible for instigating spawning activity once reproductive condition has been reached (Roughley,1933; Stephen,1980; Brayley,1982; Quayle,1988; Quayle and Newkirk,1989;). An analysis of coastal rainfall data for the period of the study (NSW Dept. Meteorology; Appendix 3.1) reveals that a major rainfall event occurred along much of the NSW coast during February 1990 and minor flooding was reported in many areas. In many areas above average rainfall persisted well into the autumn months, particularly in central and northern NSW. Although no direct observations of site salinity were made, many oyster purification plants cease operation due to low salinity (P. Bird, personal communication,1990) over this period. It is reasonable to suggest that falls in salinity associated with initial rainfall period may have been responsible for the initiation of a synchronous spawning event along the coast, resulting in peak in settlement that was observed along the NSW coast in February 1990. In major river systems in northern NSW with large catchments (Water Resources Commission of NSW, 1982), the Tweed (1100 km^2), Richmond (6850 km^2), Clarence (22,400 km^2), Nambucca (1460 km^2), Macleay (11,384 km^2) and Hastings Rivers (3595 km^2) oyster settlement were characterised by a single major settlement peak, followed by periods of light settlement. Undoubtedly in large river systems, such as above, prolonged period of flushing that may accompany periods of heavy rain may have a significant impact on the retention within the estuary of oyster larvae until the settlement stage (18-21 days). The effect of prolonged periods of low salinity on newly settled spat is unknown, however poor survival may explain the poor recruitment observed in 1990 in the Nambucca, Macleay and Hastings Rivers (Table 3.5) even though reasonable levels of settlement were observed during February (Fig. 3.2). In the same area those generally more saline estuaries (Wolf and Collins,1973) with relatively small catchments (Water Resources Commission of NSW, 1982), the Brunswick (160 km^2), Sandon (109 km^2), Wooli (190 km^2) and Camden Haven (720 km^2) Rivers major oyster settlement during 1990 was prolonged and continued into the early winter months. In these rivers salinity increases quickly after heavy rain due to the low catchment area and strong tidal influences (B.Shannahan, D.Gorman and B.Batson, personal communications, 1991). Recruitment in these estuaries was generally good. The lack of any apparent synchronisation in settlement between estuaries during the following much dryer (Appendix 3.1) settlement season (Fig. 3.2) is likely a result of differences between estuaries in the prevailing hydrological and their influence on the local reproductive activity of the Sydney rock oyster. Although the data is limited, significant rainfall that occurred in December 1991 after a prolonged period of low rainfall (Appendix 1) may have again instigated spawning and subsequent settlement in a number of estuaries along the coast during December 1991. It would therefore appear that those estuaries with large catchments on the north cost of NSW are at a higher rick of commercial catch failure during periods of heavy rain over the summer months, than those more saline estuaries with smaller catchments areas in the same area. The prolonged periods of settlement observed in a number of estuaries suggest that, using single seed catching techniques and possibly cement slurried tarred oyster sticks (Verdich,1989) the potential exists to obtain more than one commercial catch of Sydney rock oysters per season in these estuaries. However, this would require the careful monitoring of catching materials to indicate when sufficient settlement had occurred to enable the collectors to be moved into nursery areas thus clearing valuable catching area for the deployment of fresh catching material.

During 1990 commercial levels of recruitment were recorded on tarred substrate in 19 of the 24 estuaries and on fibro substrate in 13 of the 24 estuaries. On tarred substrate 14 estuaries recorded recruitment that was either not significantly different ($P>0.05$) to, or significantly higher ($P<0.05$) than that at commercial catching leases at Salamander Bay (Table 3.1). While on fibro substrate 11 estuaries recorded recruitment that was either not significantly different ($P>0.05$) to, or significantly higher ($P<0.05$) than that at commercial catching leases at Salamander Bay (Table 3.1). In the following, drier 1991 commercial recruitment was detected in all but one estuary. On tarred substrate 20 estuaries recorded recruitment that was either not significantly different ($P>0.05$) to, or significantly higher ($P<0.05$) than that at commercial catching leases at Salamander Bay (Table 3.1). While on fibro substrate 22 estuaries recorded recruitment that was either not significantly different ($P>0.05$) to, or significantly higher ($P<0.05$) than that at commercial catching leases at Salamander Bay (Table 3.1). Given the conservative nature of the method for classifying recruitment as commercial, in which a site may be classified as non commercial as a result of high site variability, the data indicate that estuaries in which commercial levels of spatfall may be obtained are spread throughout NSW. In many of these, sites occur at which the recruitment of the Sydney rock oyster is equivalent to or greater than that occurring in the major commercial recruitment area in Salamander Bay Port Stephens. A preliminary ranking of estuaries based on cumulative mean recruitment over the two years of the study (Table 3.5) ranks Port Stephens at 5th in terms of overall recruitment in 1990 and 13th in terms of overall recruitment in 1992.

There are however, a number of considerations that need to be addressed regarding the exploitation of the this apparently abundant and renewable natural spatfall resource in NSW. Currently there are a number of restrictions in place in NSW that limit the movement of oysters and oyster spat between estuaries. Firstly, due to the prevalence of QX disease in the Tweed, Richmond and Clarence River estuaries, the movement of oysters from these estuaries to other estuaries in NSW is prohibited by NSW Fisheries. The occurrence of this disease in these estuaries from time to time results in massive mortalities of cultivated oysters as well as wild oyster populations and the subsequent low broodstock numbers may in part explain the low settlement and recruitment rates observed in this study in the Tweed, Richmond and to a lesser extent Clarence Rivers. The exclusion of spat from these estuaries would not have a significant impact on supplies of spat in NSW. Secondly, the presence of the Pacific oyster in many estuaries and measures put in place by NSW Fisheries to control it's spread, will however, have a significant impact on the availability of spat from estuaries with significant numbers of Pacific oysters. Movements of spat from these estuaries would be subject in many cases to stringent inspection criteria and conditions, and may be prohibited to Pacific oyster free estuaries. The area available at Port Stephens for the production of caught sticks was substantial, supplying approximately 1.5 million caught sticks annually to other estuaries in NSW (Anon,1986). Although areas in many estuaries exhibit excellent potential as commercial catching areas there is little opportunity outside Port Stephens to deploy large numbers of catching sticks on existing leases and in recent hears there has been a moratorium on the granting of new leases. A large number of farmers, still rely solely on the stick method of cultivation, and as such these farmers are reliant on supplies of caught sticks. In many instance this is due to a resistance to change, however, in southern NSW many farmers are of the opinion that oysters grown on sticks are less susceptible to winter morality (a disease that periodically causes significant mortality in oysters in southern NSW) than single oysters grown either on trays or in baskets. Considerable scope may exist in many of these estuaries to reduce losses due to winter mortality by improved management techniques (Smith,1987) and further developments in this area could see single seed production a viable alternative to stick oyster production in many of these areas. The current trend by many farmers in NSW to move towards single seed production may see the need for large catching areas in many areas diminish to the point where local areas can easily meet local demand for caught sticks. As single seed spat production techniques provide a more productive method of wild spatfall utilisation, in which large numbers of oyster spat can be produced in considerably less space than can be achieved by the conventional stick method of production. The rationale for this is as follows, conventional stick catching leases produce between 25 and 50 sticks per metre of rack, based on a yield at the end of the grow-out period of approximately 50 marketable oysters per stick, this equates to between 625 and 1250 marketable oysters per meter of catching rack. Using lime-cement slurry coated single seed collectors, commercial single seed producers in the Brunswick River harvest on average in excess of 200 marketable spat per collector (B.Batson, personal communication, 1992). Using similar collectors, Holliday et. al (1993) reported an average yield of 575 per collector during a period of heavy settlement in Salamander Bay. Using the lesser of the two harvest rates and a mortality rate during the grow-out period of 9.2% on trays and 23% in baskets (Holliday, 1991), 50 single seed collectors per metre of rack have the potential to yield in excess of 9,000 marketable oysters from trays, or 7,000 marketable oysters from baskets. This equates to in excess of a 5 fold increase in productivity of the catching area.

From time to time there have been large scale failures of natural spatfall in NSW, which have had a considerable impact on subsequent oyster production. The reasons for these failures are unknown, however they tend to be regional involving a number of estuaries. Port Stephens has long been praised for its seasonal reliability as a catching area with a reported failure rate of 1 year in 7 (Korringa,1976). Although this study demonstrates a considerable potential for the commercial exploitation of natural spatfall throughout NSW further studies need to be carried out as to the long term reliability of these estuaries.

3.5 CONCLUSIONS

1. Considerable variation exists in the settlement of the Sydney rock oyster both between estuaries and within estuaries between years.

2. Temperature appears to have a broad control over the reproductive activity of the Sydney rock oyster along the NSW coast.

3. Rainfall and subsequent falls in salinity may be an important factor in both the instigation of spawning and the success of commercial recruitment.

4. In a large number of estuaries in NSW Commercial recruitment occurs at a level equal to or greater than that occurring at commercial catching leases at Port Stephens.

5. The duration of the settlement period in a number of estuaries in NSW may allow more that one commercial catch to be obtained per season.

6. Due to the limited area (hectares) available for the placement of catching sticks in estuaries other than Port Stephens, further expansion of the Sydney rock industry will be dependent on a shift by industry to the cultivation of single seed oysters.

7. Further investigations of the long term reliability of catching areas are required.

4 THE EFFECT OF SUBSTRATE TYPE AND COLLECTOR SHAPE, SPACING AND ORIENTATION TO PREVAILING TIDAL CURRENT, ON THE SETTLEMENT OF THE SYDNEY ROCK OYSTER (*Saccostrea commercialis*) (Iredale & Roughley).

4.1 INTRODUCTION

The method of collecting the natural settlement of Sydney rock oysters using tarred oyster sticks placed in areas of abundant natural oyster settlement (Croft,1967; Malcolm,1971) has been the basis for the development of the modern Sydney rock oyster industry. This technique of wild seed (spat) procurement provides a cheap, renewable seed resource and allows oysters to be moved attached to the sticks to take advantage of more favourable growing conditions in other growing areas either within the estuary or between estuaries that may be many hundreds of kilometres apart (Croft,1967). The availability of reliable supplies of Sydney rock oysters caught on tarred sticks (known in the industry as "caught sticks") has fostered the development of the Sydney rock oyster industry in many estuaries where reliable commercial quantities of Sydney rock oyster spat had not previously been locally available. Due to the abundant and reliable settlement of Sydney rock oysters that occurred in large areas of Port Stephens, this estuary evolved as the major source of spat for the Sydney rock oyster industry. In recent years the proliferation of the Pacific oyster at Port Stephens (Reid,1990,1991; Nell and Mason,1991) and the subsequent controls put in place by NSW Fisheries, at the request of the industry, to limit the spread of this introduced species between estuaries in NSW (Holliday and Nell,1990), has had a dramatic impact on the availability of caught sticks in NSW. Oyster farmers previously reliant on caught sticks and culled spat (oysters manually removed from sticks) originating in Port Stephens and elsewhere have been forced to investigate alternative supplies of oyster spat. For some, this has involved attempts at catching commercial quantities of oyster spat in their local estuaries using the traditional tarred stick catching techniques. For others, it has involved experimenting for the first time with techniques such as cement slurried oyster sticks (Virdich,1989) or the production of single seed oysters from spat caught naturally using a variety of catching substrates (Holliday et al.,1988). In many cases these efforts have been based on trial and error with little or no reliable information available as to how to maximise the chance of commercial success.

The spread of the Pacific oyster to a number of estuaries in central and southern NSW (Reid,1990,1991) has also forced the industry to development management techniques to control the overcatch of this species on maturing Sydney rock oyster crops. Currently, drying (Nell and Mason,1991) and cooking (the temporary emersion of oysters in hot seawater 80°C, quickly followed by quenching in cold sea water) are the only economically viable methods of controlling Pacific oyster overcatch. Both these methods require oysters to be unattached, either as oysters culled from sticks or as single seed. These methods are not economically feasible for use with oysters attached to tarred sticks. Consequently, in estuaries where overcatch of Pacific oyster is a problem, more and more farmers are turning to single seed production techniques in order to control Pacific oyster overcatch.

The difficulty in obtaining reliable supplies of caught sticks that has been experienced by many farmers and the shift in production techniques brought about by the proliferation of the Pacific oyster, has lead to an increasing demand for single seed oysters. This has lead to considerable interest in single seed oyster production techniques as well as ways in which catching methods may be modified to enhance the settlement of the Sydney rock oyster on commercial catching substrates. Currently a small industry producing single seed oyster from natural spatfall of the Sydney rock oyster is developing. To date attempts to service the single seed Sydney rock oyster market with single seed oysters produced by private commercial oyster hatcheries have been largely unsuccessful.

Commercial single seed production requires that oysters remain as single discreet oysters. To achieve this it is essential that oysters are removed from any catching substrate prior to the oysters growing into and attaching to one another, or being settled upon by later settlement cohorts of oysters. It is therefore necessary that the spat are removed from the catching substrates as soon as possible after settlement (3-6mm). As this production technique is at this stage labour intensive, commercial considerations also dictate that settlement per collector is maximised to offset collector handling costs.

Little information is available to assist farmers in the modification, or design of catching techniques to optimise the production of single seed oysters from the available natural spatfall. Apart from the work of Potter (1984), little attention has been given to the initial settlement behaviour of the Sydney rock oyster. The few studies that have been carried out on the settlement of the Sydney rock oyster in the field (Thomson,1950; Holliday et al.,1993) have dealt with the net recruitment of oysters to various surfaces at periods considerably beyond those now commonly used by commercial operators for the production of single seed spat (harvest within 3 months of collector deployment).

The objective of the series of experiments reported in this chapter is to provide base line information as to ways in which commercial spat collection methods may be modified to enhance the natural settlement of the Sydney rock oyster at commercial oyster leases. The effect of collector substrate type and collector shape, spacing, and orientation to tidal currents on the settlement of the Sydney rock oyster is determined. These aspects have been chosen as they are those most easily modified by the farmer using the existing oyster racks and farm equipment.

4.2 MATERIALS AND METHODS

The following series of settlement experiments were carried out on commercial intertidal oyster catching leases at Port Stephens NSW (32°43′S: 152°5′E), during

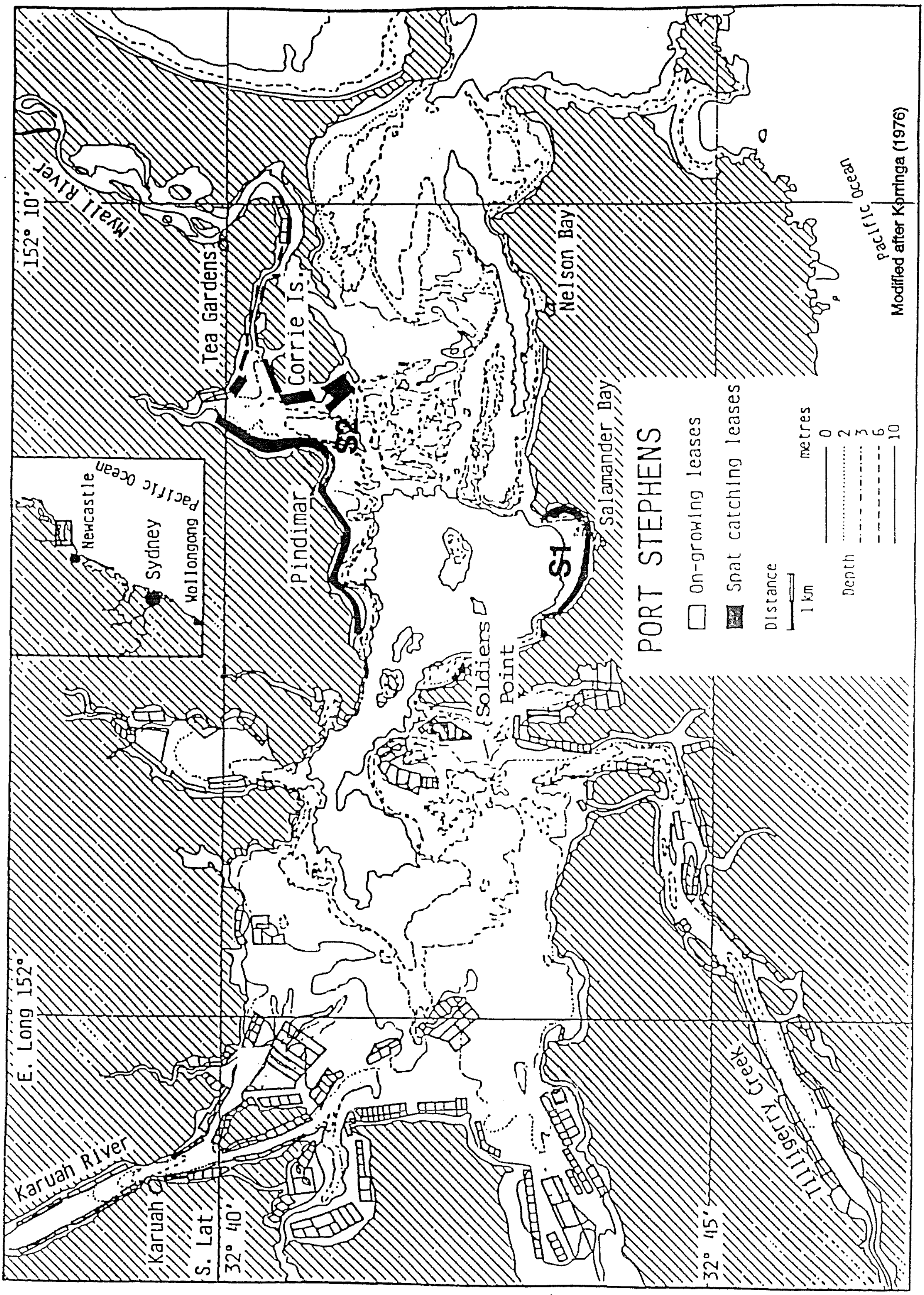


Figure 4.1 The location of oyster settlement experimental sites in Port Stephens NSW

1989, 1990 and 1991 (Fig. 4.1). In all experiments catching substrates were deployed on commercial catching racks, with the lower surface of the substrates corresponding to the lower end of the commercial catching range, this is approximately 0.8m above zero tide (indian spring low tide; tidal range 2.0m).

4.2.1 EXPERIMENT 1: COLLECTOR SUBSTRATE TYPE

The effect of surface substrate type on the settlement intensity of the Sydney rock oyster and barnacle sp. was investigated during March and April 1989 using 6 substrate types. These substrate types were; PVC plastic (new), PVC plastic (used previously as a catching substrate and cleaned), tarred fibro (tarred hardwood is the most commonly used commercial catching substrate), smooth fibro-cement (fibro-cement collectors have been used commercially in Australia and New Zealand), rough fibro-cement and lime-cement slurry (used as a catching substrate by a number of growers). These materials were chosen because they are relatively cheap, easy to prepare and all have been used in the past by commercial operators to catch spat with varying degrees of success. Holliday et. al. (1993) compared a number of these substrates, however each substrates differed considerable in shape and surface texture and no attempt was made to differentiate the substrate, texture or collector shape effects that may have modified settlement intensity. In this experiment, in an attempt to eliminate any major shape effect, all substrates were compared using flat 40mm x 250mm collectors. To investigate the effect of surface texture, smooth and rough fibro-cement collectors were prepared. Experimental substrates were prepared by cutting collectors from new and used PVC plastic commercial oyster collectors (slats, as described by Holliday et. al., 1993) and fibro-cement sheet. Tarred substrates were prepared by coating fibro-cement collectors with 2 coats of tar (Koppers "Oyster Tar" KC-700), which was allowed two weeks to dry. Slurried substrates were prepared by coating fibro-cement collectors with a lime-cement slurry comprising, 5 parts hydrated lime, 1 part cement and 1 part fire clay, mixed to the viscosity of a thick paint by the addition of the required amount of a mixture of 500ml of PVC bonding agent (Selleys Bondcrete) to 20 litres of water. Rough fibro-cement substrates were prepared by roughing smooth fibro-cement with a wire brush. Sixteen replicate of each substrate were prepared.

To investigate the effect of substrate pre-conditioning on settlement, 8 replicates of each substrate type were enclosed in a 100 μm plankton mesh bag and placed on an intertidal commercial catching lease in Salamander Bay (Fig. 4.1; Site 1) for 30 days. The mesh bag was replaced weekly and at the end of the 30 days a random inspection of substrates using a dissecting microscope did not detect the settlement of either oysters or barnacle sp. The pre-conditioned substrates were then combined with the unexposed substrates in a randomised design and quickly returned (1 tidal exposure) to the catching lease where they remained for a period of 35 days. The substrates were then removed to the laboratory where a total counts of all Sydney rock oysters and barnacle sp. present on the under side each collector was carried out with the aid of a dissecting microscope.

4.2.2 EXPERIMENT 2: COLLECTOR SPACING

An experiment to determine the effect of inter collector spacing on the settlement intensity of the Sydney rock oyster was carried out on a commercial oyster catching lease in Salamander Bay, Site 1 (Fig 4.1), using both flat and curved lime-cement slurry coated collectors. Lime-cement slurry was chosen as a substrate because previous experiments (Experiment 1) had shown that it was an excellent catching substrate, required little or no pre-conditioning and because of its ready acceptance as a catching substrate by a number of commercial single seed producers. The lime-cement slurry was prepared as described in experiment 1. All collectors used in the experiment were coated with slurry at the same time using the same batch of slurry. Curved collectors were constructed by splitting 90mm diameter PVC storm-water pipe (Hardie Iplex) longitudinally into 40mm wide strips using a table band saw. Flat collectors were constructed using lengths of 40mm fibro-cement strip (40mm Cover Mould; James Hardy Industries)
Sets of both flat and curved slurried collectors were prepared, each set (module) consisted of a pair of collectors arranged horizontally one above the other. The following horizontal inter surface spacings were used; 5mm, 10mm, 20mm and 40mm by the use of appropriate plastic spacers placed between the pair of collectors at either end. Curved collector surfaces were orientated concave down. Ladders of individual modules were prepared by attaching the modules at either end, with plastic ties, to a parallel pair of oyster sticks. Each module was allocated in a randomised design consisting of 4 replicate modules of each spacing of each surface (flat or curved) type placed at 3 locations. The ladders were attached to racks on commercial settlement leases and were between 30 and 50 metres from the shore. Racks ran perpendicular to the shore over a bottom consisting of muddy sand with a good cover of *Zostra capricornii*. The site was exposed with good water circulation. The settlement collectors were deployed for 6 weeks from the beginning of April until mid May 199O.

4.2.3 EXPERIMENT 3: COLLECTOR ORIENTATION TO TIDAL CURRENT

An experiment to determine the effect of collector orientation to tidal current on the settlement intensity of the Sydney rock oyster was carried out on a commercial oyster catching lease at Corrie Island, Site 2 (Fig 4.1). This lease is an offshore lease subject to major tidal flow with a bottom consisting of muddy sand with a deep meadow of *Posidonia australis*. Investigations of current direction and velocity were conducted at the lease at both 3/4 flood and 1/4 ebb tides during both spring and neep tides. This entailed repeated estimates of current velocity and direction using a 5 litre plastic bottle attached to a 10m chord. The bottle, filled to near capacity and sealed, was released and the time taken to travel 10m was as well as the direction of travel, were recorded with the aid of a stop watch and hand held compass. Flood and ebb tidal flows were observed to be approximate reversals of direction. The maximum flood and ebb tide current velocities were 3.25cm sec^{-1} and 2.15cm.sec^{-1} respectively. In this experiment, modules of both flat and curved slurried collectors were assembled as in experiment 2, with a 10.0mm inter-surface spacing. Modules were arranged in a randomised design at 3 locations consisting of 2 orientation treatments. The treatments consisted of modules orientated with either the long axis orientated at right angles (90°) to, or parallel (180°) to the tidal flow. Each treatment consisted of 4 replicates modules of each collector shape (flat and curved). Modules were supported clear of the support sticks by 40mm plastic spacers. The settlement collectors were deployed for 6 weeks from the beginning of April until mid May 199O.

4.2.4 EXPERIMENT 4: COLLECTOR SHAPE

To compare the effect of collector shape on the settlement intensity of Sydney rock oyster, flat and curved collector shapes were used. These 2 simple shapes were chosen for this experiments and experiments 2 and 3 because collectors could easily be constructed in these shapes by farmers from a number of cheap, readily available materials. Further, both these simple shapes can easily be coated with a settlement enhancing substrate (such as lime-cement slurry), as well as, be built up into blocks of catching material that can be placed on conventional catching racks using conventional farm lifting equipment. To compare the effect of shape on settlement intensity, data from experiments 2 and 3 were reanalysed. In experiments 2 and 3 modules (pooled surfaces n=4) were treated as replicates for the comparison of flat and curved collectors.

4.2.1 STATISTICAL ANALYSIS

Data were analysed using ANOVA. Homogeneity of variances were evaluated using Cochran's test (Winner,1971) and data were transformed $(X+1)^{0.5}$, $(X+0.1)^{0.42}$ or $\log_e(x+1)$ for homogeneity. Each experiment was conducted using an orthogonal randomised design. Where significant differences in treatment means were detected by ANOVA the Student-Newman-Keuls (SNK) multiple comparisons procedure (Underwood,1981) was used to compare the means.

4.3 RESULTS

4.3.1 EXPERIMENT 1: SUBSTRATE TYPE

The analysis of variance (Table 1) revealed significant differences ($p<0.001$) were observed in the number of oysters that settled on each substrate type, on both the unconditioned and conditioned substrates, a significant ($p<0.001$) substrate x conditioning interaction also occurred. Unconditioned substrates ranked in order of increasing oyster settlement (Table 2) were, PVC plastic (new), PVC plastic (used), tar, fibro-cement (smooth), fibro-cement (rough) and lime-cement slurry. Conditioned substrates ranked in order of increasing oyster settlement (Table 2) were PVC plastic (new), PVC plastic (used), fibro-cement (smooth), tar, fibro-cement

TABLE 1. Analysis of variance of the number of Sydney rock oyster settling on unconditioned and conditioned flat (40mm x 250mm) PVC plastic (new), PVC plastic (used), tarred, fibro-cement (smooth), fibro-cement (rough) and lime-cement slurry coated collectors. Substrates were deployed for 35 days on commercial catching leases in Salamander Bay. NS = Non significant (P>0.05). Significant differences; * = P <0.05, ** = P <0.01, *** = P <0.001. Data homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	Sig
substrate	5	316596.68	63319.34	260.30	***
conditioning	1	27371.26	27371.26	112.52	***
sub x condit	5	13284.68	2656.94	10.92	***
Residual	84	20433.13	243.25		
Total	95	377685.74			

Cochran's test c = 0.2195 Not significant

TABLE 2. The settlement of the Sydney rock oyster on unconditioned and conditioned substrates, exposed for 35 days on commercial intertidal catching leases in Salamander Bay, Port Stephens NSW. Substrate means ($\pm$S.E) are ranked in order of increasing settlement. Substrate means with similar superscripts do not differ significantly (p>0.05).

Substrate	Conditioning	Mean$\pm$S.E.
PVC Plastic (new)	Unconditioned	1.8 ± 0.5^{a}
PVC Plastic (new)	Conditioned	3.8 ± 1.3^{a}
PVC Plastic (used)	Unconditioned	18.5 ± 4.2^{ab}
PVC Plastic (used)	Conditioned	28.5 ± 3.7^{bc}
Tar	Unconditioned	39.0 ± 6.3^{c}
Fibro-cement (smooth)	Unconditioned	77.1 ± 2.6^{d}
Fibro-cement (smooth)	Conditioned	102.0 ± 4.8^{e}
Tar	Conditioned	107.3 ± 5.3^{e}
Fibro-cement (rough)	Unconditioned	108.3 ± 7.2^{e}
Lime-cement slurry	Unconditioned	142.8 ± 7.9^{f}
Fibro-cement (rough)	Conditioned	153.1 ± 9.0^{f}
Lime-cement slurry	Conditioned	$195.4\pm6.$

(rough) and lime-cement slurry. Substrates ranked in order of increasing oyster settlement (Table 2) indicate that with the exception of new and used PVC plastic, conditioned substrate types had significantly higher ($p<0.05$) settlement than the corresponding unconditioned substrate. The analysis of variance (Table 3) also revealed significant differences ($p<0.001$) in the number of barnacles that settled on each substrate type, on both the unconditioned and conditioned substrates, a significant ($p<0.001$) substrate x conditioning interaction also occurred. Unconditioned substrates ranked in order of increasing barnacle settlement (Table 4) were, PVC plastic (new), PVC plastic (rough), tar, lime-cement slurry, fibro-cement (smooth) and fibro-cement (rough). Conditioned substrates ranked in order of increasing barnacle settlement (Table 4) were PVC plastic (new), PVC plastic (used), tar, lime-cement slurry, fibro-cement (smooth) and fibro-cement (rough). As with oyster settlement a trend was also observed for generally higher numbers of barnacles to have settled on conditioned as opposed to unconditioned substrates, however the ratio of barnacle to oyster settlement was by far the lowest on lime-cement slurry substrate.

4.3.2 EXPERIMENT 2: COLLECTOR SPACING

The analysis of variance (Tables 5 and 6) indicated that spacing had no significant effect ($p>0.05$) on the intensity of oyster settlement on either flat (Table 5) or curved collectors (Table 6) and in both instances there were significant ($p<0.001$) differences in the intensity of settlement between surfaces. Overall on flat collectors, the majority of oysters settled on the lower surfaces (2 and 4) of each pair of collectors (module) (Figs. 4.2, 4.3 and 4.4); no oysters were observed to have settled on surface 1 (top collector, upper surface), while 40.2% of settlements occurred on surface 2 (top collector, lower surface), 1.1% occurred on surface 3 (bottom collector, upper surface) and 58.7% occurred on surface 4 (bottom collector, lower surface). On the curved collectors, as with the flat collectors the majority of oysters settled on the lower surfaces (2 and 4) of each pair of collectors (module) (Figs. 4.5, 4.6 and 4.7); less than 0.1% of settlements were observed to have occurred on surface 1, while 41.9% of settlements occurred on surface 2, 7.9% occurred on surface 3 and 50.1% occurred on surface 4.

In both cases (flat and curved) a significant interaction ($P<0.001$) between collector surface and collector spacing was detected. This was the result of a number of significant differences between spacings at the surface level. A trend was evident for the intensity of settlement on surface 3 (bottom collector, upper surface) of each module to increase with decreasing inter-surface space, while settlement intensity tended to decrease with decreasing inter-surface space on surface 4. Interactions between location x space, location x surface and location x space x surface were not significant ($p>0.05$; Tables 5 and 6) on both the flat or the curved collectors.

A further analysis of pooled surface settlement data for flat collectors, analysed as either all surfaces total settlement (module) (Table 7), or total settlement bottom collector (summed upper and lower surfaces of the bottom collector) (Table 8)

TABLE 3. Analysis of variance of the number of barnacles settling on unconditioned and conditioned flat (40mm x 250mm) PVC plastic (new), PVC plastic (used), tarred, fibro-cement (smooth), fibro-cement (rough) and lime-cement slurry coated collectors. Substrates were deployed for 35 days on commercial catching leases in Salamander Bay. NS = Non significant (P>0.05). Significant differences; * = P <0.05, ** = P <0.01, *** = P <0.001. Data homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	Sig
substrate	5	631426.68	126285.34	121.76	***
conditioning	1	72051.04	72051.26	69.47	***
sub x condit	5	34810.83	6962.1 7	6.71	***
Residual	84	87123.25	1037.18		
Total	95	825411.83			

Cochran's test c = 0.1747 Not significant

TABLE 4. The settlement of barnacles on unconditioned and conditiond substrates, exposed for 35 days on commercial intertidal catching leases in Salamander Bay, Port Stephens NSW. Substrate means (±S.E) are ranked in order of increasing settlement. Substrate means with similar superscripts do not differ significantly (p>0.05).

Substrate	Conditioning	Mean±S.E.
PVC Plastic (new)	Unconditioned	26.3±10.1[a]
PVC Plastic (used)	Unconditioned	66.4±6.2[b]
PVC Plastic (new)	Conditioned	67.1±8.1[b]
PVC Plastic (used)	Conditioned	78.6±7.5[b]
Tar	Unconditioned	104.9±11.7[bc]
Tar	Conditioned	128.1±10.2[c]
Lime-cement slurry	Unconditioned	130.4±10.7[c]
Fibro-cement (smooth)	Unconditioned	141.9±12.5[cd]
Lime-cement slurry	Conditioned	170.4±10.0[d]
Fibro-cement (rough)	Unconditioned	234.1±16.5[e]
Fibro-cement (smooth)	Conditioned	238.0±11.8[e]
Fibro-cement (rough)	Conditioned	350.4±16.4[f]

TABLE 5. Analysis of variance of the number of Sydney rock oyster settling on flat) lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm, and 40mm). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data transformed to $(X+0.1)^{0.42}$ to obtain homogeneity of variance.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	0.771	0.3857	1.42 (.244) NS
Space	3	1.386	0.462	1.90 (.230) NS
Surface	3	1687.608	562.536	1177.20 (.000) ***
Location x space	6	1.446	0.243	0.90 (.450) NS
Location x surface	6	2.862	0.478	1.76 (.110) NS
Space x surface	9	21.994	2.444	6.20 (.000) ***
Locat x space x surface	18	7.099	0.394	1.46 (.115) NS
Residual	144	38.995	0.271	
Total	191	1762.176		

Cochran's test c = 0.1078 Not significant

TABLE 6. Analysis of variance of the number of Sydney rock oyster settling on curved lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm and 40mm). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data transformed $(X+1)^{0.5}$ to obtain homogeneity of variance.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	3.374	1.687	2.52 (.084) NS
Space	3	5.419	1.806	3.37 (.096) NS
Surface	3	3953.268	1317.756	1323.52 (.000) ***
Location x space	6	3.218	0.536	0.80 (.569) NS
Location x surface	6	5.974	0.996	1.49 (.186) NS
Space x surface	9	123.681	13.742	35.69 (.000) ***
Locat x space x surface	18	6.931	0.385	0.58 (.912) NS
Residual	144	96.231	0.668	
Total	191	4198.097		

Cochran's test c = 0.1027 Not significant

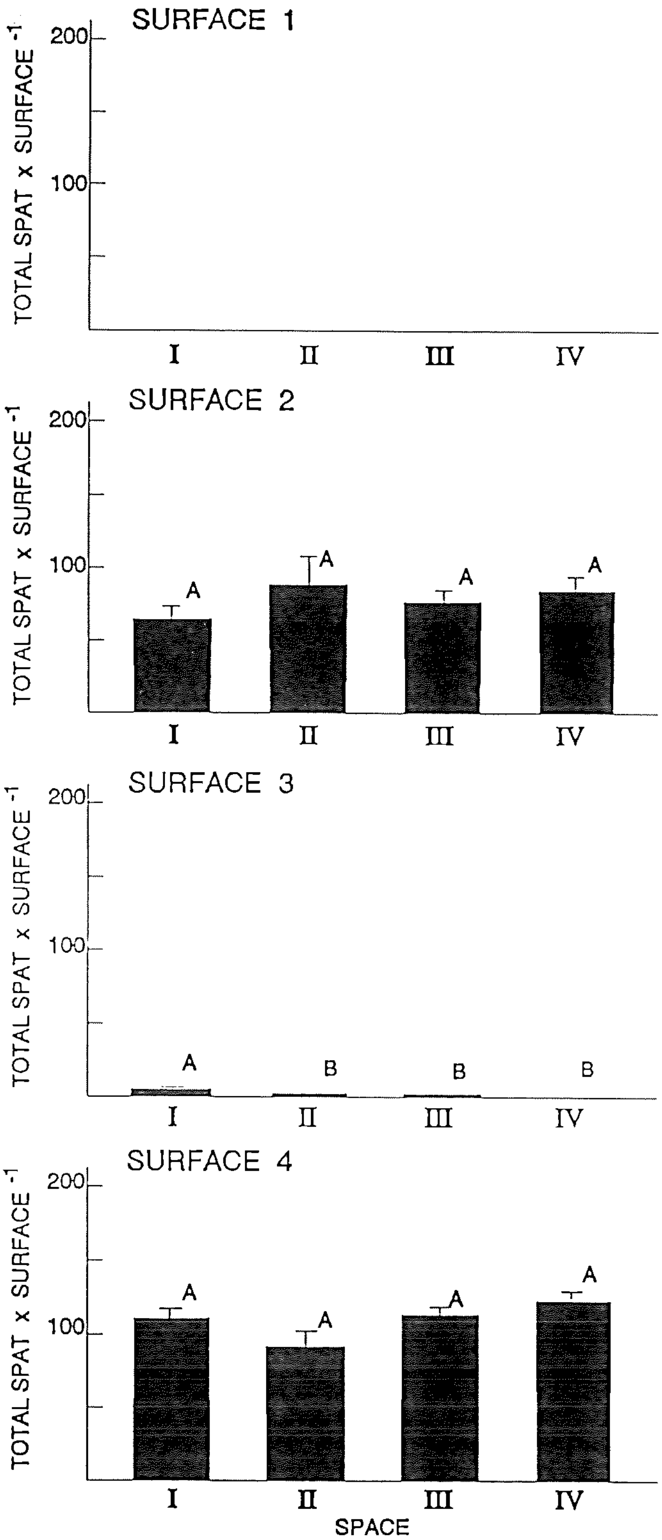


Figure 4.2 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on flat lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 1. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface, spacing means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

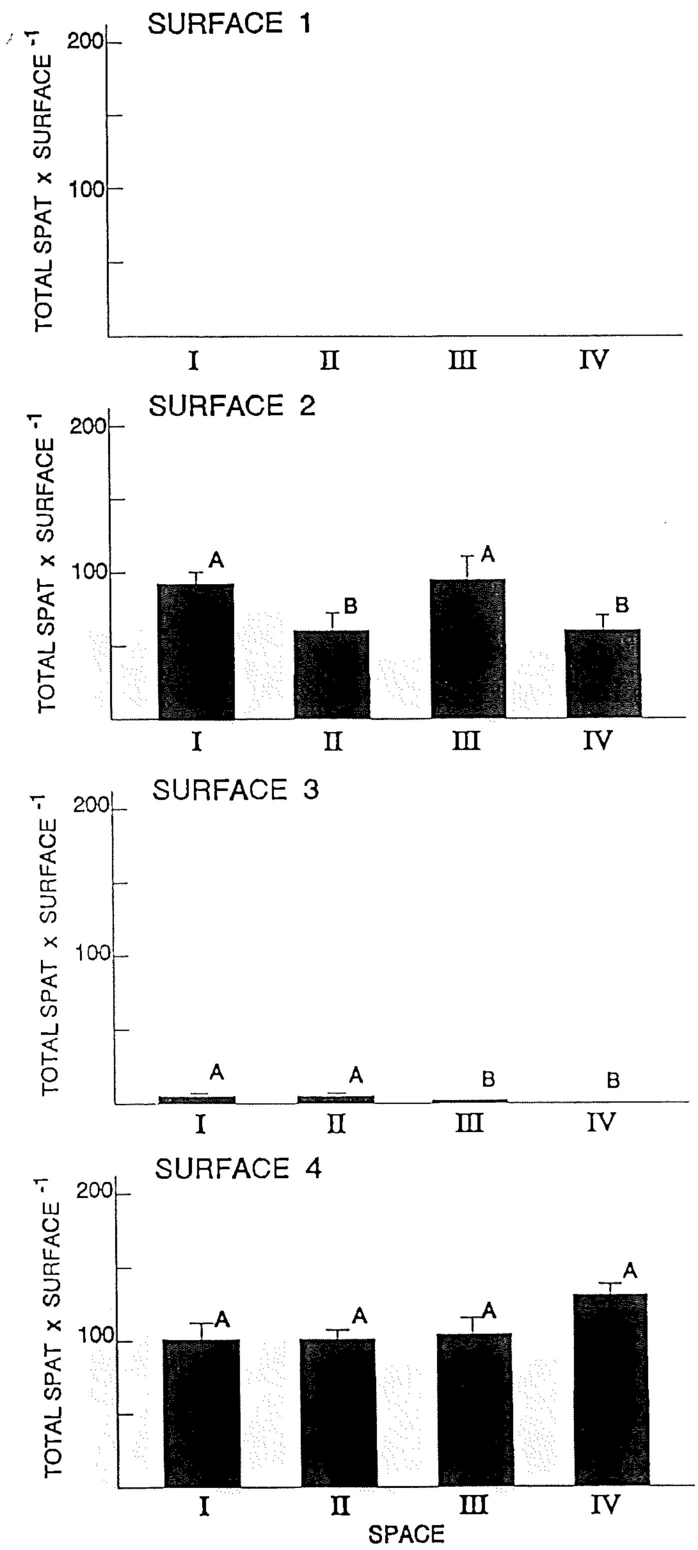


Figure 4.3 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on flat lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 2. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface, spacing means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

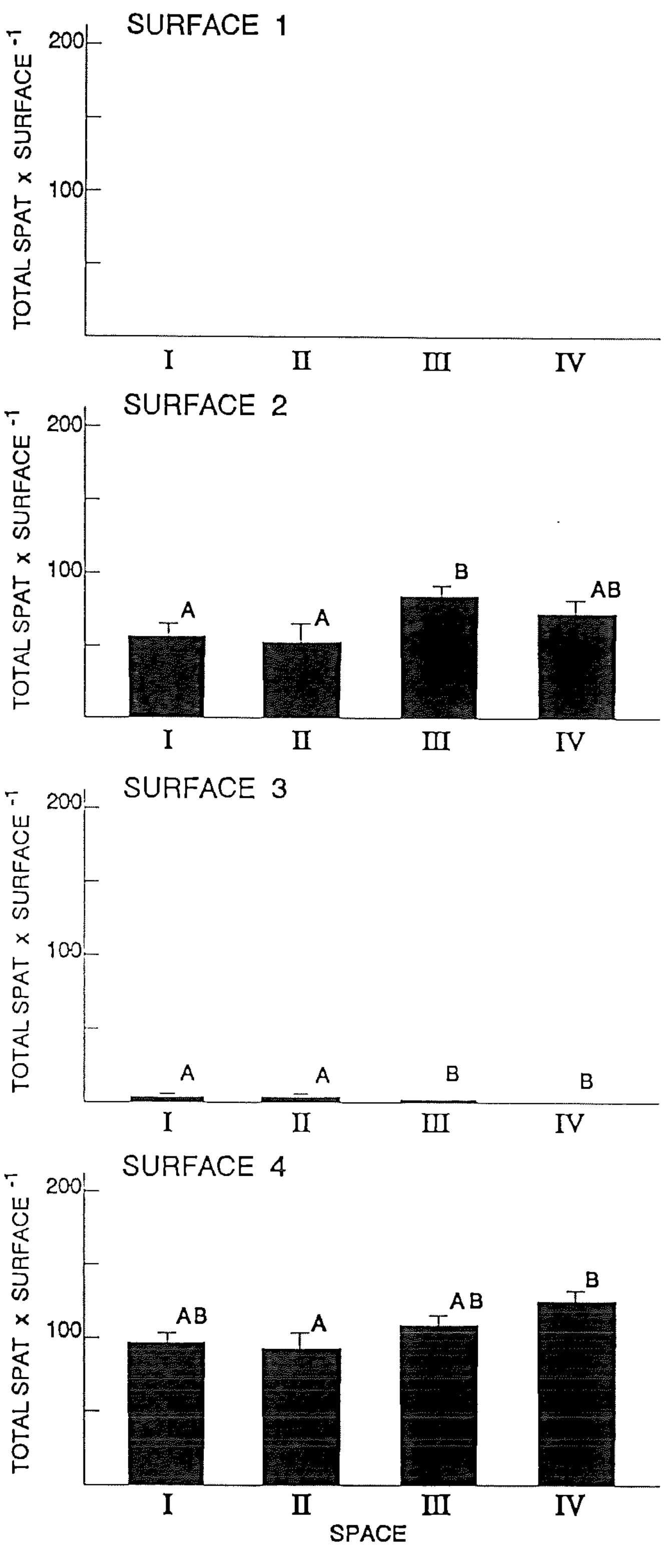


Figure 4.4 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on flat lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 3. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface spacing means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

TABLE 7. Analysis of variance of the number of Sydney rock oyster settling on flat lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm, and 40mm). Pooled surfaces (modules). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data not transformed.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	2722.167	1361.083	1.77 (.184) NS
Space	3	10919.396	3639.80	7.32 (.019) ***
Location x space	6	2983.167	497.194	0.65 (.691) NS
Residual	36	27628.750	767.465	
Total	47	44253.479		

Cochran's test c = 0.1664 Not significant

TABLE 8. Analysis of variance of the number of Sydney rock oyster settling on flat lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm and 40mm). Total settlement lower collector. NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data not transformed.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	250.167	125.083	0.65 (.530) NS
Space	3	5829.166	1943.056	9.02 (.012) *
Location x space	6	1292.333	215.389	1.11(.375) NS
Residual	36	972.000	193.667	
Total	47	14343.667		

Cochran's test c = 0.1973 Not significant

although revealing significant differences ($p<0.05$) in the intensity of settlement between spacings, it did not reveal any trend. A further analysis of pooled surface settlement data for curved collectors, analysed as either all surfaces total settlement (module) (Table 9), or total settlement bottom collector (summed upper and lower surfaces of the bottom collector) (Table 10) revealed no significant differences ($p>0.05$) in settlement intensity in either the module or lower collector data, even though a significant surface trend as described above was evident (Figs. 4.5, 4.6 and 4.7).

4.3.3 EXPERIMENT 3: COLLECTOR ORIENTATION TO TIDAL CURRENT

As was observed in the spacing experiment, the analysis of variance (Tables 11 and 12) revealed a significant difference ($p<0.001$) in the settlement intensity between surfaces on both the flat and curved collectors. The analysis (Table 11) indicated a significant difference ($p<0.01$) in settlement intensity on flat collectors between locations at the Corrie Island site, there was no significant difference ($p>0.05$) in settlement intensity between collectors orientated at 90° or 180° to tidal flow at any location (Figs. 4.7, 4.8 and 4.9). Interactions between location x surface, location x orientation and location x orientation x surface were also not significant ($p>0.05$). There were also no significant differences ($p>0.05$) (Table 12) in settlement intensity between curved collectors orientated at 90° or 180° to tidal flow, or between locations (Figs. 4.10, 4.11 and 4.12), all interactions were also not significant ($p>0.05$). As was observed in the spacing experiment the majority of oysters settled on the lower surfaces (2 and 4) of each pair of flat substrates; 1.4% of settlements occurred on surface 1, while 52.8% of settlements occurred on surface 2, 6.6% occurred on surface 3 and 39.2% occurred on surface 4. On the curved substrates 1.7% of settlements occurred on surface 1, while 54.0% of settlements occurred on surface 2, 20.1% occurred on surface 3 and 24.2% occurred on surface 4.

A further analysis of pooled surface data (module) for flat and curved substrates (Tables 13 and 14 respectively) revealed no significant ($p<0.05$) difference in settlement intensity on collectors orientated at either 90° or 180° to the tidal flow.

4.3.4 EXPERIMENT 4: COLLECTOR SHAPE

Although, in both experiments 1 and 2, curved and flat substrates modules presented the same surface area to the available oyster settlement, the analysis of variance (Tables 15 and 16) significantly ($P<.05$) more oyster settled on curved substrate pairs than did on flat substrates pairs, over all spacings and orientations.

TABLE 9. Analysis of variance of the number of Sydney rock oyster settling on curved lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm, and 40mm). Pooled surfaces (modules). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data not transformed.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	7060.448	3530.224	2.06 (.142) NS
Space	3	5385.891	1795.297	2.08 (.205) NS
Location x space	6	5181.594	863.600	0.50 (.801) NS
Residual	36	61660.813	1712.800	
Total	47	79288.745		

Cochran's test c = 0.1078 Not significant

TABLE 10. Analysis of variance of the number of Sydney rock oyster settling on curved lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm and 40mm). Total settlement lower collector. NS = Non significant (p>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data not transformed.

Source of variation	d.f	Sum of square	Mean squares	F P Sig
Location	2	3709.156	1854.578	2.81 (.074) NS
Space	3	3403.599	1134.533	2.67 (.141) NS
Location x space	6	2549.010	424.835	0.64 (.695) NS
Residual	36	23772.313	660.342	
Total	47	33434.078		

Cochran's test c = 0.2392 Not significant

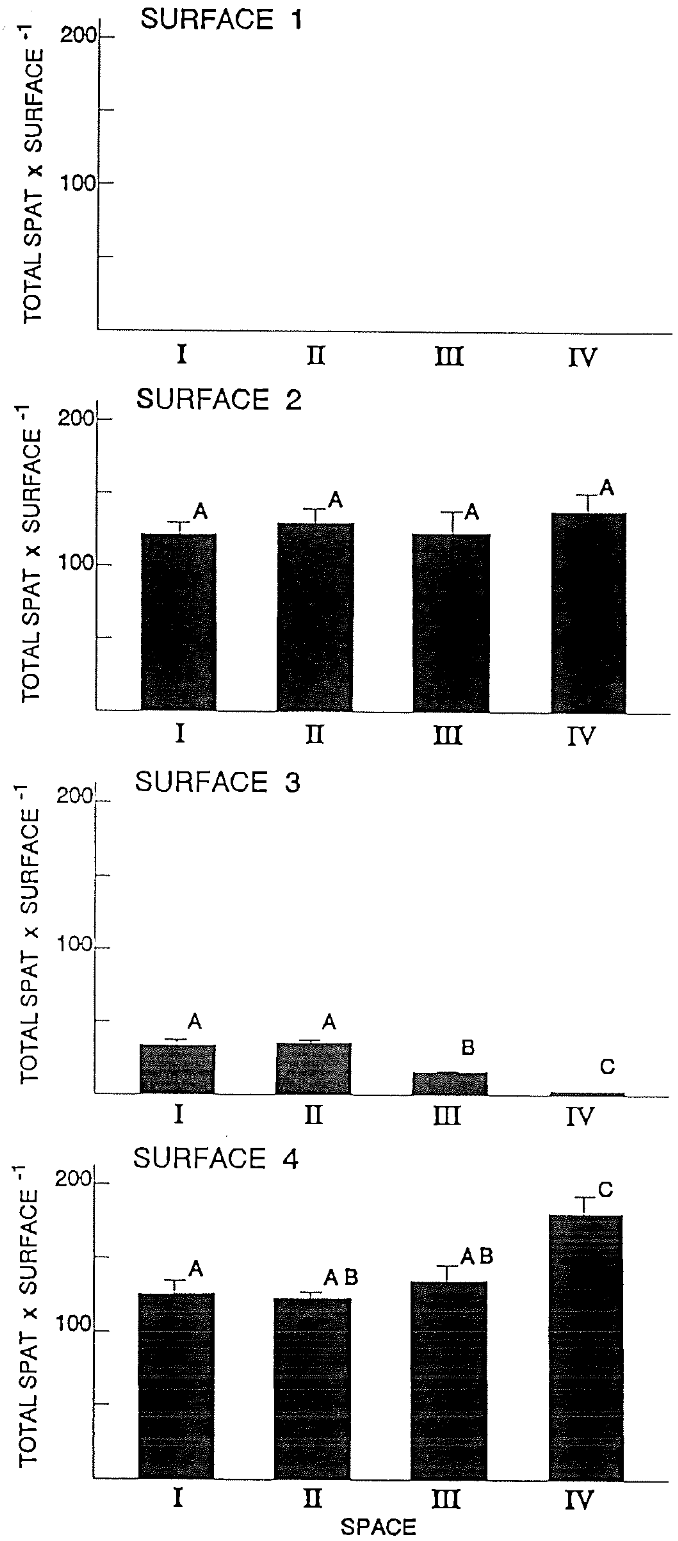


Figure 4.5 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on curved lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 1. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface, spacing means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

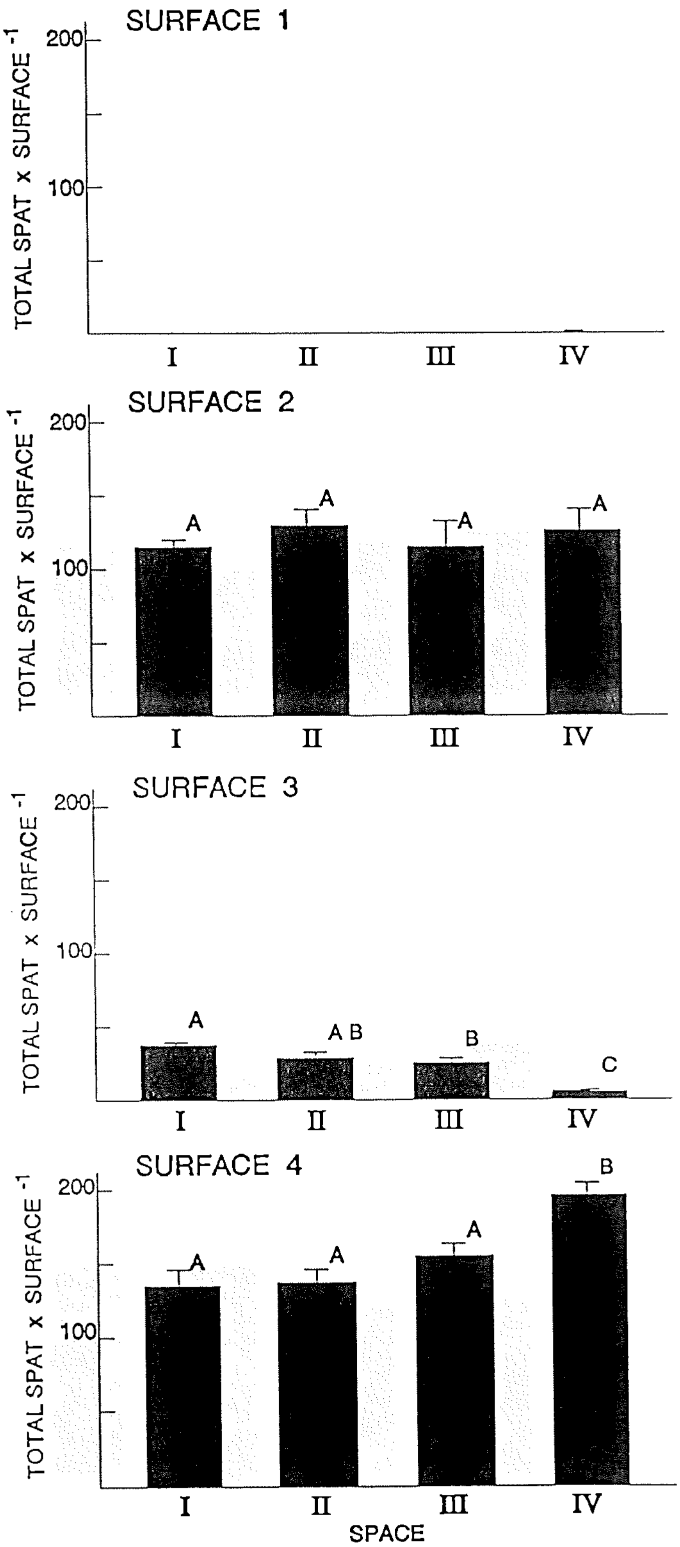


Figure 4.6 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on curved lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 2. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface, spacing means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

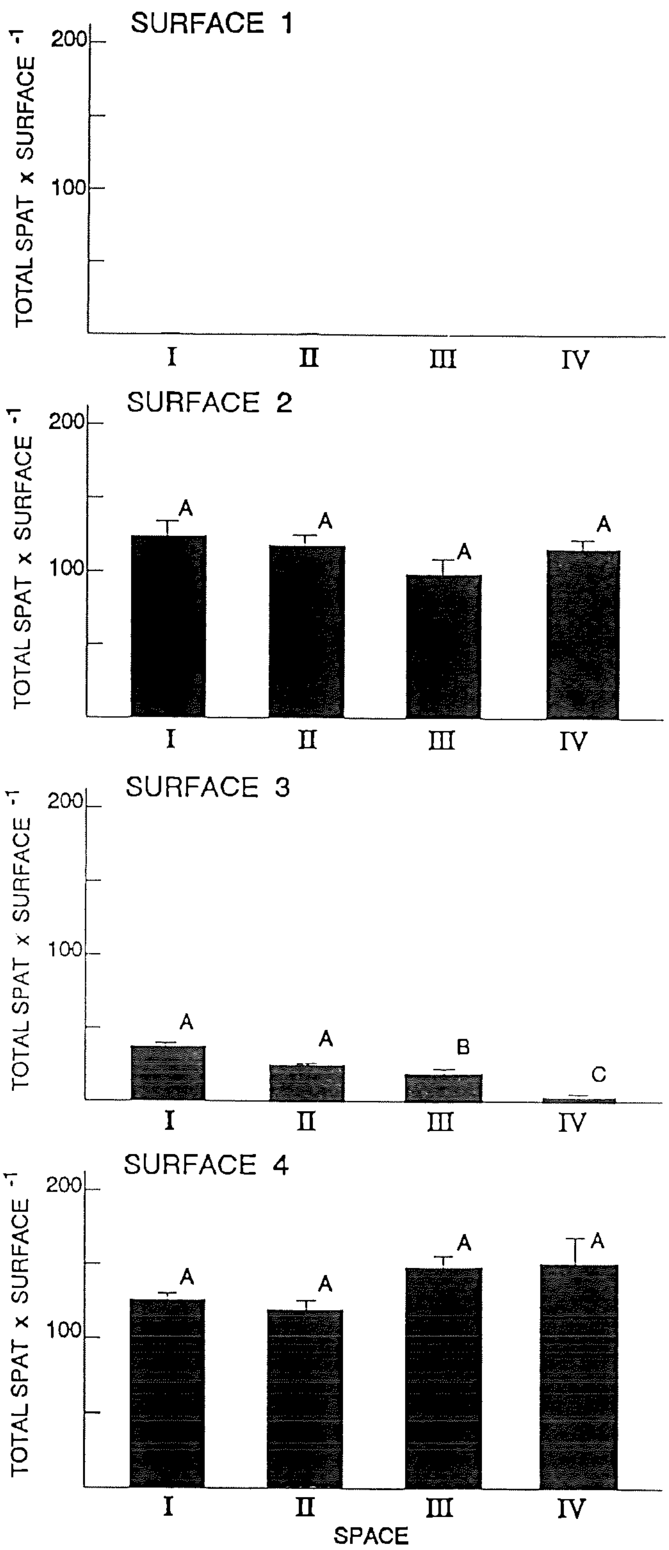


Figure 4.7 The settlement of the Sydney rock oyster (mean ± S.E; n=4) on curved lime-cement slurry coated collectors, set at 4 different inter surface spacings (I=5mm; II=10mm; III=20mm; IV=40mm) at Site 1, location 3. Surface 1 = top collector, upper surface; Surface 2 = top collector, lower surface; surface 3 = bottom collector, upper surface and surface 4 = bottom collector, lower surface. For each surface, means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

TABLE 11. Analysis of variance of the number of Sydney rock oyster settling on flat (480mm x 40mm x 5mm) lime-cement slurry coated collectors, set at 90° or 180° to the prevailing tidal current at an inter-surface space of 10mm. NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data transformed $Log_e(X+1)$ to obtain homogeneity of variance.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Location	2	4.182	2.091	5.64	(.005)	NS
Orientation	1	0.341	0.341	0.87	(.449)	NS
Surface	3	181.206	60.402	157.56	(.000)	***
Location x orientation	2	3.218	0.536	0.80	(.569)	NS
Location x surface	6	5.974	0.996	1.49	(.186)	NS
Orientation x surface	3	123.681	13.742	35.69	(.000)	***
Locat x orien x surface	6	6.931	0.385	0.58	(.912)	NS
Residual	72	96.231	0.668			
Total	95	4198.097				

Cochran's test c = 0.1613 Not significant

TABLE 12. Analysis of variance of the number of Sydney rock oyster settling on curved (480mm x 40mm x 5mm; radius =45mm) lime-cement slurry coated collectors, set at 90° or 180° to the prevailing tidal current at an inter-surface space of 10mm. NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Untransformed data variances homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Location	2	2123.266	1061.633	1.87	(.162)	NS
Orientation	1	1712.815	1712.815	3.04	(.223)	NS
Surface	3	486315.883	162105.293	269.64	(.000)	***
Location x orientation	2	1127.037	563.518	0.99	(.376)	NS
Location x surface	6	3607.109	601.185	1.06	(.395)	NS
Orientation x surface	3	3592.591	1197.530	1.76	(.254)	NS
Locat x orien x surface	6	4082.964	680.494	1.20	(.317)	NS
Residual	72	40882.063	567.806			
Total	95	543443.727				

Cochran's test c = 0.1119 Not significant

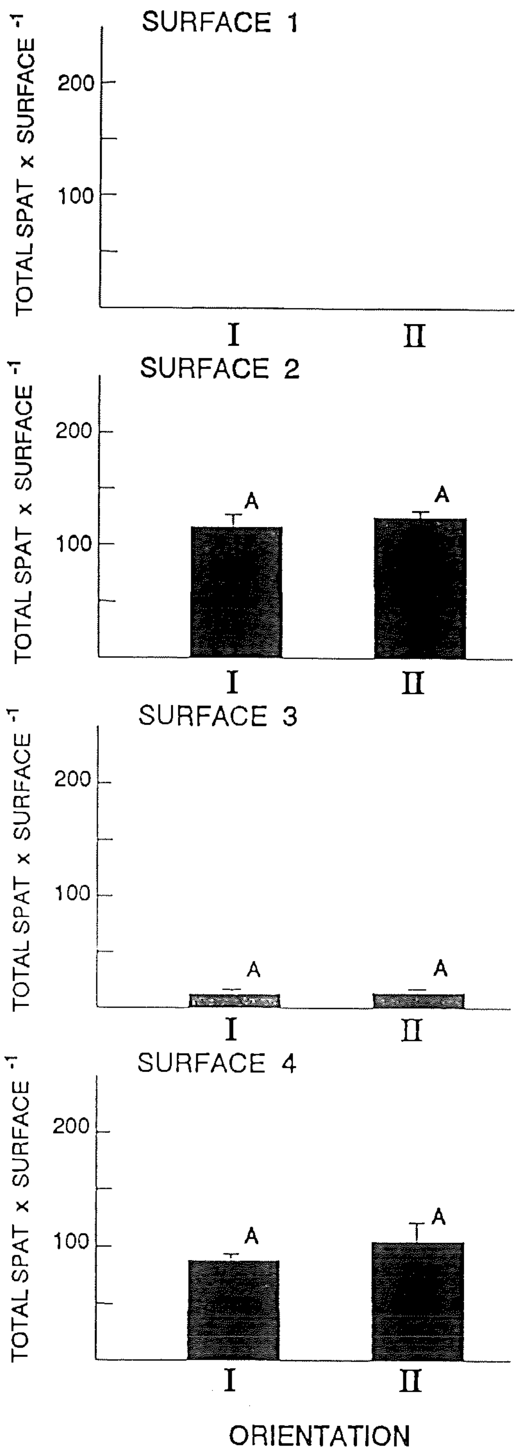


Figure 4.8 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on flat lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 1. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

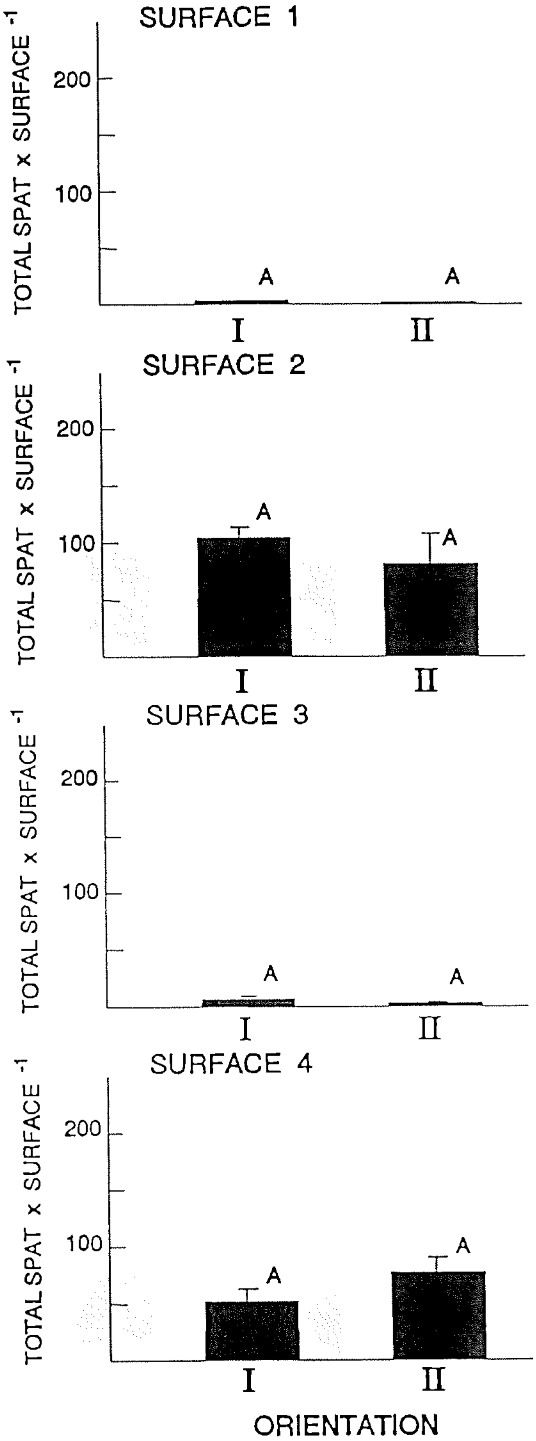


Figure 4.9 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on flat lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 2. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

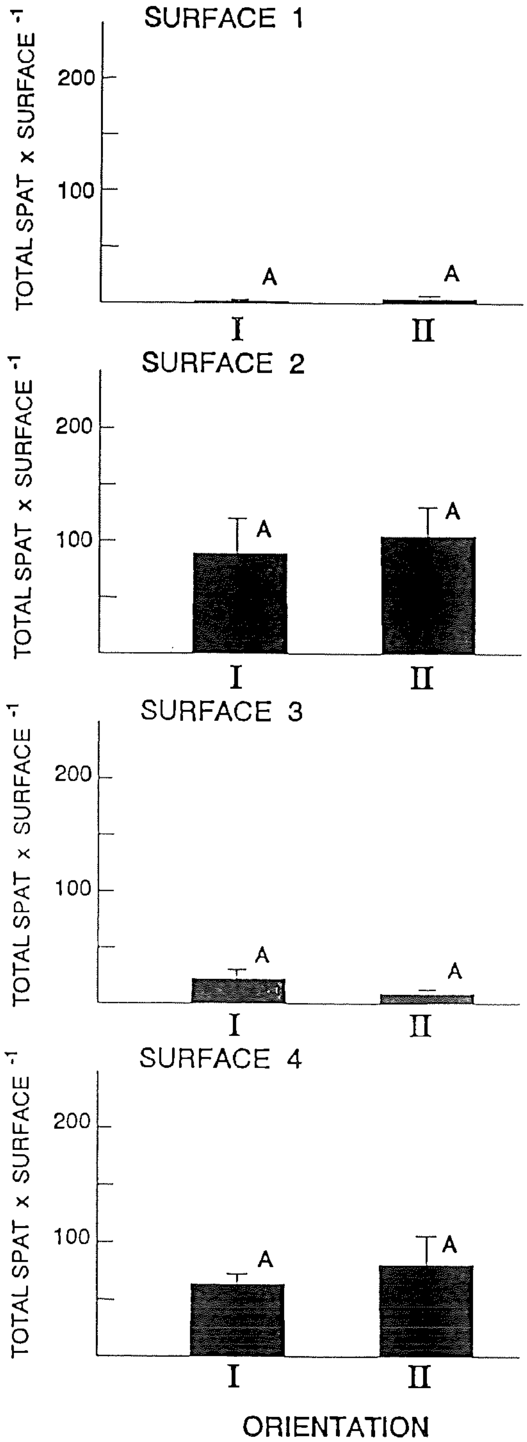


Figure 4.10 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on flat lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 3. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly (p>0.05; S.N.K.).

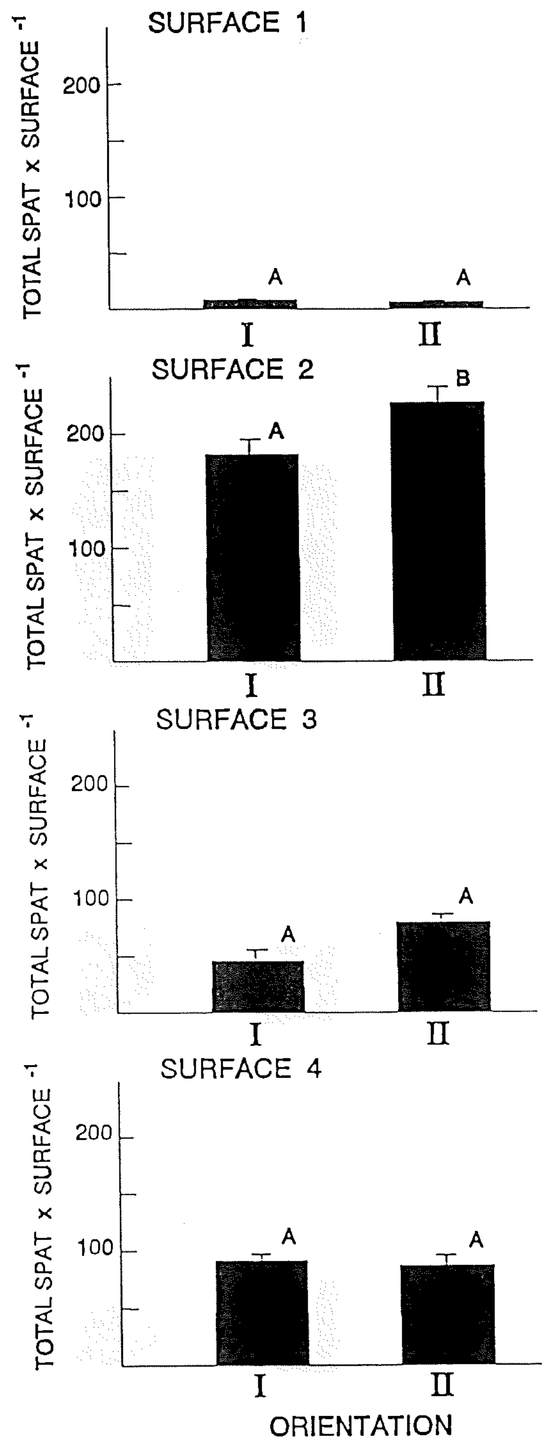


Figure 4.11 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on curved lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 1. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

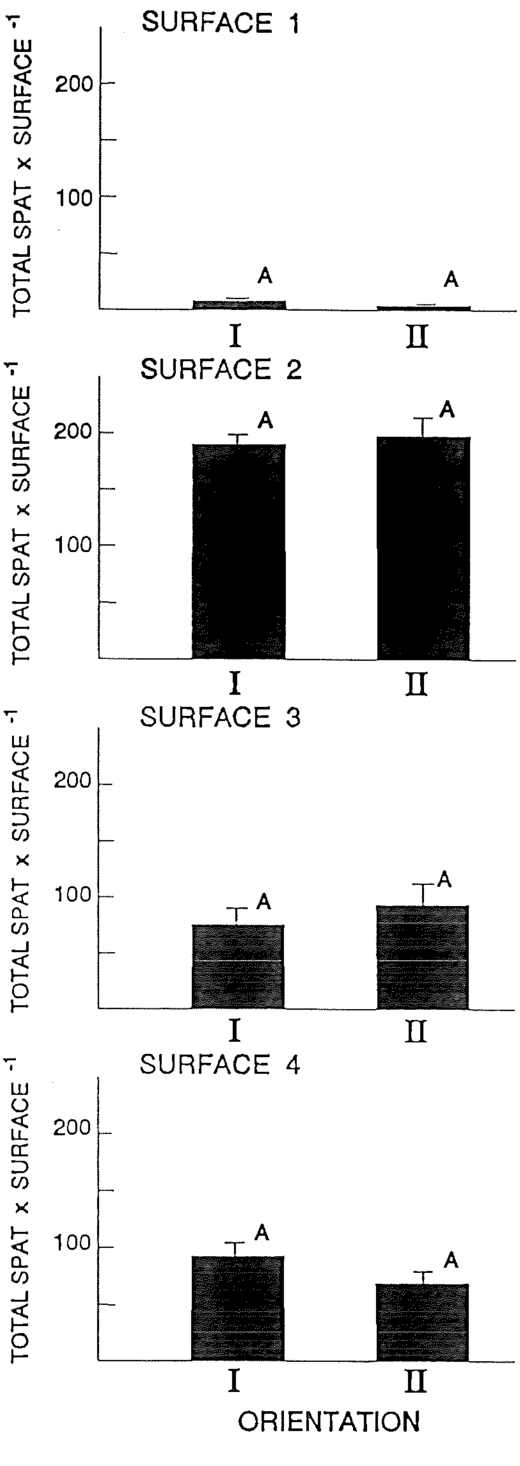


Figure 4.12 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on curved lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 2. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

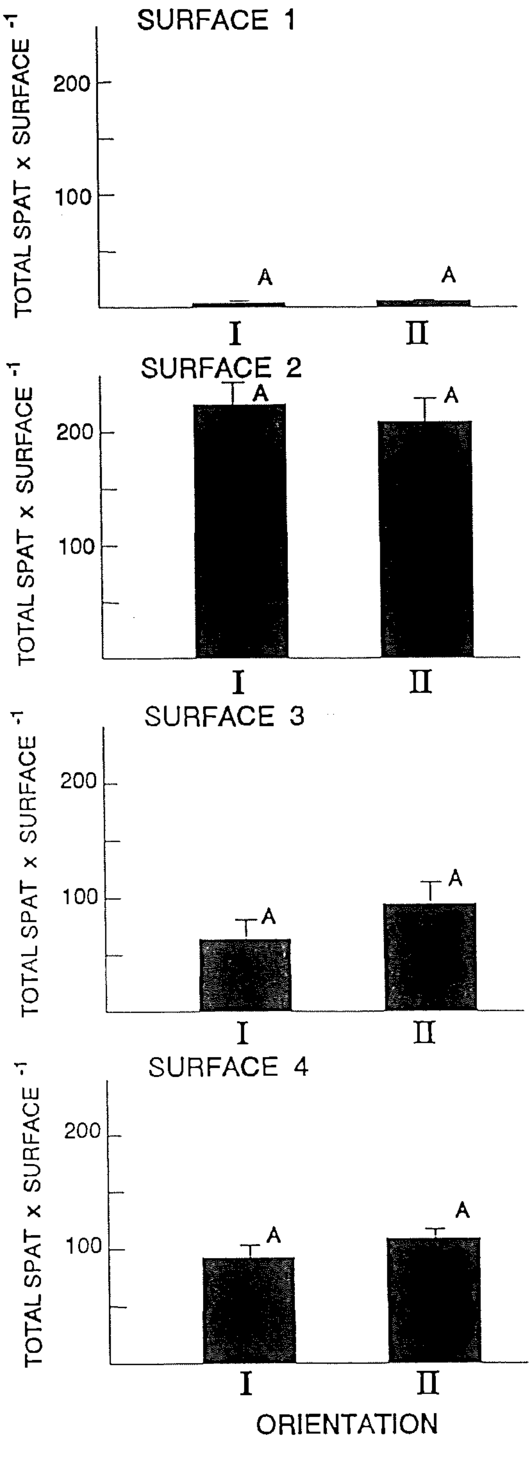


Figure 4.13 The settlement of the Sydney rock oyster (mean ± S.E.;n=4) on curved lime-cement slurry coated collectors, set at 90° (I) or 180° (II) to the prevailing tidal current at site 2, location 3. Collectors set with an inter surface space of 10mm. For each surface, orientation means with similar superscripts do not differ significantly ($p>0.05$; S.N.K.).

TABLE 13. Analysis of variance of the number of Sydney rock oyster settling on flat lime-cement slurry coated collectors, set at 90° or 180° to the prevailing tidal current at an inter-surface space of 10mm. Pooled surfaces (modules). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Data transformed $Log_e(X+1)$ to obtain homogeneity of variance.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Location	2	17001.583	8500.791	5.64	(.005)	NS
Orientation	1	1247.042	1247.042	0.87	(.449)	NS
Location x orien	2	1595.083	797.542	0.58	(.912)	NS
Residual	18	105892.250	5882.903			
Total	23	125735.958				

Cochran's test c = 0.1613 Not significant

TABLE 14. Analysis of variance of the number of Sydney rock oyster settling on curved lime-cement slurry coated collectors, set at 90° or 180° to the prevailing tidal current at an inter-surface space of 10mm. Pooled surfaces (Modules). NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Untransformed data variances homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Location	2	8493.063	4246.531	1.31	(.295)	NS
Orientation	1	6851.260	6851.260	3.04	(.223)	NS
Location x orientation	2	4508.146	2254.073	0.69	(.513)	NS
Residual	18	58541.188	3252.288			
Total	23	78393.656				

Cochran's test c = 0.1119 Not significant

TABLE 15. Analysis of variance of the number of Sydney rock oyster settling on flat (480mm x 40mm x 5mm) and curved (480mm x 40mm x 5mm; radius =45mm) lime-cement slurry coated collectors, set at 4 different spacings (5mm, 10mm, 20mm and 40mm), surfaces pooled for module total. NS = Non significant (P>0.05). Significant difference; * = P <0.05, ** = P <0.01, *** = P <0.001. Transformation, none, data variances homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Shape	1	263498.648	263498.648	78.75	(.013)	*
Location	2	7703.974	3851.987	3.59	(.033)	*
Spacing	3	6362.216	2120.739	0.75	(.562)	NS
Shape x location	2	6691.828	3345.914	3.11	(.051)	NS
Shape x space	3	2713.529	904.510	0.95	(.475)	NS
Location x space	6	16998.339	2833.056	2.64	(.023)	*
Shape x locat x space	6	5734.401	955.734	0.89	(.507)	NS
Residual	72	77337.938	1074.138			
Total	95	387040.872				

Cochran's test c = 0.1180 Not significant

TABLE 16. Analysis of variance of the number of Sydney rock oyster settling on flat (480mm x 40mm x 5mm) and curved (480mm x 40mm x 5mm; radius =45mm) lime-cement slurry coated collectors, set at 90o or 180o to the prevailing tidal current, surfaces pooled for module total. NS = Non significant (P>0.05), * = P <0.05, ** = P <0.01, *** = P <0.001. Transformation, none, data variances homogeneous.

Source of variation	d.f	Sum of square	Mean squares	F	P	Sig
Shape	1	402508.755	4025808.577	51.70	(.019)	*
Location	2	9925.198	4962.599	1.09	(.348)	NS
Orientation	1	6972.130	6972.130	2.45	(.258)	NS
Shape x location	2	15569.448	7784.724	1.70	(.196)	NS
Shape x orientation	1	1126.172	1126.172	5.60	(.142)	NS
Location x orientation	2	5700.948	2850.474	0.62	(.542)	NS
Shape x locat x orien	2	402.281	201.141	0.04	(.957)	NS
Residual	36	164433.438	4567.596			
Total	47	606638.370				

Cochran's test c = 0.2517 Not significant

4.4 DISCUSSION

The initial settlement choices made by oysters, barnacles and other sessile marine organisms that colonise hard substrate are complex, in many cases involve a number of biotic and abiOtic cues (Barnes,1955: Quayle,1969; Connell,1985; Wethley,1986). In experiment 1 a 100 fold difference was observed between the lowest (unconditioned; PVC, new) and highest ranked (conditioned; lime-cement slurry) settlement substrates (Table 2). Oysters have long been known to settle readily on lime and cement based substrates (Medcoff,1955; Curtin,1973; Kong and Luh,1976; Gunn,1984). The excellent performance of lime-cement slurry as a settlement substrate for harvesting natural Sydney rock oyster spat is further emphasised when the settlement on lime-cement slurry is compared to that which occurred on the traditional tar settlement substrate. Settlement on unconditioned lime-cement slurry was approximately 3 times that which occurred on unconditioned tar, while conditioned lime-cement slurry was approximately twice that of conditioned tar. It therefore may be possible to significantly enhance settlement with the use of a lime-cement slurry in areas of marginal Sydney rock oyster catch, thus increasing the number of areas that may provide a commercially viable catch of oyster spat to industry. This is particularly the case where a slurry is applied to traditional sticks, in a method described by Verdich (1989) for use with traditional stick methods of production. Lime-cement slurry had by far the lowest ratio of barnacle to oyster settlement of all substrates tested and as such may be a valuable oyster catching substrate in areas of high barnacle catch. Experiment 1 demonstrated that on both unconditioned and conditioned fibro-cement substrates the Sydney rock oyster settled in larger numbers on rough as opposed to smooth fibro-cement substrate. The majority of spat were observed to settle in grooves on the rough fibro-cement formed during roughing with a wire brush. This cryptic settlement behaviour has been observed on numerous occasions by the author and most recently when assessing settlement on newly available vinyl plastic settlement collector for local oyster growers. On these collectors, which are embossed with a wood-grain pattern, approximately 87% of settlement by Sydney rock oysters and 74% of settlements of Pacific oyster took place in the fine grooves (groove <.5mm in width) of the collector. A cryptic settlement behaviour by oysters has been reported by a number of authors (Butler,1992;Michener and Kenny,1991). Therefore it may also be possible to further enhance the settlement of Sydney rock oysters on collectors by providing a rough or grooved substrate. Roughly grooved PVC plastic collectors have been shown to be excellent spat collectors (Gunn,1984;Curtin,1985;Holliday et. al.,1993). As a result of the poor performance of both new and used smooth PVC plastic collectors in experiment 1 these collectors cannot be recommended as catching substrates for the exploitation of natural spatfall for single seed over short exposure periods. In experiments conducted by Holliday et. al.(1993), these collectors caught significant numbers of Sydney rock oyster spat. However, when consideration is given to the differences in the deployment period in the two studies, 35 days (this study) as opposed to 127 days of Holliday et. al. (1993) the differences may reflect a substantial improvement in substrate acceptability for settlement by the Sydney rock oyster imparted by a prolonged conditioning of the substrate. Such an improvement was observed on all substrates in experiment 1 (Table 2). Conditioning (or soaking) has been reported to increase settlement of oysters on a number of substrates and has been attributed to the establishment of biological films (Tritar et. al.,1992), the leaching of settlement inhibiting substance (Gunn,1984) and increasing substrate complexity. The poor settlement observed on PVC substrates in experiment may be due to the presence on the surface of the collector of waxes used to aid in the PVC extrusion process or the presence of plasticising compounds (Hardie Iplex; Technical Division). Quayle (1988) identified waxy surfaces as unacceptable for the settlement of Pacific oysters. It has been a long held view by oyster farmers that tar needs considerable time to soak on the catching lease to allow volatile and water soluble fractions of the tar to dissipate before settlement of the Sydney rock oyster will occur. Experiment 1 demonstrated that although Sydney rock oysters will settle on tar within a month of deployment improvement is substantial on conditioned substrate.

Although surface areas were equal, curved substrates caught significantly more Sydney rock oysters than flat substrates in both experiment 1 and experiment 2. This may be a result of a reduction in current shear across the settlement offered by curved surfaces as opposed to the flat surfaces. Active choices by barnacle for areas of low current shear has been suggested as an important factor in settlement of barnacles sp. (Crisp,1961,1976;Wethey,1986). The use of curved substrates, as described here, also has the added advantage over flat substrates of the same thickness, of being architecturally more ridged in spanning unsupported distances. This is an important consideration in the construction of blocks of catching substrates. The use of curved substrates will result in a lighter structurally rigid block of catching substrate that can be lifted more easily with conventional lifting equipment. The inherent strength of the surface also imparts more resistance to flexing that can dislodge spat during the removal of collectors from the catching lease, as well as to wave action which may also cause substrates to flex resulting in the loss spat, a problem observed on flexible substrates by the author.

The excellent settlement of Sydney rock oysters on lime-cement slurried surfaces during both the space and current experiments, confirms the suitability of this substrate for use in the exploitation of naturally occurring spatfall. In all experiments here a significant settlement preference by the Sydney rock oyster was observed for the under surface of collectors deployed at the mid intertidal range was observed and demonstrated. The preferential settlement of oyster spat on the under surfaces of settlement collectors has been reported for a number of species by numerous authors (Nelson,1927; Hopkins,1935; Bonnot,1937; Thomson,1950; Cole and Knight-Jones,1939; Knight-Jones,1951; Medcoff,1955; Galstoff,1964; Curtin,1971,1973; Dinamani and Lenz,1977; Kenny et al.;1990; Michener and Kenny,1991). However, other authors have also reported a preference for the upper surfaces of settlement substrates in a number of these species (Butler,1955; Miyazaki,1938; Korringa,1941). The ambiguity of some of these results have been attributed to differences in sampling techniques by Cranfield (1968). Cranfield (1968) investigating the settlement behaviour of *Ostera lutaria*, observed that only in the presence of light did lower surfaces have more spat than upper surfaces.

Ritchie and Menzel (1969) demonstrated in the laboratory that the settling stage larvae of *Crassostrea virginica* are light sensitive preferring to settle on unilluminated surface. They also demonstrated that reducing the intensity of illumination from above increased settlement on upper surfaces. Investigating the same species, Kenny et al. (1990) proposed that the increased settlement of oysters on the upper side of plates in the lower intertidal and subtidal levels may have been due to ambient light levels falling below the threshold of avoidance for longer periods, due to high water turbidity. Potter (1984) using scallop shell (*Amusium balloti*) collectors noted that at a number of settlement sites the settlement of Sydney rock oysters was higher on the upper surfaces of scallop shells at levels in the lower intertidal. However, Potter made no mention of any difference in the surface characteristic of upper and lower surfaces of *A.balloti* which may have preferentially enhance settlement, as was observed by Baker (1992). Observations in the field of the recruitment of the Sydney rock oyster on a number of catching substrates including traditional tarred oyster sticks by Holliday et. al. (1993) at 4 months and on fibro catching material by Thomson (1950) at 1 year indicate that, by far the large majority of recruitment of this species occurs on the lower surface of substrates. However, it is not clear in these studies whether the observed recruitment was a function of the preference of larvae for shaded settlement sites, an artefact of differential survival on upper and lower surfaces, or a combination of both. Differential settlement and mortalities between upper and lower surfaces have also been attributed to siltation and fouling of upper surfaces (Butler,1935; Knight-Jones,1951; Kennedy,1986). In this series of experiments, no marked siltation of any surface was observed, it is therefor reasonable to reject this factor as a major contributing factor to the observed settlement distribution. In these experiments the increase in the settlement of Sydney rock oysters on upper surfaces of the lower collector (surface 3) with decreasing inter-surface space implicates light as a factor influencing the observed settlement distribution. Where substrates are closer together less light should penetrate, and where the surfaces were curved (concave down, radius = 45mm) this effect should be more marked. This would account for the higher intensity of settlement that occurred on the upper surface of the lower collector on curved substrates as opposed to flat substrates. A number of authors have also implicate a reduction in ambient light as a factor responsible for increased settlement of other oysters species on upper surfaces of substrates when inter-substrate spacings have been decreased (Ogasawara,1972; Shaw,1967; Dinamani and Lunz,1977). Dinamani and Lunz (1977) also proposed that larvae of the NZ rock oyster *Saccostrea glomerata* began to settle on the upper surfaces of collectors once the densities on the lower collectors became high. However, the data presented here indicates that while settlement on the upper surface of the lower collector (surface 3) tended to increased with decreasing inter-surface space, settlement on the lower surface of the lower collector (surface 4) tended to decreased indicating that the observed increase was not a result of increasing density on the lower surface as observed by Dinamani and Lunz (1967). When spacings were compared using the total settlement on the lower collector (pooled upper and lower surfaces) there were no significant differences between spacings in the number of Sydney rock oysters that settled. This suggests that the observed trend may have been the result larvae moving selectively from the upper surface to the lower surface, during the crawling stage prior to settlement, in response to decreasing shade on the upper surface associated with the increasing inter-surface spacing.

Tidal currents have been implicated by a number of authors as a factor influencing the settlement distribution of oyster larvae (Prytherch,1929; Thomson,1950; Cranfield,1968; Ogasawara,1972). Thomson (1950) suggested that large blocks of catching substrate may have an effect on settlement. Thomson (1950), demonstrated that blocks of fibro-cement slats set parallel to the prevailing current flow caught more Sydney rock oyster spat than those set at right angles to the current flow. Thomson (1950) suggested that the lower settlement on substrates set at right angles to the prevailing current flow may have been a result of impeded flow of water across the substrates due to the orientation of the substrate. In experiment 3 substrates were arranged to allow a substantially unimpeded tidal current flow. Under these conditions the data presented here does not indicate any significant difference ($P<.05$) in the settlement of Sydney rock oysters on flat or curved substrates set at right angles to or parallel to the prevailing current flow. However, it is quite plausible as suggested by Thomson (1950), that large areas of racks of closely spaced settlement collectors may impede tidal flow to such an extent that the delivery of settling stage larvae to the catching substrates is reduced.

4.5 CONCLUSIONS

The objective of the series of experiments is to provide base line information as to ways in which commercial spat collection methods may be modified to enhance the natural settlement of the Sydney rock oyster at commercial oyster leases. Techniques have been chosen that are those most easily modified by the farmer using the existing oyster racks and equipment. In this setting the following conclusions have been drawn.

1. The use of a lime-cement slurry on plastic or tarred collectors will significantly increase the attractiveness of the collectors for settlement by the Sydney rock oyster.

2. Increasing surface roughness will increase the attractiveness of collectors for settlement by the Sydney rock oysters.

3. Curved collectors (concave down) catch significantly more Sydney rock oysters than flat collectors.

4. Varying the inter-surface spacing of collectors does not significantly effect the number of oysters settling on the substrate.

5. Varying the inter-surface spacing of collectors does effect the distribution of oyster settlement.

6. Varying the orientation of collectors from 90° to 180° to the tidal current does not significantly effect the number of oysters that settle on the substrate.

GLOSSARY OF TERMS

Block	frames of tarred sticks, interlocked one on top of the other to form a block of frames consisting of 5 or 6 layers approximately 25cm deep.
Crate	see frame
Ebb tide	out going tide
Flood tide	incoming tide
Frame	tarred sticks nailed parallel to oneOSSARY OF TERMS
Block	frames of tarred sticks, interlocked one on top of the other to form a block of frames consisting of 5 or 6 layers approximately 25cm deep.
Crate	see frame.
Ebb tide	out going tide.
Flood tide	incoming tide.
Frame	tarred sticks nailed parallel to one another on a tarred stick runner approximately 20cm from either end.
Intertidal range	the vertical range covered by the tide between indian spring low tide (0 tide) and indian spring high tide.
Larvae	free swimming stage of an oysters development prior to settlement.
Marine borer	any one of a number of species bivalve mollusc capable of boring into timber severely weakening it's structure.
Rack	parallel rails of tarred hardwood 50mm x 25mm suspended at approximately 1m above zero low tide by posts driven into the bottom.
Rail	see rack.
Settlement	the act in which the larvae permanently cements itself to a surface.
Seed oysters	juvenile oysters to be on grown to a marketable size.

Single seed	oyster grown singularly and unattached to any substrate produced either by scraping young spat from settlement substrate or by hatchery techniques.
Spat	juvenile oyster.
Spatfall	the natural settlement of oysters from wild or cultivated parental stock.
Stick	a commercial hardwood oyster stick 1800mm x 25mm x 25mm.
Tarred stick	commercial oyster stick coated with coal or petroleum tar to protect it from marine borers.

REFERENCES

Andrews, J.D., 1979. Pelecypoda: Ostreidae. Eds. Giese, A.C. and J.S. Pearse. Reproduction of Marine Invertebrates. Vol. 5. Molluscs: Pelecypoda and Lesser Classes, N.Y: Academic Press.

Andrews, J.D., 1983. Transport of bivalve larvae in the James River, Virginia. *J. Shellfish Res.* 3: 29-40.

Anon., 1970. Port Stephens Pilot Model Progress Report. Public Works Department NSW. Manly Hydraulics Laboratory. Report No. 153.

Anon., 1979. Nelson Bay Erosion Study. Public Works Department NSW. Civil Engineering Division. Report No. 79003.

Anon, 1982. Water Resources Inventory. NSW Water Resources Resources Commission.

Anon, 1985. Mesh cylinders: Do they herald a revolution. *Aust. Oyster,* 4(3): 8-9.

Anon, 1986. The Port Stephens Oyster Industry. A survey by the Australian Oyster Farmers Producers Association, Port Stephens Branch.

Baker, P., 1992. Roles of physical cues in oyster larval settlement site choice. *J. Shellfish Res.* 11(1): p. 189 (summary only)

Barnes, H., 1955. Further observations on rugophilic behaviour in *Balanus balanoides. Vidensk. Meddr. dansk. natuhr. Foren.* 117: 341-348.

Bayne, B.L., 1976. The biology of mussel larvae. pp. 81-120. In: Marine mussels: their ecology and physiology. Ed. Bayne B.L. Cambridge University Press London.

Bonnot, P., 1937. Setting and survival of spat of the Olimpia oyster, *Ostrea lurida* on upper and lower horizontal surfaces. California Division of Fish and Game, 23(3): 224-228.

Brayley, R. 1982. Reproductive periodicity in the indigenous oyster *Saccostrea cucullata* in Sasa Bay, Apra Harbour, Guam. *Mar. Biol. (Berl.)* 69: 165-173.

Buroker, N.E., W.K. Hersberger, and K.K.Chew, 1979. Population genetics of family Ostreidae. 1. Intraspecific studies of *Crassostrea gigas* and *Saccostrea commercialis. Marine Biol.*, 54: 157-169

Butler, P.A., 1955. Selective settling of oyster larvae on artificial cultch. *Proc. Nat. Shellfish Assoc.* 45: 95-105

Carriker, M.R., 1951. Ecological observations on the distribution of oyster larvae in New Jersey estuaries. *Ecol. Monogr.* 21: 19-38.

Carriker, M.R., 1961. Interrelation of functional morphology behaviour, and autecology in early stages of the bivalve *Mercenaria mercenaria*. *J. Elisha Mitchell Sci. Soc.* 77: 168-241

Chanley, P. and J.D. Andrews, 1971. Aids for the dentification of bivalve larvae of Virginia. *Malacologia* 11(1): 45-119.

Chanley P and M. Chanley, 1980. Reproductive biology of *Arthritica crassiformis* and *A. bifurca*, two commensal bivalve molluscs (Leptonacea). *N.Z. J. Mar. Freshwater Res.* 14: 31-43.

Chew, K.K., 1991. Ecological and Biological Considerations for the Introduced Pacific Oyster to the West Coast of the United States. In: The Ecology of *Crassostrea gigas* in Australia, New Zealand, France and Washington State. Oyster Ecology Workshop. Annapolis, Maryland Seagrant College USA.

Cole, H.A. and E.W. Knight-Jones, 1939. Some observations and experiments on the setting behaviour of larvae of *Ostrea edulis*. *J. Cons.* 14(1): 86-105.

Connell, H.J., 1985. The Consequences of Variation in Initial Settlement vs. Post-settlement Mortality in Rocky Intertidal Communities. *J. Exp. Mar. Biol. Ecol.*, 93: 11-45.

Crisp, D.J., 1961. Territorial behaviour in barnacle settlement. *J. Exp. Biol.* 38: 429-446.

Crisp, D.J., 1976. Settlement responses in marine organisms. pp. 83-124. In: R.C. Newell ed. Adaptations to environment: essays on the physiology of marine animals. Butterworths, London.

Cranfield, H.J., 1968. An unexploited population of oysters, *Ostrea lutaria* (Hutton), from Foveaux Straight. Part I. Adult stocks and spatfall distribution. *New Zealand J. Mar. Freshwater Res.* 2: 3-22.

Croft, H.G., 1967. Stick cultivation of oysters in New South Wales. The Fisherman, Sydney. 2(11): 12-15.

Croft, H.G., 1968. Tray cultivation of oysters. The Fisherman, Sydney. 3(1): 12-14.

Cullinay, T.L., Boyle P.J. and Turner R.D., 1975. New approaches for studying bivalve larvae. In: Culture of Marine invertebrates. Ed. W.L. Smith and M.H. Chanley. Plenum Press. New York.

Curtin, L. 1970. An experiment to determine the suitability of concrete slab spat collectors for rock oyster cultivation on the hard limestone foreshore at Kaipara Harbour. New Zealand Marine Dept. Fisheries Tech. Rep. 51

Curtin, L. 1973. Rock oyster spat catching program 1971-72. New Zealand Ministry of Agriculture and Fisheries. Fisheries Tech. Rep. 110

Curtin, L. 1985. Oyster spatfall and developments NZ Shellfisheries Newsletter 29. p. 3

Dinamani, P., 1973. Embryonic and larval development in the N.Z. Rock oyster, *Crassostrea glomerata* (Gould, 1850). *The Verliger* 15(4): 295-299.

Dinamani, P. and P.A. Lenz, 1974. Some aspects of spatfall of the New Zealand rock oyster during 1994. *Verliger*, 20(1): 17-26.

Galstoff, P.S., 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64, pp. 440.

Gunn, C.R., 1984. A report on the development and use of artificial cultch suitable for off bottom oyster culture in British Columbia. Fisheries Development Report 33, Mar. Res Branch, pp. 25.

Haven, D.S. and L.W. Fritz, 1985. Setting of the American oyster *Crassostrea virginica* in the James River, Virginia, USA: temporal and spatial distribution. *Mar. Biol.* 86: 271-282.

Holliday, J.E., 1985(a). Current oyster spat research in NSW. *Aust. Fish.,* 44(3): 24-26.

Holliday, J.E., 1985(b). International Developments in Oyster Hatchery Technology. *Fish. Div. Misc. Bull.,* 1, Dept. of Agriculture, NSW, Sydney, pp. 101.

Holliday, J.E. and L.J. Goard, 1986. Survey of Sydney rock oyster larvae settlement at Port Stephens NSW. *Aust Fish.* 45(3): 27-28

Holliday, J.E., G.B. Maguire, and J.A. Nell, 1988. Alternative cultivation methods for the Sydney rock oyster *Saccostrea commercialis.* In: *Proc 1st Shellfish Aquaculture Conf.* pp. 234-265. Eds. L.H. Evans and D. O'Sullivan. Perth W.A: Curtin University of Technology.

Holliday, J.E., J.A. Nell, 1990. Pacific oysters in NSW. Agfact, F2.1.3, 2nd ed. NSW Agriculture and Fisheries, Sydney, NSW, pp. 4.

Holliday, J.E., G.L. Allen, J, Frances and L.P. Diver, 1993. Evaluation of commercially-used collectors for Sydney rock oysters, *Saccostrea commercialis* and Pacific oysters *Crassostrea gigas. Aquacult. Eng.,* 12: 63-79.

Hopkins, A.E., 1935. Attachment of larvae of the Olympia oyster *Ostrea lurida* to plane surfaces. *Ecology*, 16(1): 82-87.

Korringa, P., 1941. Experiments and observations on swarming, pelagic life and setting in the European flat oyster *Ostrea edulis. L. Arch. Neerland. Zool.* 5: 1-249.

Korringa, P., 1976. Farming the cupped oysters of the genus Crassostrea. Elsevier Scientific Publishing Company. New York.

Kennedy, V.S., 1986. Expected seasonal presence of *Crassostrea virginica* (Gmelin) larval populations, emphasising Chesapeake Bay. *American Mal. Bull.* Special Edition. 3: 25-30.

Kenny, P.D., W.K. Michener and D.M Allen, 1990. Spatial and temporal patterns of oyster settlement in a high salinity estuary. *J. Shellfish Res.*, 9(2): 329-339.

Knight-Jones, E.W., 1951. Aspects of the settling behaviour of larvae of *Ostrea edulis* on Essex oyster beds. Cons. perm. Inter. Explor. Mar. Proc-verb. Reun., 128(2): 30-34.

Kong, C.P. and L.A. Luh, 1976. Notes on the efficiency of various materials tested as spat collectors in Cowie bay, Sabah. *Malaysian Agric. J.*, 50(94): 462-479.

Malcolm, W.B., 1971. The Sydney rock oyster. *Aust. Nat. Hist.* 17(2): 46-50.

Mason, C.J. and J.A. Nell, 1991. Seasonal variation in meat and gonad condition of Sydney rock oysters *Saccostrea commercialis* and Pacific Oysters *Crassostrea gigas* in Port Stephens NSW. In: Pacific oysters in NSW. Final Report (FIRTA 86/66;DAN11Z) to Fisheries Research and Development Corporation, pp.246.

Medcof, J.C, 1955. Day and night characteristics of and of behaviour of oyster larvae. *J. Fish. Res. Brd. Can.*, 12(2): 270-286.

Michener, W.K. and P.D. Kenny, 1991. Spatial and temporal patterns of *Crassostrea virginica* (Gmelin) recruitment: relationship to scale and substratum. *J. Exp. Mar. Biol. Ecol.*, 154: 97-121.

M^cOrrie, S.R., 1984. The seasonal occurrence and settlement of the larvae of *Saccostrea commercialis* and other bivalves in Port Stephens NSW. Unpublished Hons. Thesis University of NSW.

McOrrie, S.R., 1995. The Salamander Bay Spatfall Regime. Prepared on Behalf of Port Stephens Shire Council. (In Preparation)

Miyazaki, I., 1938. On fouling organism in the oyster farm. *Bull. Jap. Soc. Sci. Fish.* 6(5): 223-232.

Nell, J.A., 1986 Pacific oyster research. Proceedings of 1986 Open Day 1986. Brackish Water Fish Culture Research Station, Division of Fisheries, NSW Agriculture and Fisheries. Salamander Bay NSW.

Nell, J.A. and J.E. Holliday, 1988. Effects of salinity on the growth and survival of the Sydney rock oyster *Saccostrea commercialis* and the Pacific oyster *Crassostrea commercialis* larvae and spat. *Aquaculture*, 68: 39-44.

Nell, J.A and Mason, C., 1991. Pacific oysters in New South Wales. In: Final Report (FIRTA 86/66;DAN11Z) to Fisheries Research and Development Corporation, pp. 246.

Nell, J.A., 1993. Farming the Sydney rock oyster *Saccostrea commercialis*) in Australia. *Rev. Fish. Sci.* 1(2): 97-120.

Nell, J.A. and I.R. Smith, 1988. Management, production and disease interactions in oyster culture. In: *Fish Diseases*. pp. 127-133. Ed. D.I. Bryden. Post Graduate Committee in Veterinary Science University of Sydney.

Nelson, T.C., 1927. Report of the department of biology. *Rept. Dept. Biol. N. J. Agric. Exp. Stn.* for 1926. pp. 103-113.

Nelson, T.C., 1955. Observations of the behaviour and distribution of oyster larvae. *Proc. Nat. Shellfish Assoc.* 45: 23-28.

Ogasawara, Y., 1972. Basic studies on methods of farming oysters *Crassostrea gigas* (Thunberg). On the spats collection. Proc. 2nd Int. Ocean Development Con. Tokyo.

Pritchard, D.W., 1953. Distribution of oyster larvae in relation to hydrographic conditions. *Proc. Gulf. Caribb. Fish. Inst.* 5: 123-132.

Prytherch, H.F., 1928. Investigation of the physical conditions controlling spawning of oysters and the occurrence, distribution and setting of oyster larvae in Milford Harbour, Connecticut. *Bull. U.S. Bur. Fish,* 44: 429-503.

Potter, M.A, 1984. Selection of areas for the commercial collection of spat of the Sydney rock oyster *Saccostrea commercialis,* in subtropical Moreton Bay, Australia. *Qld. J. Agric. Anim. Res.* 41(2): 125-134.

Quayle, D.B., 1969. Pacific oyster culture in British Columbia. *Bull. Fish. Res. Board Can.* 169: pp. 34.

Quayle, D.B., 1988. Pacific oyster culture in British Columbia. *Can. Bull. Fish. Aqat. Sci.* 218: 241 p.

Quayle, D.B. and G.F. Newkirk, 1989. Farming bivalve molluscs: Methods for study and development. Advances in World Aquaculture Vol 1. The World Aquaculture Soc. International Development Research Centre Canada Pub.

Reid, D.D., 1991. 1991 Pacific Oyster Survey. *Australian Oyster,* December 1991, 45-48.

Reid, D.D., 1990. 1990 Pacific Oyster Survey. Internal Report #49, Fisheries Research Institute, Cronulla, NSW pp. 23.

Ritchie, T.P. and R.W. Menzel, 1969. Influence of light on larval settlement of American oysters. *Proc. Natl. Shellfish Assoc.,* 59: 116-120.

Richardson, D.L., 1991. Some aspects of food and feeding in the Sydney rock oyster *Saccostrea commercialis* (Iredale & Roughley) in Port Stephens, NSW. University New England Northern Rivers, Lismore, NSW. Unpublished Hons. Thesis. pp. 117.

Rochford, D.J., 1951. Studies in Australian Estuarine Hydrology. I. Introductory and Comparative Features. *Aust. J. Mar. Freshwater Res.* 2(1): 1-117.

Roughly, T.C. 1933. The life history of the Australian oyster *Ostrea commercialis. Proc. Linn. Soc. NSW.* 58: 279-333.

Roy P.S., Thom B.G. and L.D. Wright, 1980. Holocene sequences on an embayed high energy coast: an evolutionary model. *Sedimentary Geo.* 26: 1-19.

Seliger, H.H., J.R. Boggs, R.B. Rivkin, W.H. Biggley and K.R.H. Aspden, 1982. The transport of oyster larvae in an estuary. *Mar. Biol.* 71: 57-72.

Shaw, W., 1967. Seasonal fouling and oyster setting on asbestos plates in Broad Creek, Talbot County, Maryland, 1963-65. *Chesapeake Sci.* 8(4): 228-236.

Smith, G.S. Southern Queensland oyster industry. *J. R. Hist. Soc. Queensl.,* 11(3): 45-58.

Sokal, R.R. and F.J. Rohlf, 1981. Biometry. Freeman, N.Y., pp. 859

Stephen, D., 1980. The reproductive biology of the Indian oyster *Crassostrea madrasensis. Aquaculture*, 21: 139-146.

Sumner, C.E., 1979. Catch efficiency of oyster cultch used in the River Tamar, Tasmania. *Tasmanian Fish. Res.* 22: 3-17.

Thomson, J.M., 1950. The effect of the orientation of cultch material on the setting of the Sydney rock oyster. *Aust. J. Mar. Freshwater Res.* 1(1): 3-17

Thomson, J.M., 1952. The acclimation and growth of the Pacific oyster *Gryphaea gigas* in Australia. *Aust. J. Mar. Freshwater Res.* 3(1): 64-73.

Thom, B.G., 1965. Late Quaternary coastal morphology of the Port Stephens - Myall lakes area, N.S.W. *J. Proc. R. Soc. N.S.W.* 98(1): 23-26.

Thorson, G., 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biol. Rev. Camb. Philos. Soc.* 25: 1-45

Tranter D.J. and P.E Smith, 1974. Filtration performance. In: Zooplankton sampling. pp. 57-76. Ed. D.J. Tranter. UNESCO Press.

Tritar, S., D. Prieur and R. Weiner, 1992. Effect of bacterial films on the settlement of the oysters, *Crassostrea gigas* (Thunberg,1793) and *Ostrea edulis* (Linnaeus, 1750) and the scallop *Pecten maximus* (Linnaeus, 1758). *J. Shellfish Res.* 11(2): 325-330.

Verdich, M., 1989. Proceedings of Open Day 1989. Brackish Water Fish Culture Research Station, Division of Fisheries, NSW Agriculture and Fisheries. Salamander Bay NSW.

Wethey, D.S., 1986. Ranking of settlement cues by barnacle larvae: influence of surface contour. *Bull. Mar. Sci.* 39(2): 393-400.

Wisely, B., J.E. Holliday and B.L. Reid, 1979. Experimental deepwater culture of the Sydney rock oyster *Crassostrea commercialis=Saccostrea cucullata*. 1. Growth of vertical clumps of oysters('Ren'). *Aquaculture.* 16: 127-140.

Wolf, P.H., (1973). Summary of daily temperature and salinity records for major oyster-bearing estuaries of New South Wales. 1966-1973. NSW State Fisheries Tech. Rep., pp. 108.

Wolf, P.H., and J.C. Medcof, 1973. Be on your guard against the Pacific oyster. The Fisherman, Sydney. 4(10): 3-5, 22-25