BASS STRAIT SCALLOP INVESTIGATIONS

INTERIM FINAL REPORT

PROJECT 1985/83

CSIRO MARINE LABORATORIES
DIVISION OF FISHERIES
HOBART

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A. INTRODUCTION

In 1985, CSIRO applied for funding from the Fishing Industry Research Trust Account to undertake a research program to investigate the commercial scallop (*Pecten fumatus*) in Bass Strait with the aim of providing resource assessments to guide and assist in the management of the scallop fishery. It was proposed that in the three year period from 1 August 1985 to 30 July 1988, the program would, (1) examine and analyse all biological and commercial data currently available for the fishery, and (2) initiate a research program to provide the biological data required for the efficient management of the fishery.

The research program had six objectives:

(i) To clarify the status of the commercial scallop of Bass Strait with regard to the number of species exploited, and the degree of reproductive isolation between scallops in the major regions within the fishery.

(ii) To develop methods to assess the standing stock available for annual allocation consistent with the rational exploitation of the resource.

(iii) To determine the cause of abnormally small meat weights in some populations.

(iv) To determine if the stock structure in a region results from single or multiple recruitment.

(v) To refine estimates of growth, mortality and reproduction for use in yield-per-recruit analyses.

(vi) To determine the factors controlling the observed distribution of scallop beds in Bass Strait.

The proposal was put forward as a collaborative research program with different aspects of the work to be undertaken by the Department of Genetics and Human Variation at La Trobe University, the Marine Science Laboratories, Queenscliff, and the CSIRO Division of Fisheries in Hobart. Co-operation was also to be sought from the Tasmanian Department of Sea Fisheries who were at the time conducting an investigation of the feasibility of reseeding scallop beds. The study by La Trobe University was to address objective (i), i.e. to determine the species and stock identity of the commercial scallop in Bass Strait (FIRTA 1985/50). Following the decision by

FIRTA not to fund this section of the program, alternative funding for the work was sought from the MST grants scheme. The latter agency supported the work and awarded a three year MST grant to Dr. N. Murray at La Trobe University. Because of the importance of this work to the overall study, CSIRO collaborated with Dr Murray's group whenever possible by providing specimens and data to assist with his group's research. Funding for this work ended in December 1988 and a summary of the preliminary findings of the study is included in this report.

While the original proposal recognized that there was a great deal of uncertainty about the fishing characteristics of the commercial dredge, work on this aspect was not included as a separate study but investigated in conjunction with those parts of the program dealing with the development of sampling gear and the estimation of mortality rates (objectives (ii) and (v) respectively). These studies highlighted the considerable loss to industry which resulted from the high level of non-yield mortality caused by the commercial scallop dredge, and led to the Tasmanian Department of Sea Fisheries applying to FIRC for funds to undertake an the evaluation of potentially less damaging dredging techniques. This proposal was funded by FIRC, and CSIRO co-operated with the Tasmanian Department of Sea Fisheries, making available both staff and underwater TV equipment as required.

The field component of the CSIRO studies is now complete, most of the data is analysed, and results and conclusions are in the process of being written up, either as articles for industry publications, or research papers for the scientific literature. The incomplete nature of some analyses, however, precludes the finalization of the study and preparation of a final report. The principal objectives have, however, all been addressed and conclusions relevant to management and future research needs are presented here in the form of an interim final report which will be followed by a more detailed final report when all analyses are complete and written up.

B. PRINCIPAL RECOMMENDATIONS FOR MANAGEMENT

Management philosophy in Australia has in the past been dominated by two assumptions which relate to the dynamics of scallop stocks. These assumptions are:

- The inherent variability and unpredictability of scallop recruitment and the lack of any demonstrable stock/recruitment relationship precludes the use of fisheries models that seek to define a sustainable yield.

- Fishing will not reduce the stock below a minimum level which is determined by the economics of fishing. This minimum stock level will provide sufficient breeding population to ensure recruitment and thus maintain the viability of the fishery.

Under these assumptions, the fishing rationale has been "one of taking whatever is there whenever it is there" and management controls have been imposed to meet social and economic objectives rather than to limit effort and protect breeding stock.

Fluctuations in recruitment and subsequent year class strength are characteristic of scallop populations in fisheries throughout the world, and the relationship between recruits and parent stock is, in all cases, poorly understood. Large interannual fluctuations in recruitment have been attributed to environmental factors, and the indirect effects of fishing, such as erosion of epifauna and substrata for settlement. It has been suggested that the destructive effects of the fishing gear on the bottom may be more important for recruitment than local stock size. Hydrological conditions have been implicated in decreased fecundity and recruitment failure in some species.

The large interannual fluctuations in production in the fisheries for *P. fumatus* in southern Australia relate to the progressive discovery and exploitation of new beds and not to erratic recruitment to existing grounds. This study has shown that the catching capacity of the fleets is so great that once a scallop bed is located, the act of fishing effectively destroys it. Scallops that are not caught may be killed by the incidental effects of dredging, and recruitment to the exhausted bed may not occur in the short (less than 3 years) or long term. The widespread recruitment failure of *P. fumatus* in Bass Strait observed during this study, and the failure of most scallop beds in southern Australia to show any significant recovery following fishing, both suggest that a minimum adult population density is required to ensure successful spawning and maintain high levels of recruitment. This minimum density is apparently higher than that set by the economics of fishing.

The results of the CSIRO studies presented here also suggest that it is unwise to assume recruitment is independent of stock size. The number of *P. fumatus* spat settling on collectors was correlated with the adult population density in the adjacent areas and, although larvae of *P. fumatus* are potentially capable of being advected large distances, modelling studies indicate that there may be little large-scale movement in Bass Strait. These studies suggest that under the appropriate conditions, tidal circulation patterns and wind-induced currents will tend to keep larvae close to the parental population.

The effects of low residual spawner density on recrutiment are compounded by current fishing practice which takes scallops before, or at, the age at which scallops complete their first significant spawning.The reliance of the Port Phillip Bay fishery on 1+ year group scallops has arisen as a consequence of the progressive elimination of older year classes under intensive fishing. In unfished populations, the potential longevity of *P. fumatus* is greater than 10 years and later year classes would be expected to make a substantial contribution to the total population fecundity. Management strategies for Port Phillip Bay and Bass Strait are aimed at maximizing yield by targeting ripe individuals just prior to spawning. Although *P. fumatus* spawns over several months, successful recruitment in any year appears to result from a relatively brief period of major spawning which occurs several months after the start of the fishing season. In any year this results in much of the potential spawning stock being removed before many scallops have begun to spawn.

Although our analyses are not yet completed, the general conclusions are unequivocal. Management strategies whose sole aim is to maximize yield and do not incorporate measures designed to ensure a minimum level of egg production and spawning, will inevitably result in "recruitment overfishing" and reduction in stock levels. Current fishing and management practices have failed to prevent the decimation of the *P. fumatus* fishery in southern Australian and a new approach which aims to conserve breeding stocks and increase the chances of successful recruitment is urgently required. Our principal recommendations for management are as follows.

1) The disastrous reduction in in *P. fumatus* stocks over the past few years shown both in catch statistics and surveys, makes it imperative that no fishing be permitted on any of the few remaining scallop beds in Bass Strait until stocks recover. Failure to protect existing beds may preclude the possibility of scallop stocks in Bass Strait showing any significant recovery. As we have no information on which to base an estimate of how long this recovery may take, or the pattern of such a recovery, high priority must be given to regular monitoring of the distribution and abundance of recruits, and the size and condition of the few remaining scallop beds in Bass Strait.

2) In the event that a substantial recovery of stocks does occur in Bass Strait, consideration should be given to establishing mechanisms whereby some grounds can be closed to fishing indefinitely to provide protected breeding populations. The selection of such grounds would depend on their location and their potential to act as sources from which larvae could be advected to establish new beds in other areas.

3) If the potential for recruitment failure is to be reduced, harvesting strategies that maximize yield per recruit while maintaining an appropriate level of egg production must replace those that seek only to maximize yield. In the absence of any information as to the nature of the egg production-recruit curve, arbitary levels which correspond to the egg production of scallops of known age will have to be used. As age-shell size relationships vary throughout Bass Strait, appropriate minimum size limits which correspond to the desired age will need to be set for different zones within the fishery. Indications are that only three, or possibly four, broad zones would be required. It is acknowledged that strategies involving different size limits in different zones of the fishery would be difficult to administer, but the alternative of applying a single minimum legal size would inevitably result in some slow growing populations not achieving the minimum size and thus never being available to the fishery.

4) Substantial immediate gains in egg production per recruit could be achieved under current management regimes by allowing populations to complete spawning each year before fishing begins. This could be achieved by restricting fishing to the summer months (November - February) and shifting from a "roe-on' to a"roe-off" fishery. The potential loss in catch (up to 20%) resulting from this change would likely be offset by a reduction in losses due to natural mortality that would occur if fishing was delayed a full year. The major disadvantage of this approach is that fishing activity would be concentrated during the period when spat settlement is at its peak and the disruptive effects of dredging could be expected to have a severe impact on recruitment success.

5) Restrictions on fishing for specified year classes may be implemented by regional closures only when populations consist of a single, dominant year class. Mixed aged populations frequently occur, and if these are to be exploited in such a way that underaged animals are neither caught nor damaged, new harvesting methods will need to be developed. The dredge currently in use in the fishery is inefficient, has a broad selectivity ogive, and damages much of the resource.

C. FUTURE RESEARCH PRIORITIES

Although the present research program has added much to our undertanding of the biology of *P. fumatus* and the scallop fishery in Bass Strait, because the goals of the study were limited, it has gone only part of the way towards providing all the information required to rationally manage the resource. With respect to the management recommedations outlined in section **D** above, three areas stand out were further research is urgently needed. These are:

- the factors influencing recruitment,
- spatial variation in fecundity and natural mortality,
- fishing gear and fishing practice.

Recruitment failure in Bass Strait has been clearly demonstrated, but the factors that control recruitment are still not fully understood. While there is evidence that the population size and effective fecundity of spawners is important, other factors such as water turbulence, availability of spat settlement surfaces, and post settlement mortality may play a large part in determining recruitment success. The destructive nature of current fishing techniques on fished populations has now been well documented but it is not known if dredging also changes the characteristics of the surface sediments and/or epibiota to make fished beds unsuitable for subsequent spat settlement.

If recruitment overfishing and low stock levels are not to be a persistent feature of the Bass Strait scallop fishery, the only option for management in the short term is to substantially increase egg production per recruit. Assuming stock levels do improve, long-term management strategies must involve a balance between yield and egg production that ensures a continued high level of recruitment. Such an approach requires detailed knowledge of age-specific fecundity and mortality schedules and these are not currently available.

Increasing egg production per recruit must in result in some corresponding decrease in yield per recruit due to the effects of natural mortality acting over a longer time period. Such losses in harvestable biomass may be offset by improved fishing techniques which take target age classes more efficiently and have little impact on younger age classes.

In summary, the principal research needs relating to the management of the fishery for *P. fumatus* in Bass Strait are as follows:-

1) Continued monitoring of scallop recruitment in Bass Strait to determine the extent to which recruitment patterns are related to the distribution and size of residual adult stocks.

Monitoring the distribution of new recruits and residual adult stocks and modeling the effects of real-time wind-induced currents on larval distribution will yield valuable insights into the stock-recruitment relationships and patterns of recruitment of scallops in the Bass Strait region. Using the sampling gear developed by CSIRO, juvenile scallops can be detected 12 – 18 months before they enter the fishery. This gives management agencies time to implement controls that will ensure the protection of breeding stock, and provide industry with an early indication of stock levels.

2) *The relative influences of passive water transport and active substrate selection on the water-column distribution and settlement of scallop larvae.*

The CSIRO study found that in addition to controls on the production and survival of larvae to metamorphosis, there are additional factors which influence the settlement of larvae on the sea bed and their subsequent survival as juveniles. These may include limits imposed on settlement by small scale hydrodynamic processes or the absence of suitable settlement substrata. The vertical distribution of larvae approaching metamorphosis and the hydrodynamic environment to which they are subjected, may be crucial components in the successful settlement of invertebrate larvae. Spat abundance in collectors was found to be consistently higher in collectors placed in the bottom third of the water column. It is not known if this distribution reflects the relative abundance of larvae at different heights in the water column, or is an artefact resulting from higher water flow through the collectors in the mid-water region. There is little information available on the behaviour of scallop larvae in the wild and it is not known if *P. fumatus* larvae can regulate their position in the water column.

There is an extensive literature based on small-scale laboratory experiments in still water that attests to the ability of invertebrate larvae to actively select suitable substrates on which to settle. Under natural conditions, however, even average current velocities may cause turbulent mixing which will prevent larvae reaching the sea bed or result in transport rates over the bottom that may inhibit active searching behaviour by pediveligers. This suggests that the formation of a scallop bed may be the result of local conditions that in some way alter current flow allowing larvae to be passively deposited onto the sea bed. Under this scenario, active habitat selection would play a secondary role in the settlement process, perhaps operating at a scale of millimetres or centimetres. Support for this hypothesis comes from the distribution of scallop beds in Bass Strait, many of which have been associated with topographic features, such as headlands or islands, that may modify or inhibit current flow.

3) The impact of predation on the survival of scallops through early-post-settlement life.

The success of any settlement event may be dramatically modified by the level of early post-settlement mortality. Field studies to determine mechanisms controlling benthic community structure seldom attempt to distinguish between differential larval settlement and differential post-settlement mortality, although the distinction may be vital to the success of stock enhancement programs. Preliminary results from the joint DSF/OFCF program in Great Oyster Bay indicate that predation is a major source of mortality of reseeded juvenile scallops.The predators involved should be identified and their relative predation rates on recently settled scallops assessed. This information is an essential prerequisite to the introduction of predator control in mariculture and reseeding programs.

4) The determination of age specific fecundity and mortality schedules for different zones within the fishery.

The CSIRO study found differences in growth rate and condition between populations that were consistent with regional differences in primary productivity. This suggests that to maximize yield from the fishery, management strategies must be tailored to take account of regional differences in population productivity and natural mortality. The institution of optimum harvesting strategies that combine both egg production and yield per recruit requires a detailed knowledge of age specific mortality and fecundity schedules for each potential management zone within the fishery. With the current low level of scallop stocks in most areas of Bass Strait, studies to obtain this information cannot at present be undertaken. This research must, however, be given a high priority as soon as stock levels show signs of increasing.

5) The development of new fishing gear.

Although some work on alternative fishing techniques has recently been carried out by the Tasmanian Department of Sea Fisheries, there is still need for rigorous investigation of the catching characteristics of any new fishing gear before it is introduced into the Bass Strait scallop fishery. Such a study must include the determination of selectivity ogives and the level of age-specific, non-yield fishing mortality that results from the use of the new gear.

D. THE FISHERY, BIOLOGY, AND MANAGEMENT OF THE COMMERCIAL SCALLOP, *PECTEN FUMATUS*: A REVIEW OF EXISTING INFORMATION.

1. INTRODUCTION

The scallop species of major commercial importance in Australian coastal waters belong to three genera: *Pecten*, *Chlamys* and *Amusium*. Like the fisheries for *Pecten maximus* and *Pecten jacobeus* in Europe, *Pecten* fisheries in the southern hemisphere are largely confined to temperate waters. In Australia, these fisheries are now largely limited to Tasmanian and Victorian waters but in the past, commercial quantities of *Pecten* species have been taken in New South Wales, South Australia and Western Australia (see figs 1a and 1b for all localities mentioned in the text). *Pecten* fisheries have historically been by far the most important scallop fisheries in Australian waters and, at their peak in 1981-82, collectively produced over 4000 tonnes of scallop meat.[(a)] In all areas *Pecten* spp. are caught by dredging, landed in the shell, split manually and sold "roe-on" for local consumption and to European markets.

Despite the importance of the *Pecten* genus to the scallop industry, its taxonomy has been confused. The literature describes four species of *Pecten* that have variously contributed to commercial catches in southern Australia: *Pecten fumatus* Reeve, 1852, originally described from Sydney, New South Wales; *Pecten alba* Tate, 1886, described from Western Port Bay, Port Phillip Bay and Bass Strait in Victoria; *Pecten meridionalis* Tate, 1886, described from southern Tasmania; and *Pecten modestus* Reeve, 1852, described from Western Australia. Current opinion suggests that the first three of these are clinal variants of a single species, *Pecten fumatus*, known throughout the region as the commercial scallop.[1]

(a) Commercial catch figures are available for all *Pecten* fisheries in Australia from 1929 onwards and, despite the varying way in which the data was recorded (e.g. thousands of scallops, total weight, flesh weight), sufficient information is included in contemporary documents to permit all data to be converted to flesh weight.

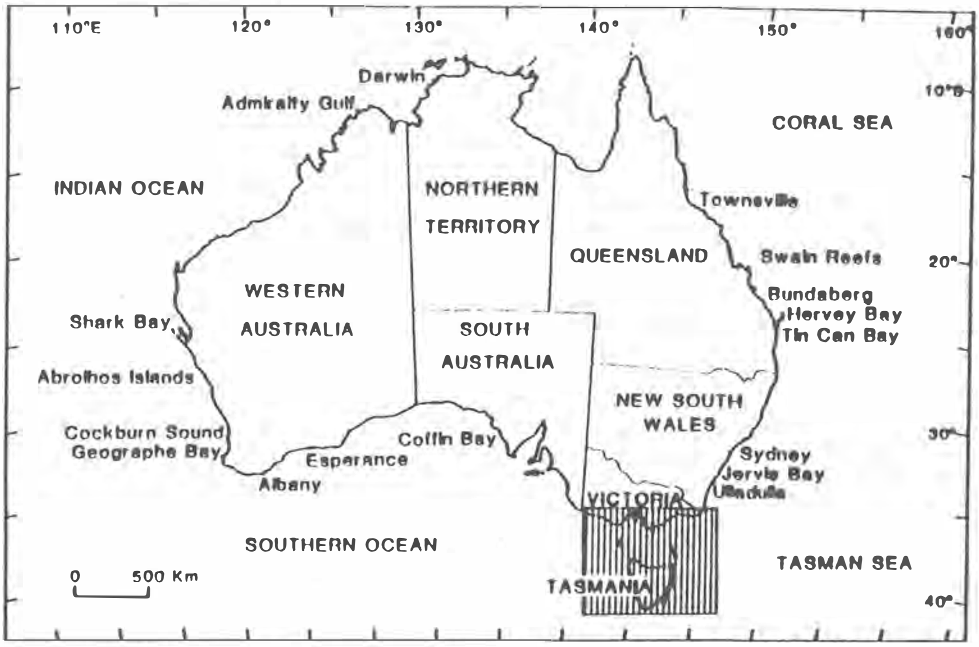

Fig. 1(a) Locality map, Australia.

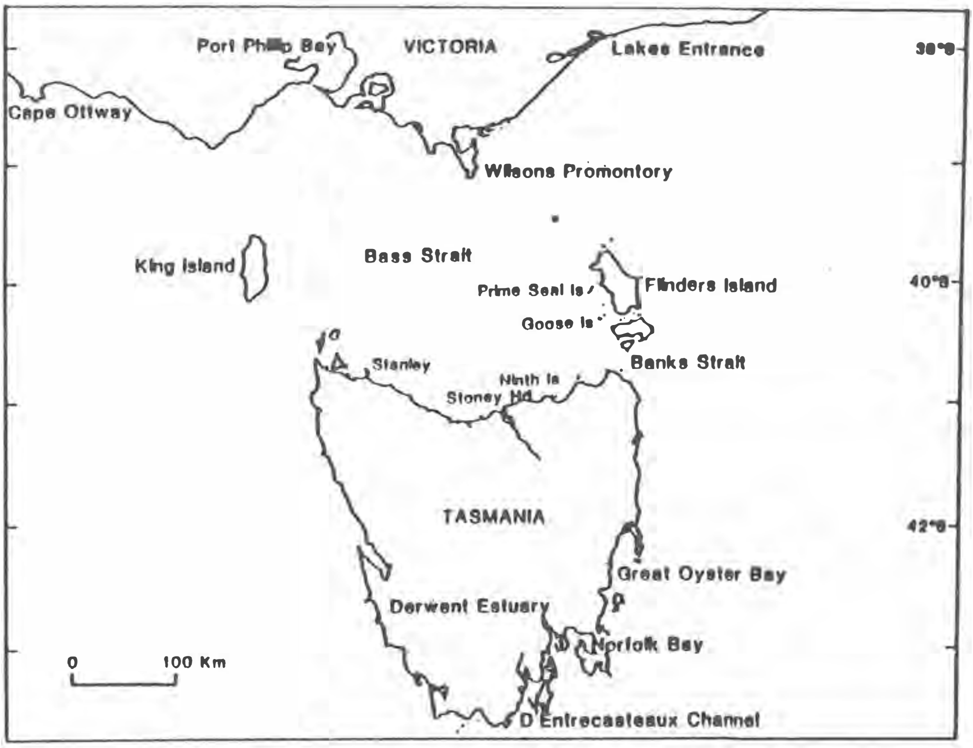

Fig. 1(b) Locality map, southeastern Australia.

2. HISTORY AND DEVELOPMENT OF THE FISHERY

The fishery for *P. fumatus* began in Australia about the turn of the century with the exploitation of beds in the upper parts of the Derwent estuary in southern Tasmania.[2] By 1920, fishing in the upper Derwent had almost ceased and the focus of scalloping moved further south to the D'Entrecasteaux Channel, where it remained during the 1930s. The catches were a mix of of *P. fumatus* and *Chlamys asperrimus*.[2] By 1940 annual landings amounted to between 150 and 200 tonnes flesh weight (fig. 2) and the catch consisted almost entirely of *P. fumatus*. Annual catches rose steadily until 1947, but a subsequent drop in landings was only halted in 1953 when fishing began in Great Oyster Bay on the Tasmanian east coast.[3] In 1955 catches were augmented by the discovery of substantial new beds in Norfolk Bay, east of the Derwent estuary. In 1956 these beds contributed 369 tonnes to the then record catch of 534 tonnes flesh weight.[4] By 1960 however, the Norfolk Bay beds had been completely exhausted; they have never again contributed significantly to Tasmanian catches.

In 1964 new beds were discovered off the Tasmanian east coast,[1] but these added little to the total Tasmanian catch, which continued to decline. By 1967 the D'Entrecasteaux Channel beds, for so long the mainstay of the Australian scallop fishery, had been depleted and were closed. In 1970 no scallop landings were reported from Tasmanian grounds.[1]

In 1963, Tasmanian scallopers began fishing previously unexploited stocks of *P. fumatus* in Port Phillip Bay in Victoria; this fishery subsequently proved to be one of Australia's few enduring scallop fisheries. Over the next three years landings increased dramatically and in 1966 most of the total Australian catch of 2008 tonnes came from the Port Phillip Bay beds.[1] Following what by now had become a familiar pattern with Australian scallop fisheries, the Port Phillip Bay fishery crashed and in 1969 produced only 286 tonnes of meat. Although catches from here subsequently improved, this decline stimulated exploration for new resources and in 1970 new beds were located off Lakes Entrance in eastern Victoria. In their first year these grounds produced 641 tonnes of flesh, reviving the scallop industry in that state.[5]

Scallop fishing in southern Australia expanded in the 1970s when *P. fumatus* was found in commercial quantities and exploited in two more states. As though inevitable, the history of each fishery was identical: rapid expansion followed by equally rapid collapse. In South Australia, the Coffin Bay fishery produced 22 tonnes in 1972, 105 tonnes in 1973, 20 tonnes in 1974 and nothing since.[6] The Jervis Bay fishery in southern New South Wales produced 184 tonnes in 1971, declined over the next three years, and ceased by 1975.[7] In 1978 scallops were again found in Jervis Bay. Landings peaked at 367 tonnes in 1981; by 1983 the beds were exhausted and there has been no commercial fishing in the area since.[8]

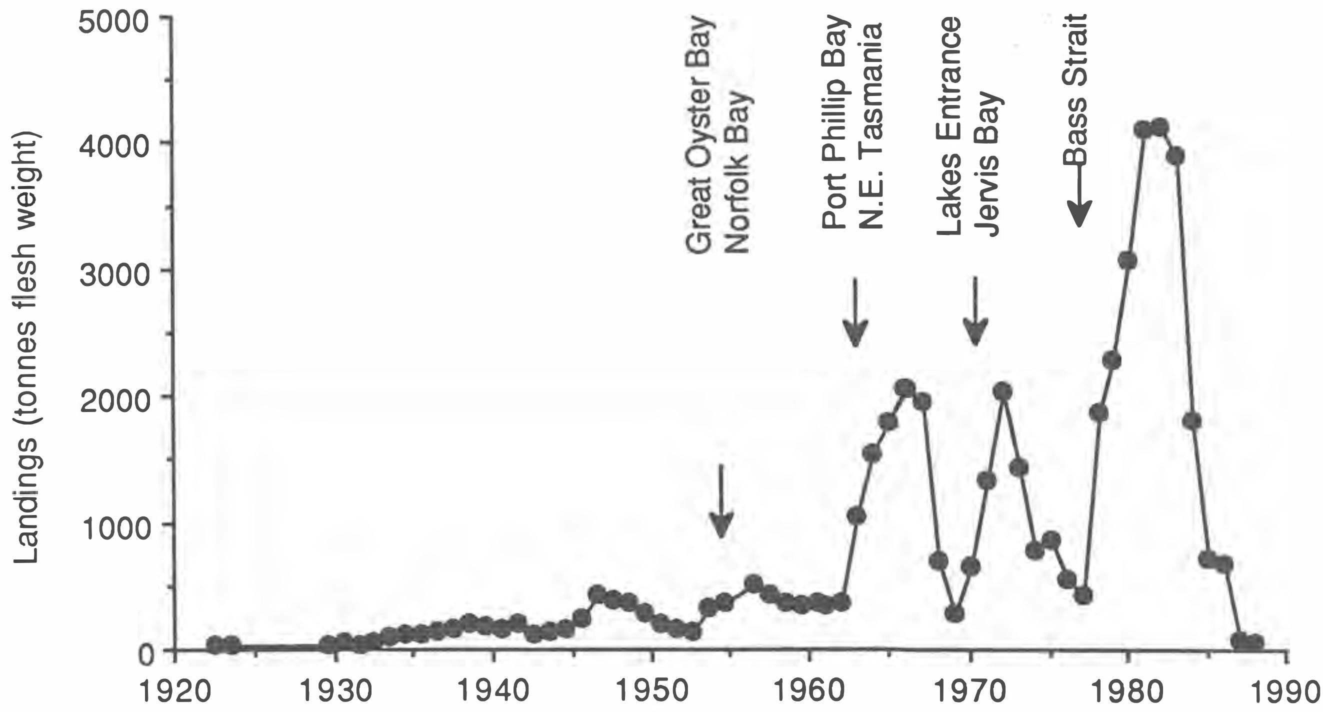

Fig. 2. Combined annual landings of *Pecten fumatus* (1922-88) and *Chlamys* spp. (1922-67) from southern Australia. Arrows indicate the commencement of the various contributing fisheries.

For the short time that all these fisheries operated they boosted the Australian scallop production to 2036 tonnes in 1972. Government sponsored research surveys between 1971 and 1973 located promising new beds in Bass Strait along the north coast of Tasmania.[9,10] These beds were first exploited in 1973, a year that also saw a resurgence of fishing activity in Port Phillip Bay.

The discovery of major new grounds off the Furneaux Group in eastern Bass Strait in the late 1970s sparked off a period of rapid expansion and unprecedented optimism in the scallop industry. The new grounds were exploited by boats from both Victoria and Tasmania and the high catch rates attracted large investments in the industry. Fishing effort in the region increased dramatically with landings from Bass Strait in 1982-83 at a record high of 4136 tonnes. By 1985 the main beds were depleted and the decline in landings that followed was as dramatic as the rise that preceded it. The last major bed in Bass Strait was fished out during the 1986 season, leaving the industry with few prospects for the remainder of the decade and a legacy of excess fishing capacity that will ensure the rapid depletion of any new beds that may be found in the future.

3. BIOLOGY

(i) Distribution and behaviour

Pecten fumatus occurs in the coastal waters of southern Australia from the central New South Wales coast in the east, around Tasmania, and westward beyond the border between South Australia and Western Australia (fig. 1). The western limits of its distribution are presently unclear. Within this range it occurs in enclosed embayments (e.g. Jervis Bay, Port Phillip Bay) and exposed oceanic situations (e.g. Banks Strait). It is found in depths ranging from 7-60 m on bottoms varying from muddy sand to coarse sand.

P. fumatus is usually found buried in the bottom sediment with only the flat, right valve visible. The exposed upper valve is often covered with a layer of sediment and may also accumulate a variety of epibiota. Individuals often occupy saucer-shaped depressions on the bottom. Scallops are frequently aggregated into beds, the orientation of which is influenced by the strength and direction of tidal flow. In areas where tides are strong, beds in exposed situations have their long axis parallel to the direction of flow; in sheltered bays, scallops are distributed along bottom contours. In areas where tides are weak, scallops tend to be distributed more evenly.[11]

P. fumatus can swim and individuals have been observed to rise up to 1.7 m off the bottom and cover horizontal distances of up to 4 m. The ocelli around the mantle are light sensitive and scallops react to the approach of divers and dredges. On the basis of visual assessment of the texture and colour of adductor muscles, it has been suggested that active swimmers have adductor muscles in "good condition" and that scallops in "poor condition" are the first to be caught by dredges.[11] There is, however, no empirical evidence to support this suggestion.

(ii) Reproduction and larval life.

P. fumatus is a functional hermaphrodite, individuals maturing as both male and female in their second year of life. Macroscopic and histological examination of gonads indicates that spawning activity occurs from August to October in southern Tasmania[12] and from June to November in Port Phillip Bay.[13,14] Peak activity in both locations occurs in spring. Further north in Jervis Bay, spawning peaks were observed in late winter to early spring, early summer and late autumn.[15] Similar variability in the timing of spawning has also been reported for *Pecten maximus* in Europe[16,17] and *Pecten novaezealandae* in New Zealand.[18] In the case of *P. maximus*, transplant experiments have shown that variations between populations in the timing of spawning are the result of unspecified local environmental conditions.[19] Under laboratory conditions, gonadial development and spawning can be induced in both *P. maximus* and *P. fumatus* at any time of the year by controlling food supply and water temperature.[20,21] If this also applies in nature, then the observed geographical differences in the spawning season of *P. fumatus* probably reflect environmental influences rather than different endogenous rhythms of separate breeding subpopulations.

The larval development of *P. fumatus* has been studied in the laboratory where, at temperatures between 13 and 15°C, fertilised eggs become trochophores after 2 days and secrete the prodissochonch shell to become straight hinged veligers after 3 days. Umbones and larval shell are secreted when larvae are about 220 μm and metamorphosis occurs around 31 days after fertilisation.[22] Recent studies indicate that the time taken to reach metamorphosis can be reduced to 16 days at 20°C.[20] In the wild, recently-settled spat have been observed attached by a byssus to an unidentified species of filamentous algae and also to detached, partly-buried fronds of seagrass.[22]

As *P. fumatus* spat settle readily on monofilament netting in collectors,[24] the timing and duration of settlement have been examined by deploying spat collectors in south-east Australia. On the east coast of Tasmania, the period of peak settlement occurs in in September (early spring) with a minor settlement in late spring and early summer.[24,25] Settlement in collectors was observed between October and December in Port Phillip Bay,[23] in spring and summer in eastern Bass Strait,[26] and in early winter and late spring in Jervis Bay.[15] These observations are in general agreement with the geographical differences in the timing and duration of spawning referred to above.

While settlement may occur over an extended period, consistent with the duration of spawning, there is some evidence to suggest that major settlement peaks result from gametes shed over a more limited period. The peak settlement period in Port Phillip Bay is in December and may result from the major spawning period later in the season, rather than the earlier partial spawnings.[14] Similar observations have been made on the settlement of spat from spring and autumn spawnings of *Pecten maximus* off the British Isles. In populations off the Isle of Man, 90% of the adults where thought to be the result of a major autumn spawning;[27] however the spring spawning off Ireland and Holyhead was said to produce most spat.[28,29] These observations suggest that successful spatfall relates to both spawning intensity and subsequent hydrological conditions and not only to the number of gametes shed.

The abundance of spat settling in collectors varies with depth. In collectors set in 16 m and 31 m of water off eastern Tasmania, spat settlement was highest in midwater.[24,25] A similar result was reported from collectors set in 13 m of water in Port Phillip Bay.[23] In the Irish Sea, *P. maximus* spat were also most abundant in midwater collectors.[30] No attempt has been made to correlate the vertical abundance with larval behaviour or water column structure.

The extent to which the abundance of spat in collectors reflects the numbers settling on the bottom is a problem that has rarely been addressed for any pectinid species and what little information is available on this relationship is equivocal. Observations over a four-year period in Port Phillip Bay have shown a consistent positive relationship between the abundance of *P. fumatus* spat in collectors and subsequent year class strength of juveniles.[31]

(iii) Growth.

The post-settlement growth of *P. fumatus* during its first year of life has been well studied. Growth of spat held in collector bags off eastern Tasmania averaged 1.5 mm week^{-1}. Highest growth rates occurred in late spring and in the bags closest to the water surface.[25] Spat held in lantern cages off eastern Tasmania[24] and in Port Phillip Bay[23] attained shell heights of around 60 mm after their first year of post-settlement growth. This growth rate was similar to that observed for tagged spat placed on the sea bed in Port Phillip Bay and also to that estimated from size frequency distributions obtained by regular sampling of wild populations at the same location.[23] Similar growth rates have been reported for juveniles of *Pecten maximus* resulting from the spring spawning at Holyhead.[29]

Although *P. fumatus* in southern Tasmania is reported to live for up to 14 years,[2] its growth is highly variable. Two-year old scallops in Port Phillip Bay attain shell heights of between 71 and 87 mm.[23] The same species in Jervis Bay was shown from tagging experiments to reach 70 mm shell height after two years and 77 mm by the end of the third year.[32] Even greater variability has been reported for populations in relatively limited geographic areas in Bass Strait.[33] Ageing studies using shell growth rings confirm the variable nature of shell growth. Scallops of 78 mm shell height were shown to vary from 2.5 to 6 years old, depending upon the region from which they were collected.[2] Similar variability in age/shell height relationships between local populations has been reported in other *Pecten* species. In *P. maximus*, for example, variability in growth has been attributed to differences in temperature and food abundance.[34]

Growth of *P. fumatus* in Port Phillip Bay was examined in two tagging experiments conducted 20 years apart. Estimates of the von Bertalanffy growth parameters from the earlier experiments, carried out between 1964 and 1967, were 0.59 year $^{-1}$ for K and 92.5 mm for L_∞. Estimates for the same parameters from tagging experiments between 1983 and 1985 and after 20 years of fishing, were 1.57 year $^{-1}$ for K and 85.9 mm for L_∞. The Port Phillip Bay population during the early years of the fishery in the 1960s contained up to seven year-classes, while samples taken since 1983 contain mainly newly recruited 1+ year old scallops, with few older than two years. To test if the observed changes in growth and asymptotic size where due to bias in the age structure of scallops used in the two experiments, growth parameters were also estimated using only scallops less than one year old and, therefore, directly comparable. The estimates obtained confirm that growth rates in Port Phillip Bay have increased substantially over the 20 year period.[35] While some reduction in the number of older age-classes would be expected as a result of fishing, these results show that *P. fumatus* in Port Phillip Bay is now growing faster but reaching a smaller maximum size than it did when the fishery started in 1964. The authors suggested that heavy dredging over the 20 year period coupled with increased nutrient levels in Port Phillip Bay may have relaxed density-dependent restraints on growth.[35]

(iv) Disease, commensalism and parasitism.

There are a number of records of parasites infecting *P. fumatus*. Parasitic castration by cercariae of a bucephalid trematode was described in Port Phillip Bay.[36] Similar infections were found in scallops off Wilson's Promontory and Lakes Entrance in northern Bass Strait.[37] A subsequent, more detailed, examination showed that the condition was due to sporocysts of an unidentified species of *Bucephalus*. The infected gonad becomes a uniform red colour as gonadial tissue is replaced by developing cercariae in the sporocysts. Infection rates of *P. fumatus* were as high as 36% in Port Phillip Bay,[38] and up to 8% in Jervis Bay.[32] Between 1 and 6% of *P. modestus* in samples from Cockburn Sound were also infected.[39] The high incidence of infection reported in Port Phillip Bay indicates that this parasite has the potential to significantly reduce population fecundity. Despite this, no attempts have been made to identify the parasite to the species level or to determine the final host and mode of infection. Bucephalid larvae have not been described from other species of *Pecten* and this genus has not been reported from scallops outside Australia.

Larval nematodes of the genus *Echinocephalus* are reported to cause a conspicuous lesion on the adductor muscle of *P. fumatus* in Port Phillip Bay. The average infection rate reported was 7.2%, although at some sites over 50% of scallops were infected. The pathological nature of the lesion was not described but parasite abundance was positively correlated with scallop abundance and shell size.[40] Again no attempt was made to identify the parasite to species level or to determine the final and intermediate hosts. Larvae of this genus had previously been identified in *Argopecten aequisulcatus* from Baja California. Adults have been found in the alimentary tract of elasmobranchs. and the final host was thought to be an unidentified species of that group.[41]

(v) Predation and natural mortality.

Causes of natural mortality are poorly documented for *P. fumatus*. In Jervis Bay, a " commensal polychaete worm " was reported to cause the death of scallops if it covered more than 40% of the area of the left shell valve.[32] The mudworm *Polydora websteri* was considered to be a significant cause of mortality of *P. fumatus* held in lantern cages in Tasmania.[24] This same species attacks the shell of *Placopecten magellanicus,* reducing the strength of the shell and thereby making individuals more susceptible to crushing by predatory decapods.[42] Molluscan predators of *P. fumatus* include the whelk *Fasciolaria australasia* in Tasmanian waters,[11] and octopus in Jervis Bay.[32] Another whelk, *Bedeva hanleyi,* has been reported to feed on *P. modestus* in Cockburn Sound.[43]

Asteriid starfish in Australian waters, as elsewhere, are major predators of scallops. The sea star *Coscinasterias calamaria* has been cited as a significant predator of *P. fumatus* in southern Tasmanian. Predation by *C. calamaria* over a four year period is reported to have caused the deaths of between 75 and 80% of the scallops on one bed in the D'Entrecasteaux Channel.[11] In Port Phillip Bay the distribution of this starfish has been correlated with a high incidence of intact, empty scallop shells.[44] Although *C. calamaria* is undoubtedly a significant predator on *P. fumatus*, much of the evidence for this is anecdotal. The extent to which *C. calamaria* and other species prey on either juvenile or adult *P. fumatus* is still unknown, and their contribution to scallop mortality has never been investigated.

Estimates of natural mortality rates are only available for *P. fumatus* in Port Phillip Bay. The instantaneous natural mortality rate estimated from tagging experiments was 0.52 $year^{-1}$, which is equivalent to a mortality of 41% per year.[35] This is within the range of independently-derived estimates of natural mortality obtained from successive surveys of scallop abundance. These ranged from 38% to 50% per year between 1982 and 1984.[45] These rates are much higher than, for example, those estimated for an unfished population of *Pecten maximus*, where mortality rates increased with age from 0.16 $year^{-1}$ at age 7 to 0.48 $year^{-1}$ at age 16.[46] However, they do lie within the estimates of the mean natural mortality rate of *P. maximus* on fished grounds of between 10 and 50% per year.[47] The high natural mortality rates in Port Phillip Bay and observations of dredge-induced damage associated with exploited beds elsewhere,[48,49] suggest that there is a significant incidental mortality associated with dredging as it is currently practiced. Estimates of natural mortality rates on unfished grounds are required in order to assess the magnitude of this component.

4. FISHING GEAR AND METHODS

The fishing gear and methods used to take scallops in Australian waters have developed along two distinct lines. In southern waters, *Pecten* and *Chlamys* species are caught with dredges while in northern waters, *Amusium* species are fished with trawl nets. This dichotomy is largely a reflection of differences in the behaviour and distribution patterns of the main target species. *P. fumatus* is relatively sedentary, usually lying partly buried in the bottom sediment and often occurring in relatively small, discrete, high-density beds.[11] In contrast, *A. balloti* is an active swimmer,[50] that lies exposed on the sea floor and usually occurs in large aggregations separated by areas of low or zero density.[51]

At the turn of the century when the *Pecten* and *Chlamys* fishery started in the upper Derwent estuary in Tasmania, scallops were caught with small dredges towed by rowing boats. By 1943 all boats in the fishery were engine-powered, had powered winches and could deploy up to three dredges. Because weather conditions largely determined the areas that could be fished, the boats increased steadily in size, and by 1949 vessels up to 15.2 m long capable of towing up to six dredges, were operating in the fishery.[2] In that year, regulations were introduced to limit the number of dredges to two and their size to a mouth opening of not more than 1.2 m wide and 0.3 m high. These traditional "Lip" dredges consisted of a wire mesh bag suspended from a mouth frame with a metal blade along its lower margin (fig. 3).

As the fishery expanded into new areas in southern Tasmania, dredges capable of operating over a wider range of bottom types and at greater depths were developed. These developments included the addition of runners beneath the bag, as in the "Dicker" or "Oldham" dredge, and a tooth bar and depressor plate in the modified "Baird" dredge,[52] known locally as the "Sputnik" (fig. 3). The "Sputnik" dredge, first used in Tasmania in 1957, was reported to be 50% more efficient than other types under some conditions.[53] It was subsequently banned from the D'Entrecasteaux Channel because fishermen feared it was damaging scallops and destroying the beds, but it remained in use on the Tasmanian east coast grounds. Since 1961 the "Digby" or "Lip" dredge has been the only type of dredge permitted in the D'Entrecasteaux Channel. No restriction has been placed on boat size in this fishery but dredge width is limited to 1.3 m.[54]

When Tasmanian fishermen began scalloping in Victoria in 1963, they used their traditional fishing gear and methods.[55] The "Sputnik" dredge was the first dredge used in the fledgling Port Phillip Bay fishery. It was quickly modified to meet the new conditions encountered in Port Phillip Bay and evolved into what is known as the "mud" or "box" dredge (fig. 3). With no limits placed on dredge size or construction, heavy dredges up to 4.9 m wide and boats with mechanical tippers were soon operating in Victorian waters.[56] Mud dredges and self-tipping cradles are now used in all *Pecten* fisheries in south-eastern Australia. Present regulations limit the maximum dredge width to 3.36 m. A mud dredge of this size weighs around 270 kg.[56]

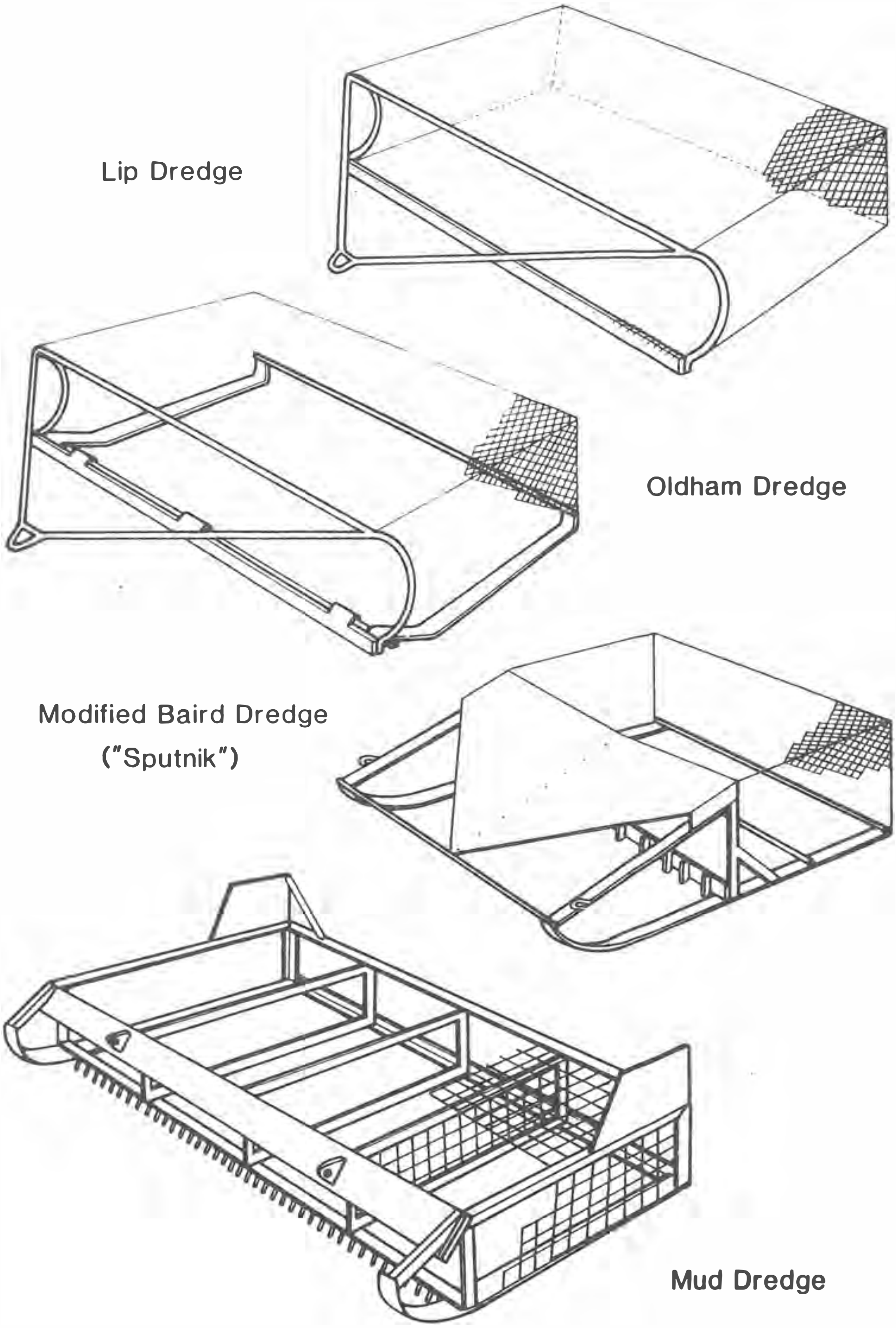

Fig. 3. Dredges used during the development of the Australian *Pecten* fishery.

Irrespective of the type of dredge employed, the methods used to fish *Pecten* spp. in Australia waters have changed little since the beginnings of the fishery. When scallops are found in commercial quantities, a "strip" or "drag" is set up and marked at each end by dahn buoys. The length of the drag depends on the density of scallops and the amount of bottom debris, but is usually between 0.5 and 1.0 km long. With towing speeds of around 3 knots this distance is covered in 5 to 10 mins. It is frequently stated by fishermen that, when first established, a drag may need to be worked for an hour or more, depending on the number of boats involved, before it will yield good catches.[2,11,57] This assertion has never been scientifically investigated, and if true, the need to "work up" a new scallop drag suggests that the catching efficiency of a dredge changes with time, possibly due to changes in the behaviour of the scallops,[11] or smoothing of the bottom by repetitive dredging.[57]

Although a knowledge of the catching efficiency of fishing gear is fundamental to stock assessment, few attempts have been made to rigorously assess the fishing characteristics of any dredge used in the southern scallop fishery. A superficial study of the catching efficiency of a 1.2 m "Sputnik" dredge was carried out in Port Phillip Bay. This showed that in some areas a haul of 1 min duration caught 47% of all scallops estimated by divers to be in the path of the dredge, but surprisingly, only 6% were caught when the length of tow was extended to 8 minutes. Similar differences occurred between different areas sampled by the same length of tow. It was concluded that this was due to overfilling of the dredge with scallops when scallop density was high, or with debris from variable epibenthos cover when it was low.[58]

Trials carried out in Jervis Bay found that a 2.4 m mud dredge was 3.54 times more efficient than a 1.1 m "Sputnik" dredge. However, the report of these trials does not give comparative catch rates, and no statistical tests were carried out. The same study concluded that a towing speed of 3 knots was necessary for the efficient operation of the mud dredge.[59] Similar trials in Geographe Bay indicated that highest catches of *P. modestus* were obtained with a dredge towed at between 1.7 and 2.1 knots.[60] Whether this represent different catchabilities for the two species, or simply reflects differences in the substrate characteristics of the two beds, is not known.

In recent years, annual scallop catchability estimates for Port Phillip Bay have used dredge efficiencies ranging from 37% to 55.8%. These were derived from the difference between population sizes estimated from surveys, and catch statistics for the same population in the subsequent fishing season.[45,61] These efficiency estimates are substantially higher than the 13 to 35% efficiency reported for dredges used in the similar fishery for the related *Pecten maximus* in Europe.[62,63]

Two studies of the impact of scallop dredging on the benthic environment were undertaken in response to industry or public concern that dredging caused mortality of other benthic organisms.[48,64] In Port Phillip Bay the short-term effects on the macrobenthos was examined by sampling selected areas before and after dredging. Three grab samples were taken at random in each area with a $0.1m^2$ Smith-MacIntyre grab before and after dredging, and divers collected epibenthos from randomly placed $1m^2$ quadrats. The fauna was identified to the lowest taxa possible, usually genus. A classification using the Bray-Curtis coefficient showed no coherency between pre- and post-dredging samples, and a univariate analysis of variance failed to reveal significant differences between the abundances of the 5 most dominant taxa. Long-term changes in infaunal composition were examined by comparing samples obtained during the study with similar samples collected from the same areas 18 years previously. No difference was found between samples in the number of taxa, number of individuals, the Shannon-Weiner diversity index and Pielou's index of evenness.[64] Unfortunately no information was presented to indicate the amount of dredging to which the area had been subjected to before, or since, the earlier sampling period.

A less rigorous study carried out in the same year in Jervis Bay concluded, on the basis of qualitative observations by divers, that there was "no lasting alteration to the environment" as a result of dredging.[48] This same study briefly addressed the problem of damage to scallops caused by dredging. The report noted that at the time of the study, damaged scallops represented 25 - 33% of commercial catches and divers estimated that around 10% of scallops on the bottom were dredge-damaged. As damaged scallops from previous drags are sorted and discarded during dredging, the proportion of damaged scallops on the grounds and in catches will rise as dredging proceeds. The damage levels reported cannot be interpreted, as the report gave no indication of how long the particular bed had been fished.

5. MANAGEMENT

The successful management of a fisheries resource requires 1) a knowledge of the distribution, abundance and productivity of the resource, 2) a management policy for its exploitation, 3) a management model designed to achieve a yield consistent with this policy, 4) a set of input and/or output controls, usually in the form of enforceable regulations and, 5) the collection of catch and effort data to assess the effectiveness of the management strategy.

The extent to which these requirements have been met in the management of scallop fisheries in Australian waters varies. These differences can be attributed in part to the fragmentation of management responsibility resulting from State jurisdiction over Australian coastal waters. With the exception of the Bass Strait grounds, which until 1986 were administered by the Commonwealth Government, the scallop fisheries have been in State waters and managed by State authorities. While avenues existed for consultation and the exchange of scientific information, the management policies adopted by each State have been strongly influenced by the different social and political pressures exerted on fisheries managers during the development of each fishery. It has also resulted in management policies that do not take into account such considerations as stocks overlapping State boundaries.

The different approaches to the management of scallop resources in each state have often resulted in what appear to be inconsistencies in the application of controls and a lack of objectivity in the evaluation of their effectiveness in achieving stated goals. For example, the *P. fumatus* fishery in Port Phillip Bay, is managed as a continuing, limited entry fishery with both input and output controls designed to control the rate of exploitation, equitably distribute the catch and maximize the yield per recruit. In Tasmania, fishermen are encouraged to fish *P. fumatus* when it is abundant and to move into other fisheries, such as those for shark and rock lobster, when scallops are scarce. Management measures are chiefly output controls designed to achieve an equitable distribution of the catch, rather than to restrict overall fishing effort. In the same State, however, the *Chlamys* fishery in the D'Entrecasteaux Channel is managed as a continuing fishery with output controls designed to limit the total catch.

Given these different exploitation strategies, it would not be surprising to find that the research priorities of the management authorities in each state are also quite different. In general, however, the priorities in all the Australian scallop fisheries have been to assess stock and maximize yield-per-recruit.

(i) Stock assessment.

The goal of stock assessment is to obtain a scientifically based estimate of the distribution and size of an exploited stock. In the context of the Australian scallop fisheries, this has meant either exploratory surveys or annual surveys depending on the geographical extent of the fishery. Both types of survey have provided information on species distribution, size composition, indices of scallop condition and estimates of relative abundance, but the sampling design has often been inadequate to provide a reliable estimate of stock size.

a) Exploratory surveys

These have been undertaken to locate new grounds when existing stocks have declined or to establish new fisheries in other areas and reduce the fishing pressure on known stocks. Exploratory surveys in Australian waters have frequently covered large areas and used a variety of sampling strategies to overcome the problems of sampling contagiously distributed species in areas with heterogeneous benthic environments.

The first documented exploratory survey for scallops was in Victoria, in Port Phillip Bay between 1949 and 1950, when trial dredgings were undertaken over "the most promising localities".[65] It was concluded from these trials that a small commercial fishery could be viable, but 13 years elapsed before scallop fishing began in Port Phillip Bay. The report of a 1966 survey of the Victorian coast between Cape Ottway and Lakes Entrance did not describe the survey procedures but took into account bottom type and fishermen's reports of scallop beds, noting that dredging was concentrated in areas within four hours' steaming from a port and in depths less than 73 m.[37] This survey did not find beds of commercial significance; however, commercial fishing began off Lakes Entrance four years later. It is not clear whether these beds resulted from recruitment after the survey, or if the survey failed to detect the grounds.

Prior to the 1970s, exploratory fishing to locate new scallop grounds in Tasmanian waters was largely left to the scallop industry. However, exploratory surveys undertaken by the Tasmanian Government in 1971[9], 1973[10], 1979[66] and 1987[67] located substantial stocks of *P. fumatus*, *C. asperrimus* and small stocks of *C. bifrons* in Bass Strait. The 1973 survey, covering all Bass Strait waters less than 73 m deep lying south of 39°12′ S, is the only complete pre-fishing survey of scallop stocks in southern Bass Strait. Sampling stations were located on a regular grid and the number of scallops in the dredge were used to indicate relative abundance. Catches were not standardized by tow duration, although this was reported to vary. In all, 336 stations were occupied over 59 days, and an area of over 20,000 km^2 was covered.[10] The new grounds located were opened to fishing later in 1973.

A subsequent survey of southern Bass Strait carried out by the same authority in 1987 "to target commercial scallop beds . . . and delineate areas with significant juvenile settlement", discarded the grid system in favour of a more "practical method . . . of random sampling, with intensive sampling in areas where high numbers of scallops were located."[67] This survey detected no commercially viable scallop beds, although there was some fishing when the season opened three months later.

Because dredge efficiency varies with bottom type,[58] estimates of relative abundance obtained during surveys may not reflect true densities on the bottom. It has also been widely reported that several boats working together achieve higher catch rates than a single boat on the same ground.[2,11,57] Single-boat surveys may not, therefore, provide a true indication of commercial potential. This was recognized in exploratory fishing for *P. fumatus* off the New South Wales coast in 1972. In these surveys it was assumed that the occurrence of even a single scallop during exploratory fishing could indicate the presence of scallop beds of commercial size. The aim of this survey was to locate beds, not to make detailed investigations of any one area. Dredging was carried out at intervals of "a few hundred yards" to 8 km within the known depth range of *P. fumatus*.[68,69] A subsequent diving survey of a bed that had shown promising catch rates during the surveys, found that the good catch rates were attributable to specific features of the bottom topography, which concentrated the scallops in small dense patches.[57]

b) Annual surveys.

The assessment of stock size and monitoring of recruitment to a fishery by periodic or annual stock surveys has been integral to scallop management strategy in Tasmania and Victoria since the 1960s. Estimates of stock size and the number of "takeable".*P. fumatus* in Port Phillip Bay were first made by a dredge survey in 1967. Standard hauls were made on a 3 x 4 mile grid and catches were converted to abundance by using estimates of dredge efficiency obtained by fishing areas of known scallop density. The number of "takeable" scallops was defined as the number in excess of a baseline abundance of 100 scallops per haul, which corresponded to an average density of 0.28 scallops per m^2. This level was equivalent to a catch rate of two "bags" an hour, which was considered to be economically viable for a boat towing two 1.2 m dredges. [70]

It was not until 1982 that regular grid sampling was discarded and stratified random survey techniques were used to provide a statistically unbiased estimate of the Port Phillip Bay population. In that year, two independent surveys were made of scallop stocks in the bay, the first using traditional dredge methods[71] and the second by divers.[72] Comparison of the two methods showed that the scallop population estimated by the dredge survey was double that estimated by the dive survey. The dredge survey also undersampled juvenile scallops, distinguishing only one mode in height distributions, while three modes were apparent in diver-collected samples. The authors concluded that diver surveys provided more precise and relatively unbiased estimates of population size, because they eliminated the need for accurate data on dredge selectivity and overall dredge efficiency.[72] Similar conclusions were reached following an investigation of techniques used to survey *Pecten. maximus.*[73] Annual diver surveys are now used exclusively to estimate the size of *P.fumatus* stocks in Port Phillip Bay.[61,74,75]

In Tasmania, annual or periodic surveys have been made to assess the need for new or continuing closures of beds in the D'Entrecasteaux Channel, Great Oyster Bay and Bass Strait, but improvements in survey design developed in Port Phillip Bay have been largely ignored. Few of the results of the surveys of the D'Entrecasteaux Channel in Tasmania have been published, and only in the reports of the 1967,[76] 1971,[77] 1986 [78] and 1987[79] surveys is any information given on sampling techniques and catch rates. Sampling in all surveys was stratified by statistical area but the method of selecting sites within these areas was not specified. Stock size in the D'Entrecasteaux Channel was not estimated, and neither apparently was scallop catchability. These surveys provide the basis for recommendations on whether the annual season will be opened, which areas will be open to fishing, for how long, and what the quotas for amateur and commercial fishermen should be.[79] How this is achieved is not clear.

Dredge surveys of Great Oyster Bay were carried out annually from 1971 to 1982 but only a few of these have been reported in any form.[80,81,82] Catch rates appear again to have been the only criterion used for setting the duration and location of fishing activities within the bay in any year. A diving survey of parts of Great Oyster Bay was undertaken in 1986, but no parallel dredge survey was carried out for comparison.[83]

Recently, attempts have been made to correlate spat abundance in artificial collectors with independent estimates of juvenile recruitment in Port Phillip Bay.[23] The aim of this work is to provide managers with a means of predicting major fluctuations in recruitment into the fishery one year in advance. Given that data to validate this relationship can only be collected annually, the aim of this study will not be achieved in the short term.[84]

(ii) Maximization of yield.

Yield analyses have been carried out on the *P. fumatus* fishery in Port Phillip Bay. The Port Phillip Bay study used dredge survey data, a dredge efficiency factor of 26% (the mean of the values determined in 1967 [70]), a natural mortality rate of 1.7% per month, and unpublished estimates of growth, to estimate the time required to deplete stocks under different exploitation rates.[44] Confidence levels were not calculated for these estimates as sampling locations were not randomly distributed. This assessment was subsequently used as as the basis for doubling the allowable catch per boat, and increasing by 25% the number of boats permitted to fish in Port Phillip Bay. Subsequent stock assessments and yield analyses have used random sample survey techniques and revised estimates of dredge efficiency, natural mortality and growth rates.[74] Using these estimates, the maximum yield per recruit in Port Phillip Bay was calculated to occur when scallops were caught at 1.5 years years of age.[35] Fishing in Port Phillip Bay takes place when scallop roes are at maximum size and this results in most scallops in any year class being taken before they spawn for the first time. The impact of this practice on the size of the breeding stock in Port Phillip Bay is now giving cause for serious concern.

Apart from the yield-per-recruit analyses described above, no other fishery models have been used for *P. fumatus* in Australia. Area closures have been used in attempts to increase meat yields from beds of small shell size scallops in Banks Strait,[85] and of low meat weight scallops at King Island[86] and off Lakes Entrance.[87,88] But estimates of natural mortality and growth rates were not available for any of these three areas when the closures were introduced.

(iii) Regulation

Few scallop fisheries anywhere in the world are regulated to address long-term management objectives. A comprehensive management policy for the Georges Bank fishery for *Placopecten magellanicus* has been proposed,[89] but this appears to be unique. Most European fisheries for *Pecten maximus* have size limits, but these are more aligned to perceived market requirements than to any attempt to maximize yield-per-recruit or protect breeding stock.[90] In Australian scallop fisheries, as in most similar fisheries throughout the world, regulations have often been imposed to deal with short term problems. Long-term objectives, which are readily accepted by industry during periods of high stock levels, are often forsaken in times of crisis.

Most regulations applied have been input controls to restrict the fishing effort, although output controls such as catch quotas and size restrictions have also been used. Australian managers have imposed a combination of gear and boat size regulations, licence limitations, area closures, temporal closures, catch quotas, and size restrictions. Where applied to *Pecten* fisheries, such measures have generally been unsuccessful in achieving stated aims and failed to conserve stocks.[33,91]

a) Gear restrictions.

Gear restrictions have been applied to both dredge and trawl fisheries. Restrictions on dredges were first introduced in the D'Entrecasteaux Channel fishery in 1949, when a limit was put on the width and number of dredges that a boat could tow.[2] The use of "Sputnik" dredges was banned in the D'Entrecasteaux Channel in 1959, following allegations by fishermen that they caused greater incidental damage to scallops than Lip or Digby dredges.[92] This decision was reversed the next year, but restrictions were imposed on various dimensions of the dredge.[93] In 1961 a select committee concluded, on the basis of fishermen's submissions, that "Sputnik" dredges should be excluded from the shallow waters of the D'Entrecasteaux Channel.[94] This decision was again based on allegations of damage to scallops on the beds but no scientific evidence to substantiate this was presented. The continued use of "Sputnik" dredges elsewhere in the fishery was justified on the grounds that a pressure plate was required on dredges used in deep water.[95]

In all cases, regulations governing the use of dredges have been introduced without prior knowledge of the catching characteristics of the gear, its effect on the sea bed and benthic communities, and the effect of controls on catch size and catch composition. In Victoria, regulations introduced in 1967 linked the permitted dredge width to the boat length. Thus a boat less than 9.1 m long could use a combination dredge width of not more than 1.5 m, while a boat over 15.2 m long was permitted to use a combined dredge width of 3.35 m.[96] Complementary regulations were introduced for Commonwealth waters adjacent to Victoria. In similar waters off New South Wales, Commonwealth regulations at the time permitted all boats, irrespective of size, to use 3.35 m dredges to complement regulations introduced by New South Wales authorities.[97] Victorian regulations have since been changed to permit a maximum dredge width of 3.36 m for boats of any length.[5]

b) Licence limitation.

The issue of a restricted number of licences to fish a resource has been used as an input control to regulate fishing effort in Victoria. This policy began in Port Phillip Bay in 1968 when, to restrict further increases in effort, a scallop licence was issued to participants in the fishery and charges were levied in proportion to the width of the dredge used.[96] Licensed entry to the Lakes Entrance fishery was introduced soon after the fishery began in 1970, with the criterion for entry being a history of fishing in the Lakes Entrance area. At that time, many of the Port Phillip Bay boats had moved to Lakes Entrance, so their owners then were licenced to work in both fisheries. Currently, Victorian scallop boats are issued with one licence that covers Port Phillip Bay or Lakes Entrance or all Victorian waters.[5]

Although limited entry has not been used by other management agencies, the number of new licences has sometimes been restricted. When for the Bass Strait fishery for *P. fumatus*, had an interim management regime, the number of boats in the fishery, licence transferability, and boat replacement were restricted.[98] A limited entry inshore zone was later proclaimed for Tasmanian waters, and in 1985 the Tasmanian government stopped the issue or transfer of scallop licences until a local management plan could be formulated.[99]

In all cases the impetus for licence limitation was a presumed excess catching capacity in the fishery. Because of the way they were allocated and the reluctance of State and Commonwealth governments to become involved in licence "buy-back" schemes, it has become virtually impossible for managers to reduce the number of licences in limited entry fisheries once they have been issued.The transferability of licences places on each a financial value, the level of which is determined by the economic expectations of participants in the fishery. However, no consideration has been given to the payment of economic "rent" by licence holders who benefit, at least in theory, from the exclusive right to fish.

c) Area closures.

Area closures, a valuable management tool in fisheries where juveniles and adults of exploited species occupy different geographical areas, have usually been introduced to protect juvenile stocks until they move to adult grounds. In the *P. fumatus* fishery in Tasmania, area closures have been imposed after depletion of grounds in the hope that stocks will recover. The first such closure was proclaimed in 1908 when the depletion of beds in the vicinity of Hobart led the then commissioner to close the grounds to fishing.[100] These grounds were subsequently re-opened in 1912 and, although continued depletion of beds in the area prompted another inquiry in 1918, no further management restrictions were imposed.[101] Since then, closures following depletion have been proclaimed for the D'Entrecasteaux Channel, Norfolk Bay, Oyster Bay and Ringarooma Bay in Tasmania, Coffin Bay in South Australia, Jervis Bay in New South Wales, and Cockburn Sound in Western Australia. On the evidence available, there is no indication that closures have resulted in any significant recovery of *P. fumatus* stocks in of these areas.

d) Temporal closures.

Seasonal closures are usually aimed at increasing the yield-per-recruit either by allowing scallops to reach a certain minimum size before capture or by concentrating fishing in that period of the year when meat returns are highest. In Victoria and Tasmania, *P. fumatus* fisheries supply "roe on" markets, so scallops are fished during the period when the gonads are best developed. For this reason, summer closures have been enforced in Port Phillip Bay since 1979, to prevent fishing when scallops are in poor condition following spawning.[102] Similar closures apply to Tasmanian waters; however, the duration of the season and the timing of its opening has been governed more by tradition than by scientific assessment.[33]

Shortening the length of the season has been used as a means of reducing fishing effort on scallop beds in Tasmania since the early days of the fishery.[103] The opening of the fishery in the D'Entrecasteaux Channel fishery is timed to coincide with the period of estimated maximum meat weight, but the length of the season varies. In 1984 the season was opened for 16 days;[104] in 1985 for only 9 days;[105] and a 4 day season was recommended for 1987.[79] The duration of the season is determined following the pre-season assessment of scallop stocks.

Night closures have also been imposed in both the Tasmanian and Victorian fisheries to reduce fishing effort or to avoid gear conflict with fishermen exploiting other resources.

e) Catch quotas.

Output controls in the form of catch quotas have been applied to the *P. fumatus* fishery in southern Australia. Processors have on occasions imposed bag limits[(b)] on vessels when supply has exceeded processing capacity,[1] and a voluntary bag limit was imposed by fishermen during the early years of the Lakes Entrance fishery in an attempt to influence the price paid by processors.[5] Daily bag limits were legislated for both the Lakes Entrance and the Port Phillip Bay fisheries in 1976. When closed seasons were introduced in Port Phillip Bay in 1979, a reduction in bag limits was to be used to discourage fishermen from taking small scallops.[102] In Port Phillip Bay, daily quotas are now set on the basis of abundance levels determined from the pre-season survey [106] and are varied over the season to increase the catch during the most productive months.[107]

In 1986, catch quotas in the form of a specified number of units per boat per trip were imposed on vessels fishing in Tasmanian waters. One unit was specified as 500 scallops and the number of units allocated to each boat was calculated on the basis of two bags per foot of boat up to a maximum of 70 feet. The quotas were intended to prevent over-exploitation of an already scarce resource, distribute the catch more evenly between vessels, and promote orderly marketing. However, the quotas were assigned without an accurate estimate of the size of the resource, and subsequent analysis has shown that only the second of these three objectives was achieved.[49]

f) Size restrictions.

Size restrictions have been in place in Tasmania since 1925, when the legal minimum size for *P. fumatus* at 90 mm was measured across the largest shell diameter. In 1935, the minimum legal size for *P. fumatus* was increased to 90 mm measured across the smallest shell diameter.[2] More recently, minimum size regulations for all commercially fished scallops in Tasmanian have used the largest shell dimension and size limits are now set at 90 mm for *P. fumatus*.[1] In 1987, with the prospect of poor catches, and with widespread violation of the existing size limit, the minimum size for *P. fumatus* was reduced to 80 mm at the maximum diameter.[33]

A minimum size limit of 3.75 inches (95 mm) at its maximum shell diameter was introduced to the Port Phillip Bay fishery in 1965 to maximize the yield-per-recruit and to enable the stock to spawn once before being caught.[108] In 1979, this minimum size limit was abolished on the assumption that the market would set a minimum acceptable size. This was anticipated to be around 94 mm;[102] however, the result was a fishery for animals of about 70 mm shell height.[107] Size restrictions in the Lakes Entrance fishery were removed in 1976, principally because of the costs of sorting and measuring, likely damage to undersized scallops, and the cost of enforcement.[5]

(b) A bag contains approximately 500 scallops *g) Miscellaneous regulations.*

A regulation first proclaimed in Tasmania in 1926 and enforced since 1932 prohibits cleaning scallops at sea during fishing. This regulation was made in the belief that discarding scallop waste onto the beds would encourage starfish.[2] This regulation was subsequently extended to all other *Pecten* and *Chlamys* fisheries in southern Australia and, although it facilitates the enforcement of fisheries regulations relating to quotas and minimum size limits, it has also effectively precluded the use of factory vessels in these fisheries.

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E. OBJECTIVES OF THE STUDY: SUMMARY OF RESEARCH AND PRINCIPAL CONCLUSIONS

1. CLARIFICATION OF THE STATUS OF THE COMMERCIAL SCALLOP IN BASS STRAIT WITH REGARD TO THE NUMBER OF SPECIES EXPLOITED, AND THE DEGREE OF REPRODUCTIVE ISOLATION BETWEEN SCALLOPS IN THE MAJOR REGIONS WITHIN THE FISHERY.

RESEARCH SUMMARY

As noted in the introduction, funding for this part of the program was provided by an MST grant to Dr N. Murray of La Trobe University. Ms. L. Woodburn was employed to carry out the research under Dr Murray's supervision and the results of this study will be written up and submitted as a PhD thesis. An MST progress report will be available after the grant terminates in December, 1988. Preliminary results have already been reported by Ms Woodburn at the VIth International Pectinid Workshop (Menai Bridge, North Wales, 1987) and at the Australasian Scallop Workshop (Taroona, Tasmania, 1988).

CONCLUSIONS

(i) The commercial scallop populations of South-East Australia belong to a single species, *Pecten fumatus* (Reeve, 1852), those in Cockburn Sound and Shark Bay, Western Australia to another species, *Pecten modestus* (Reeve, 1852), and the populations from New Zealand constitute a third valid species, *Pecten novaezealandae* (Reeve, 1852).

(ii) There is little variation in heterozygosity between populations within the Bass Strait region, indicating that gene flow between populations is sufficient to prevent significant differentiation in the alleles examined.

(iii) An examination of scallops from King Island and Banks Strait used in the reciprocal transplant experiments (see **3 (c)** below) indicated that differences in heterozygosity among the experimental animals were not significant and could not be linked with observed variations in growth or changes in condition.

2. DEVELOPMENT OF METHODS TO ASSESS THE STANDING STOCK AVAILABLE FOR ANNUAL ALLOCATION CONSISTENT WITH THE RATIONAL EXPLOITATION OF THE RESOURCE.

A. ANALYSIS OF HISTORICAL CATCH DATA

RESEARCH SUMMARY

Prior to the partitioning of the Bass Strait fishing zone under the Offshore Constitutional Settlement in 1986, the Bass Strait scallop fishery was under the jurisdiction of the Commonwealth Government. In 1984 the Bass Strait Scallop Task Force, comprising industry and government representatives from Tasmania, Victoria and the Commonwealth,was established to assess the effectiveness and impact of current management arrangements and provide a forum in which management objectives and options for the Bass Strait scallop fishery could be discussed. One of the terms of reference of the task force was to "collate existing information on the fishery and recommend modifications or additions to current data collection". A consultant (Mr N. Dow) was appointed to collate the Victorian and Tasmanian catch data but, because of delays in obtaining records, this task was not completed before the Bass Strait Scallop Task Force was disbanded in 1985.

Since then, CSIRO has located all existing catch records from Victorian and Tasmanian sources and compiled a common data base which is now held on computer at the CSIRO Marine Laboratories in Hobart. This data base includes daily catch and effort records for all fishing vessels operating in the Bass Strait region from the start of fishing in 1970 to the end of the 1987 season (the most recent data available to us). All records have been reformatted, the two data sets amalgamated, and all locations are now indexed by statistical rectangle on a 1° longitude x 1° latitude grid.

The data base has only recently been completed and to date the information has been subjected to only very preliminary analyses. Catch data have been used in the calculation of fishing mortality in restricted locations and it is further planned to use the data to examine the historical distribution and abundance patterns of scallops throughout Bass Strait.

CONCLUSIONS

(i) Annual catches have varied considerably throughout the history of the Bass Strait fishery.

(ii) The distribution of fishing effort in any year is usually very localized.

(iii) The fishery has been sustained by the progressive discovery and exploitation of new beds.

(iv) Recent catch declines are due to the absence of commercially exploitable beds.

B. THE DEVELOPMENT OF TECHNIQUES FOR ANNUAL SURVEY.

RESEARCH SUMMARY

(i) Fishing characteristics of the commercial scallop dredge.

The commercial scallop dredge currently in use in Australian waters is described in the review of fishing methods on p. 20. The fishing characteristics of this dredge were examined, initially using a dredge-mounted TV camera, and later in two experiments designed to test the efficiency of the dredge under a variety of conditions. An examination of video films taken with the dredge-mounted camera indicated that three factors were most likely to influence the catching efficiency of the dredge. These were:

- the angle of the dredge relative to ripples and sandwaves on the seabed
- the size of the scallops in the path of the dredge
- the mesh size of the dredge.

The relative importance of these three factors was tested by dredging across experimental plots containing reseeded scallops of known size and abundance. To set up an experimental plot, scallops were dredged from an existing bed, measured, and held in continuous-flow sea water tanks before release onto the sea bed within a marked 300 m x 300 m square. The research vessel then made 10 drags from one side of the square to the other, dredging along the ripples on the seabed. This was followed by 10 drags at right angles to the first 10, dredging across the ripples. For each drag, the number and size of all scallops caught was recorded. Before and after each experiment, divers inspected the sea bed within the plots to look for dead and damaged scallops, and to note any obvious effects of dredging. The dredge used was typical of those used in the fishery, consisting of a steel frame 4.2 m wide covered with 6 mm diameter welded wire mesh (70 mm x 45 mm). In the first experiment about 3,500 scallops were released, and in the second about 11,200. Here five of the ten drags from each side were made with the standard dredge and five drags with a small wire mesh (22 x 22 mm.) attached to the outside of the dredge.

Of the three factors examined only scallop size had any significant effect on dredge efficiency. The change in catching efficiency with the shell height calculated for the combined data by a maximum likelihood function for binomial data is shown in figure 4. Under the experimental conditions, an overall dredge efficiency of only 9.9% was achieved. Scallops smaller than 40 mm shell height were not retained by the dredge and the maximum efficiency of 25% was reached at a shell height of 100 mm.

As mesh size had no significant influence on catch size composition, the observed size selectivity of the mud dredge is most likely due to a combination of factors including the depth and spacing of teeth on the tooth bar, and a size related capacity of scallops to swim and avoid the dredge. Studies with the dredge-mounted TV camera indicate that only juvenile scallops swim in response an approaching dredge.

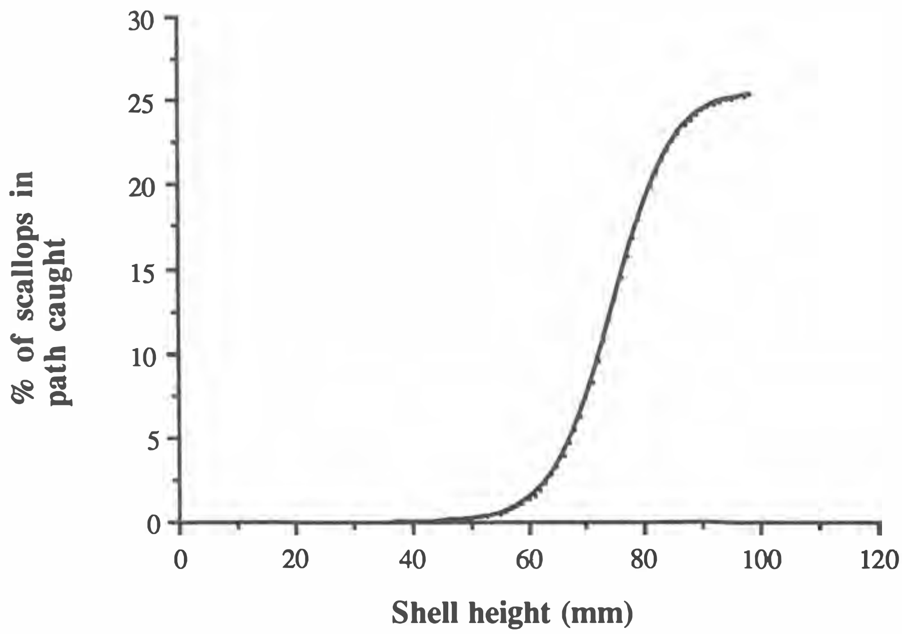

Fig. 4. Catch efficiency curve for the commercial scallop dredge

(ii) The development of new survey gear.

As the majority of scallop beds in the Bass Strait region occur in waters deeper than 30 m, dredging is the only method that can realistically be used to assess the stock of scallops available for annual allocation. An initial requirement was, therefore, to develop sampling gear specifically for survey work that would capture all age classes with a constant bias so an accurate assessment of year class strengths could be obtained.

Studies using a dredge-mounted TV camera had shown that while bottom topography was probably the most important determinant of overall dredge efficiency, escapement by swimming over the top of the dredge was an important factor in the underestimation of juvenile scallop abundance. Our studies showed that juvenile scallops passing over and through a commercial dredge could be caught by attaching a small mesh net to the back of the dredge (fig. 5).The net in current use is made from 10 mm polypropylene mesh and has a constant net opening of one metre maintained by a frame attached to the top of the dredge (fig. 6). The wings of the net are shackled to the upper and lower rear corners of the dredge and the foot rope, weighted with 2.5 cm chain, trails about one metre behind the back of the dredge. This insures that much of the material disturbed by the passage of the dredge, but not caught by it, is retained by the net. The dredge/net combination can consistently catch scallops as small as 10 mm shell height. The net can be fitted to any dredge with little modification and the combination gear is fished in much the same way as a standard commercial scallop dredge.

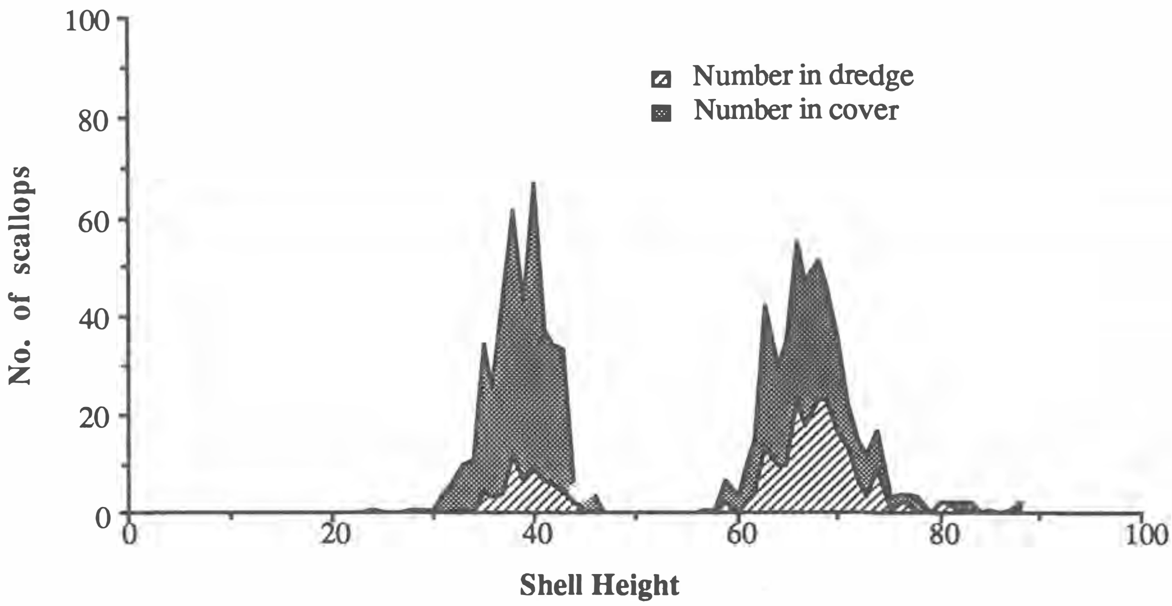

Fig. 5. Retention of scallops by the dredge and trailing net.

(iii) Assessment of stock size by annual survey.

Following the development of the combination dredge/net, a series of surveys was undertaken to examine the distributions of newly recruited and juvenile scallops. The timing of the surveys was such that recruits from the most recent spawning would have had an average shell height of less than 50 mm at the time of sampling. Surveys were undertaken in 1986, 1987, and 1988 to locate recruits resulting from the 1985, 1986, and 1987 spring/summer spawnings.

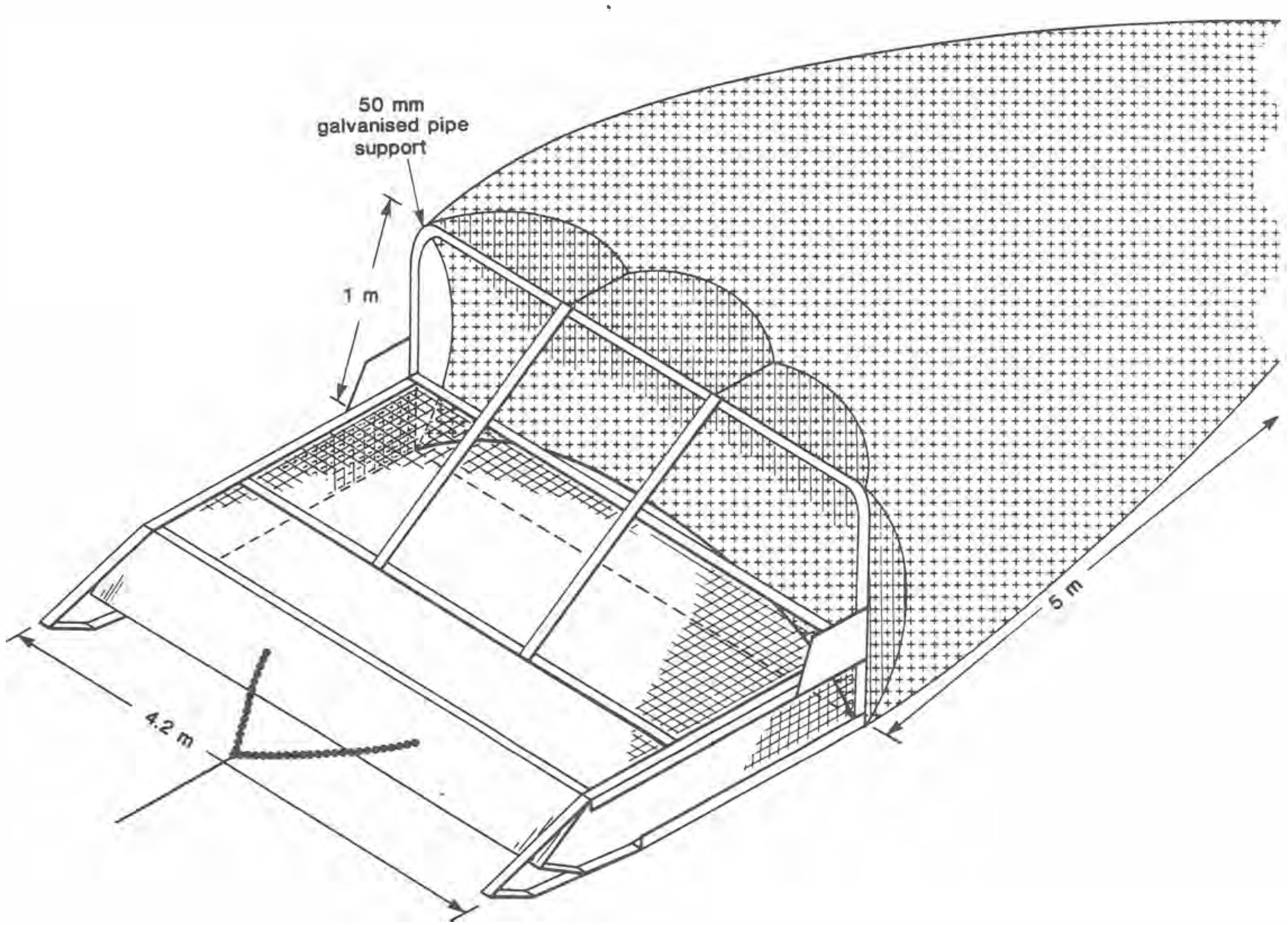

Fig. 6. Dredge/net combination used to sample juvenile and adult scallops.

In 1986 no scallops less than 50 mm shell height were located in western Bass Strait, Banks Strait or along the eastern side of Flinders Island (fig. 7). Small numbers of juvenile scallops were found off Lakes Entrance and along the western side of Flinders Island but in each case settlement had been sparse and localized. Only the area off Stoney Head on the Tasmanian northeast coast showed significant concentrations of juvenile scallops (i.e. greater than 100 scallops per drag).

From February 1987, new recruits from the 1986 spring spawning began appearing at a number of sites. Most of the beds that showed settlement in 1986 also showed some settlement in 1987 but levels were well below that recorded the previous year (fig. 8.). Juveniles found off the western side of Flinders Island during the 1985 surveys had grown slowly and many were still under 50 mm shell height when resurveyed in 1986. The only new areas settled following the 1986 spawning were along the Tasmanian northwest coast (off Rocky Cape, Table Cape and on the old scallop grounds north of Stanley) and in Banks Strait. The number of new recruits in all areas was again small.

In the 1988 survey no evidence was found for significant recruitment of juvenile scallops from the 1987 spawning anywhere within the survey area. Only 31 juvenile scallops were taken in the whole survey and over half of these were caught in two drags between Devonport and Port Sorell (fig. 9). This indicates a widespread recruitment failure following the 1987 spawning season.

The decline of scallop stocks in Bass Strait indicated by the surveys was subsequently confirmed by falling catches. In 1986, 1146 tonnes were landed, but in 1987 this fell to only 67 tonnes. Many of the scallops landed from the Stoney Head grounds in 1987 were recruited following the 1985 spawning. By the 1988 season only animals from the 1985 and 1986 spawnings remained, and with fishing confined to the Victorian zone, landings were less than 60 tonnes, the lowest since the Bass Strait fishery began in 1970.

CONCLUSIONS

(i) Dredge trials using experimental plots of known scallop density and size structure have shown that the catching efficiency of the mud dredge is low. The percentage of scallops in the path of the dredge that are caught ranged from 1% for scallops less than 50 mm shell height to 25% for scallops of 100 mm shell height. The average catching efficiency over a range of shell heights (40 to 100 mm) was 9.9%.

(ii) Small scallops which may pass under, through or over a standard dredge can be caught by attaching a small mesh net to the back of the dredge. Using this dredge/net combination, scallops as small as 10 mm shell height can be caught consistently, enabling surveys of 0+ recruits to be undertaken.

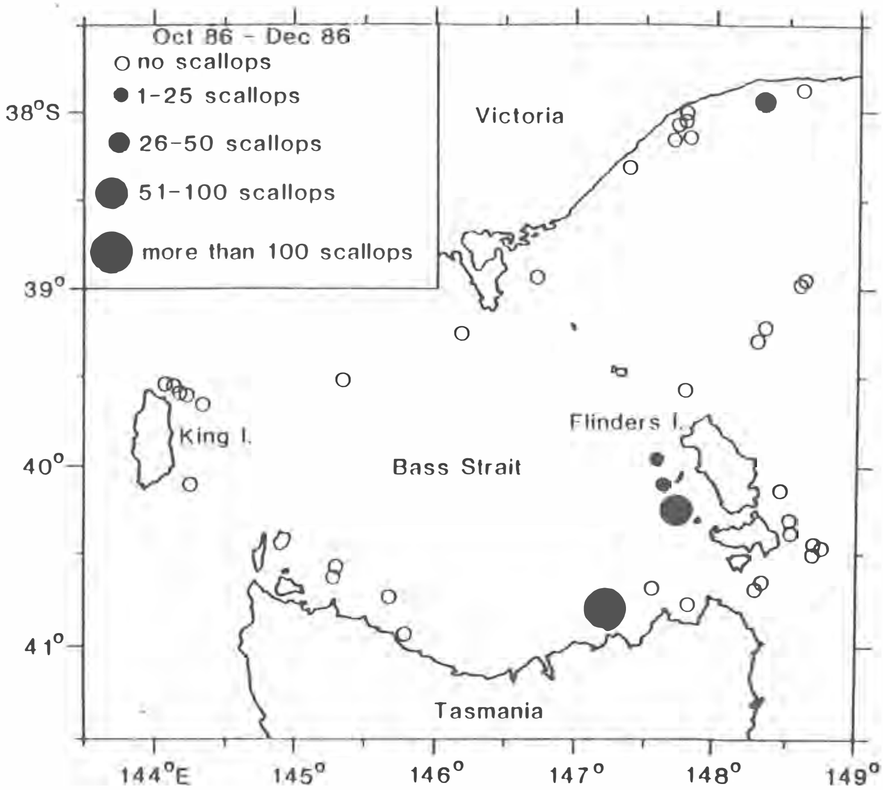

Fig. 7. Results of the 1986 juvenile scallop survey.

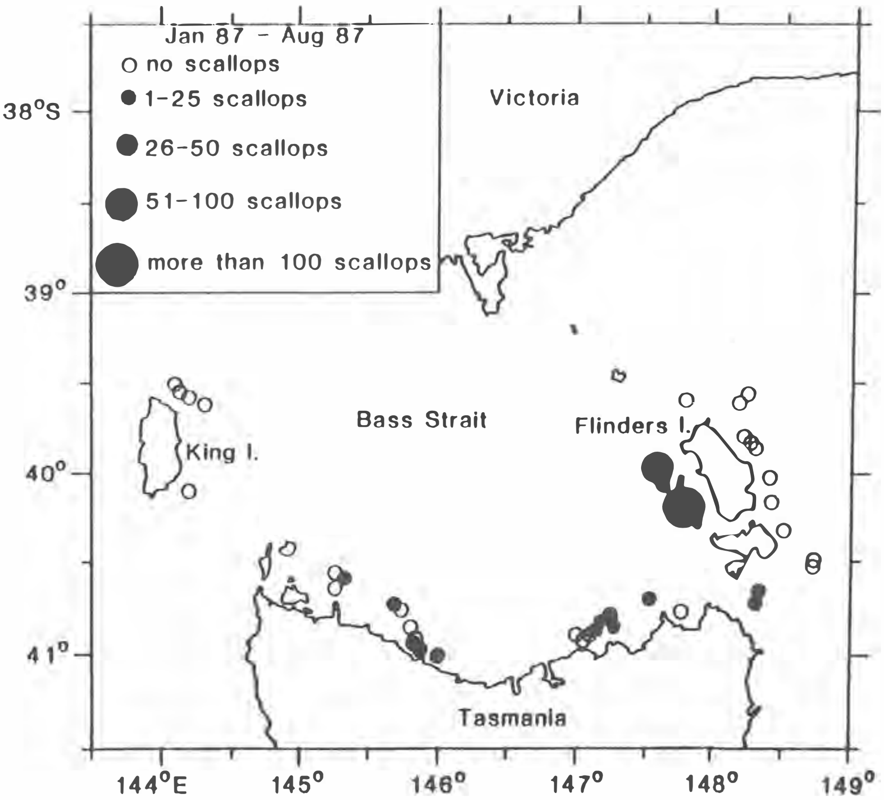

Fig. 8. Results of the 1987 juvenile scallop survey.

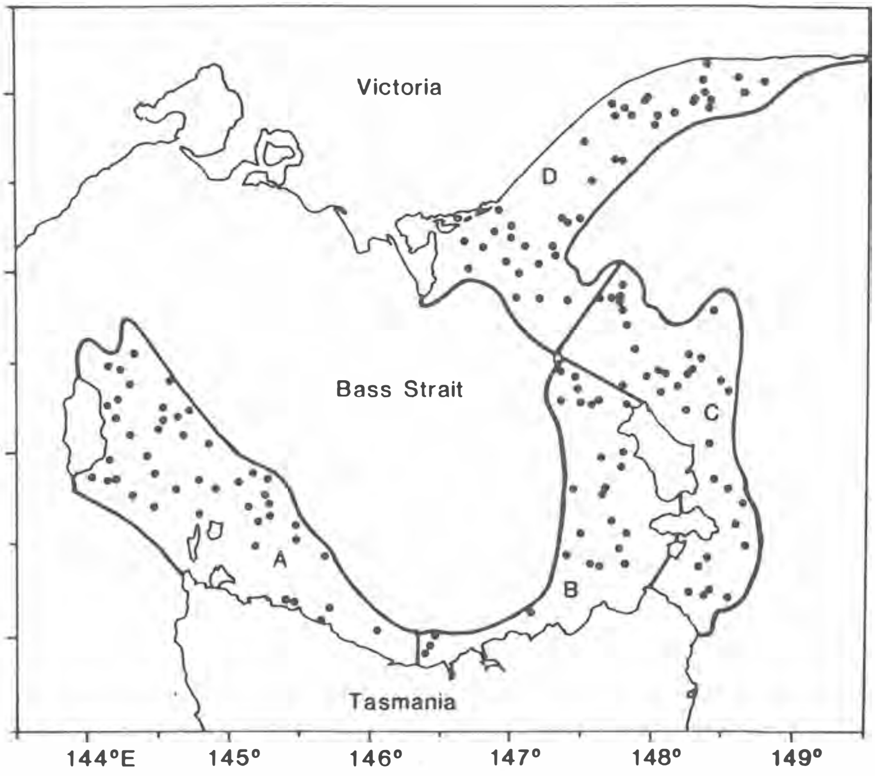

Fig. 9(a) Strata and sample sites for the 1988 scallop survey.

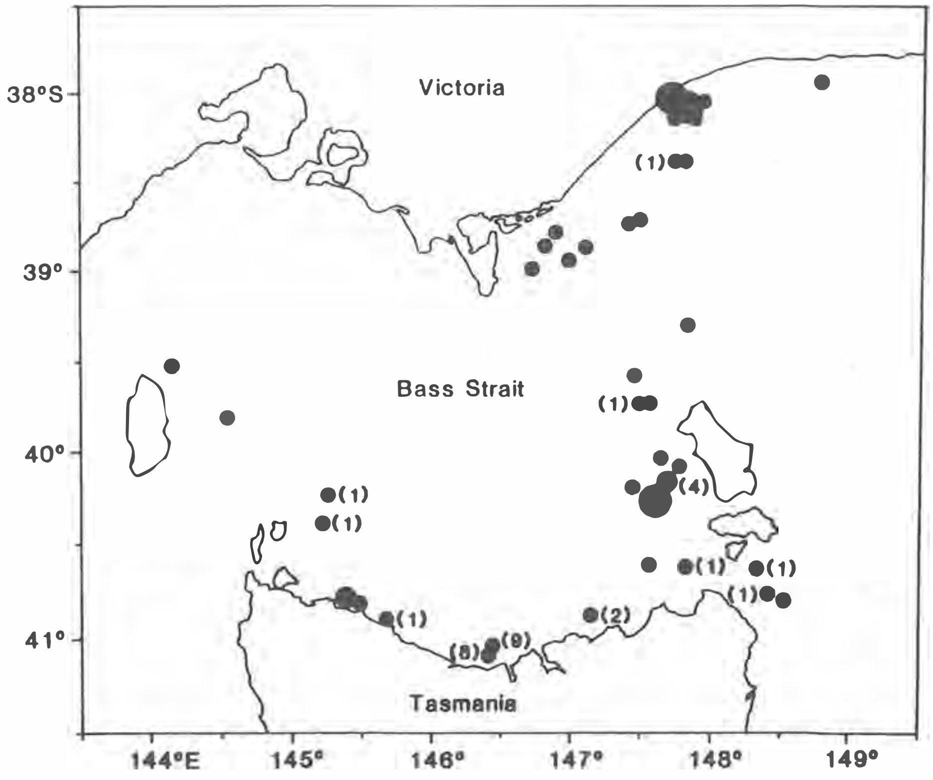

Fig. 9(b) Results of the 1988 scallop survey. The numbers of juveniles caught at each site are shown in parentheses. Scallop abundance indicators are as shown in key for Figs 7 & 8.

(iii) In the two years for which survey results and commercial catches are available, predicted stock levels and subsequent catches have shown close agreement.

(iv) The long-term prospects for the Bass Strait scallop fishery are not encouraging. The 1988 survey showed that commercial scallops have been virtually eliminated from large areas along the eastern and western margins of Bass Strait which, during the 1980's, supported the most productive scallop grounds in the history of the fishery.

C. SPAT SETTLEMENT

The spat settlement program was set up to test the feasibility of using the abundance of spat in artificial collectors to predict subsequent recruitment to scallop beds in Bass Strait. The spatial and temporal characteristics of settlement were first examined at six sites throughout Bass Strait and spat settlement was then related to the number of spawning adults, the number of juveniles, and the number of recruits to the fishery within each adjacent area.

RESEARCH SUMMARY

(i) Spatial and temporal characteristics of spat settlement on collectors.

Spat collectors were deployed in water depths between 45 and 50m at six locations close to existing or previously fished scallop beds (fig. 10). The collectors consisted of 4 mm-mesh polypropylene bags filled with approximately 1 kg of aged monofilament nylon gill netting. These were attached in pairs to a vertical line with each line carrying up to 10 pairs of bags located at 3 m intervals between 5 m and 30 m from the bottom. At each site, a new line was put down each month and recovered after 3 months in the water. Using this arrangement, a maximum of three lines were in the water at each site at any time with the oldest overlapping the other two by two months. Collectors were put in place prior to the 1985 and 1986 spawning periods and in both years they remained in place until significant settlement could no longer be detected.

Concurrent with retrieval of the spat lines, water samples were taken from the surface, midwater and bottom with 8 litre Nisken bottles and analysed for chlorophyll *a*, silicate, nitrate, nitrite, phosphate and ammonia. A submersible data logger was used to obtain temperature and salinity profiles at each site.

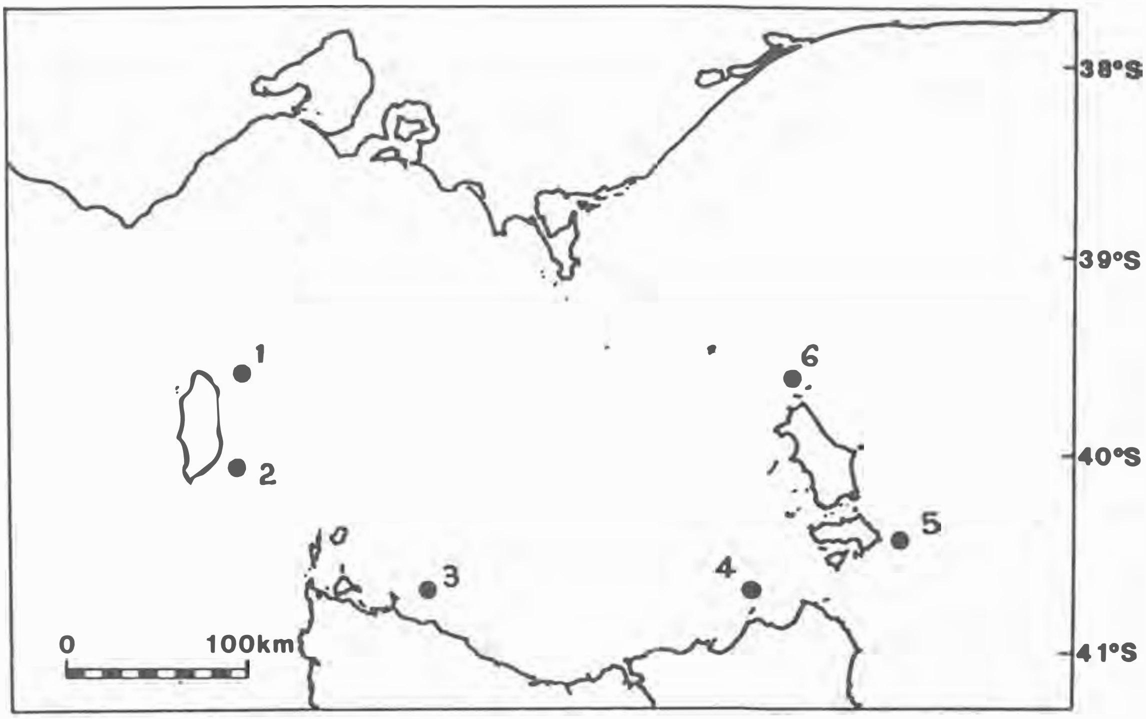

Fig. 10. Location of the CSIRO spat collectors.

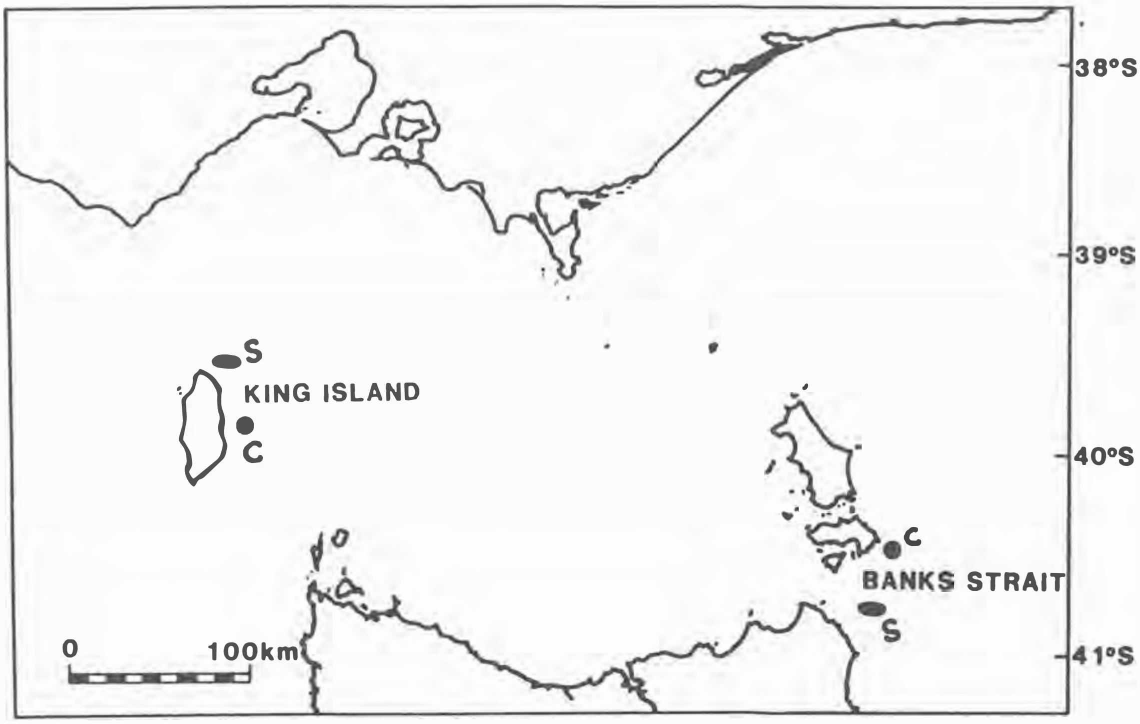

Fig.11. Location of the experimental cage sites (C) and source populations (S).

a) Small scale horizontal distribution. The size of a patch of settling larvae was examined by deploying five spat collector lines in a cruciform array, the outer collectors of which where separated by a distance of 2 km. Two such arrays were deployed at the same site off the north-west coast of Tasmania (site 3, fig. 10) and remained in the water for three months. The first was retrieved in November 1986, and the second in January 1987. An ANOVA of the abundance and size of spat collected on these two arrays showed significant differences between the two time periods, but not between lines at the same time. This suggests that a patch of settling larvae may cover an area at least 4 km wide.

b) Vertical distribution. Differences in spat abundance with height above the bottom were examined at three sites (sites 3, 5 and 6) following the 1986 spawning. Preliminary results suggest that the number of spat settling at a particular location varies with the height of the collector above the sea bed. This pattern was consistent for several months within an area when spat in the collectors were from the same settlement (fig 12). It was not consistent between areas, each showing its own pattern. Variation in spat size with depth were also examined and no significant difference was detected.This suggests that the spat settling at different depths on a line all came from the same batch of settling larvae.

c) Distribution with time.The time and duration of spat settlement was examined using only the deepest pair of collectors on each line. This ensured uniformity between samples and most closely approximated settlement conditions on the sea bed. Two collectors were examined from all sites and all times following both the 1985 and 1986 spawnings.

The number of spat settling varied considerably with location. After the 1985 spawning, lowest numbers settled north-east of King Island (site 1), and the highest off northern Tasmania (sites 3 and 4). The time of major settlement in eastern Bass Strait was between September and November, and in the west between November and January. Only at the site off north-west Tasmania (site 3) was there more than one peak of settlement, the first occurring in November-December, and the second in December-January. These coincided with similar settlement peaks on collectors at sites 1 and 2 off King Island.

The pattern of settlement following the 1986 spawning was similar to that observed in 1985. Settlement maxima occurred between October and January and settlement was again earlier in the east than in the west. Site 3 off north-west Tasmania again showed two settlement peaks, but on this occaision only the later peak (December-January) coincided with settlement at the other western sites. The earlier peak (November-December) coincided with settlement on collectors off north-east Tasmania (site 4) and north of Flinders Island (site 6). Abundances were again highest off northern Tasmania.

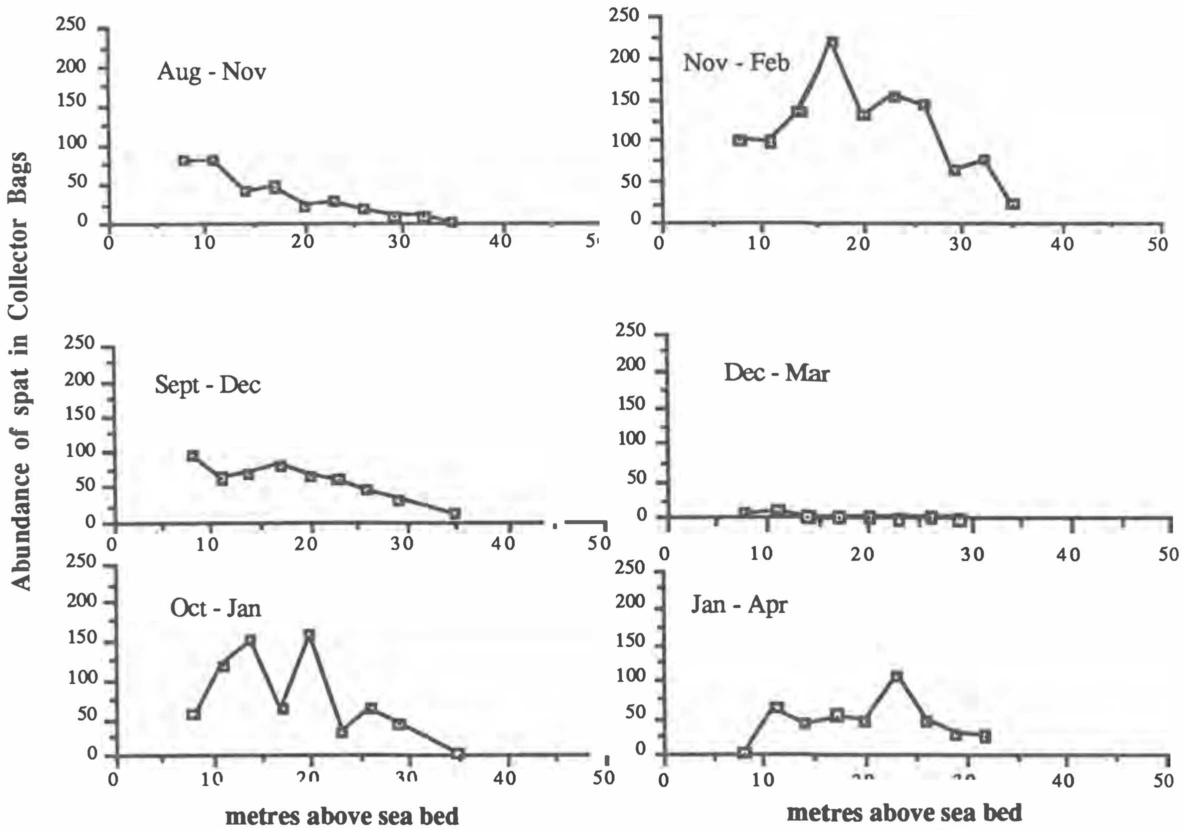

Fig. 12. Vertical and temporal variation in the abundance of spat settling in collectors at site 6, north-west of Flinders Island.

CONCLUSIONS

i) The abundance of spat, but not the time of their settling, varies with the depth of collectors in the water column. This pattern of depth related abundance varies between sites, but is consistent within sites for each batch of settling larvae.

ii) A 'patch' of settling larvae may cover an area at least 4 km wide.

iii) Although some spat were collected throughout the period over which collectors were set, most spat settled during a restricted time period which coincided with an increased percentage of ripe scallops in adjacent populations.

iv) The timing of settlement at the two sites on the Tasmanian north coast following the 1985 spawning, suggests that settling spat originated from different spawning populations. Settlement at the same sites following the 1986 spawning was consistent with dispersal from one spawning population, most likely that in eastern Banks.

(ii) The relationship between spawning stock, spat settlement in collectors, juveniles on the sea bed, and subsequent recruitment.

RESEARCH SUMMARY

A preliminary analysis of the relationship between spawning stock and the number of spat settling in collectors within the same 1° rectangle was carried out using the mean flesh weight caught per hour obtained from catch statistics over the spawning period, as an index of spawning biomass.

In 1985 and 1986, the bulk of the commercial catch came from the beds in eastern Banks Strait. Some scallops were also landed from the grounds north of King Island in 1986, but catch rates from this area were relatively low indicating that scallop densities were lower than in Banks Strait.When the data from both years were pooled, the number of spat caught in the collectors generally increased as the mean catch per hour in the corresponding 1° rectangle increased. A regression of log mean spat numbers per bag against the log mean catch per hour showed a significant linear relationship (fig. 13).

A similar analysis was carried out to examine the relationship between adult biomass and the number of juveniles caught during surveys in 1986 and 1987. Few recently settled juveniles were caught in either year and the number of juveniles showed no significant correlation with either the number of spat settling on arrays, or the catch per unit effort of the adult stock in the same region.

CONCLUSIONS

i) At the current low levels of adult biomass,the number of larvae achieving the pediveliger stage may be related to the size of the parental population. This gives credance to the view that larvae may not be dispersed widely from the adult population.

ii) In addition to controls on the production and survival of larvae to metamorphosis, there are additional factors which control settlement and survival of juveniles on the sea bed. Such factors postulated for other species, include the sometimes adverse role of small scale hydrodynamic processes, the absence of suitable settlement substrata, and the effects of predation on settled juveniles.

iii) Fishing activity which takes place before spawning will reduce the number of effective spawners and make CPUE a less reliable measure of spawning biomass.

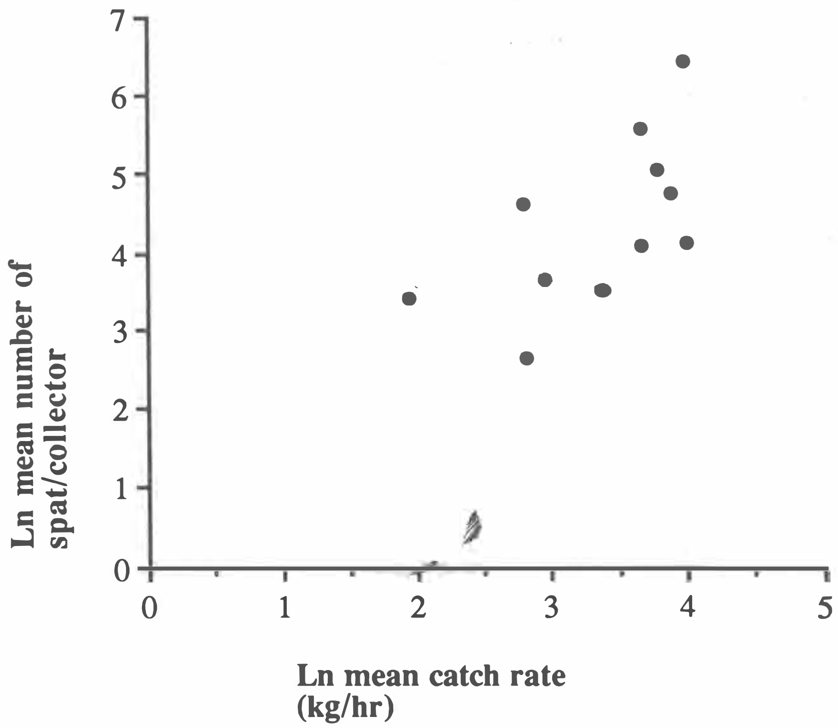

Fig.13. The relationship between spat settlement in collectors and catch per unit effort for the same 1° rectangle (1985 and 1986 combined).

3. THE CAUSE OF ABNORMALLY SMALL MEAT WEIGHTS IN SOME POPULATIONS.

Prior to the commencement of this study the King Island beds had been closed following reports of declining meat returns from scallops of normal commercial shell size.The Banks Strait bed had also been closed when surveys showed that much of the area contained scallops below commercial shell size. These closures were put in place in the expectation that the small shell-sized (juvenile) populations in Banks Strait would grow to commercial size, and that the low meat weight scallops in the King Island beds would improve in condition. On the basis of the existing data on the growth and mortality of *P. fumatus* it was not possible to predict when the juvenile scallops in Banks Strait might reach commercial size, and, apart from an assumption that the meat yield would be expected to increase with the laying down of roe prior to spawning in spring or early summer, no predictions could be made as to the likelihood of improvement in condition of scallops on the King Island beds.

In order to establish a more informed basis for such closures, a sampling program was set up to examine temporal and spatial variability in scallop condition throughout Bass Strait, and reciprocal transplant experiments were used to investigate the causes of this variability.

(i) Temporal and geographical variability in scallop condition

RESEARCH SUMMARY

Meat weights (adductor muscle + gonad) were measured for selected populations each month and for other populations at the peak of gonad development in September. The relationship between meat weight and shell height was determined from a least-squares fit of a linear regression to log-transformed data and the allometric growth coefficient (*b*) estimated for each population. The relative condition of populations was examined by comparing the meat weight of a 'standard' 80 mm scallop, estimated from the shell height-meat weight regression, during the period of maximum meat weight in September.

Estimated meat weights for six populations in southern Bass Strait showed a progressive decline towards the central north coast of Tasmania and to the north along the western side of the Furneaux Group (Table 1). The estimated meat recovery of less than 4 kg per bag for scallops from Prime Seal and Goose Islands suggests that fishing these grounds would not have been a commercial proposition. Meat weight at age curves for Ninth Island and Stoney Head diverge significantly when scallops are less than 10 months old.

Table 1. Estimated meat weight and yield per bag for an 80 mm shell height scallop from populations in southern Bass Strait. (Weight per bag based on 500 scallops per bag)

Locality	Weight (gm)	Weight per bag (kg)
King Island	12.39	6.2
Prime Seal Island	6.67	3.3
Goose Island	7.01	3.5
Banks Strait	14.84	7.4
Ninth Island	12.15	6.1
Stoney Head	11.58	5.8

Changes in population flesh weight (total weight - shell weight) over time were examined for the King Island and Banks Strait populations. Random samples were collected from each population in December 1985, March 1986, and thereafter at monthly intervals. A two factor analysis of variance showed the location of the population, time of sampling, and the interaction term were all highly significant. Scallops from King Island had smaller flesh weights than those from Banks Strait, and remained smaller, despite an overall increase in condition in both beds (fig. 14).A subsequent decline in the mean flesh weight at Banks Strait did not occur in the King Island population and by September the mean flesh weight of both populations was similar.

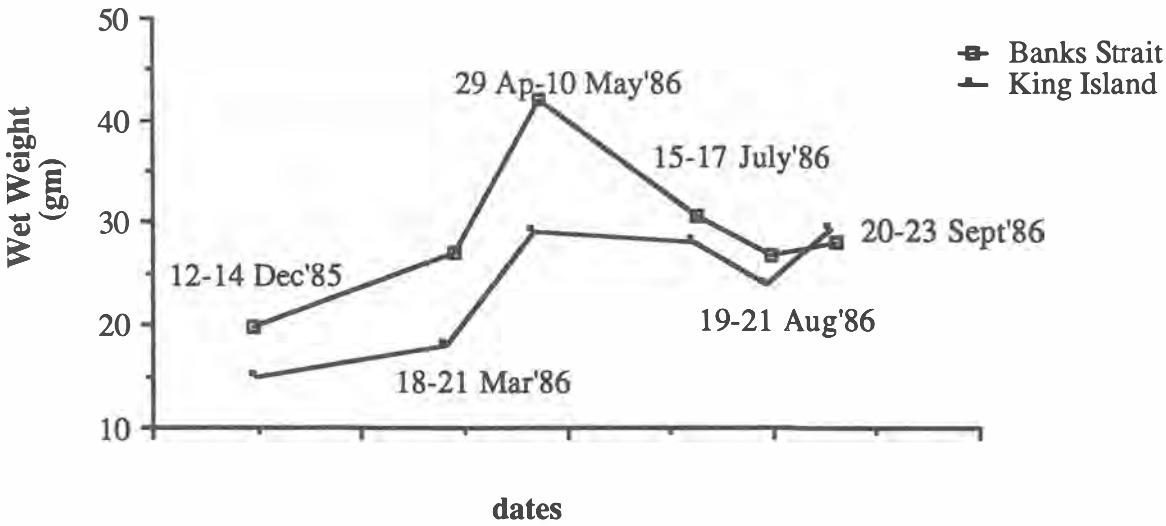

Fig.14. Changes in mean flesh weight in wild populations of *P. fumatus*

(ii) Reciprocal transplant tag-release experiment.

Changes in flesh weight of scallops from the King Island and Banks Strait populations were further examined in a reciprocal transplant experiment. The scallops were taken from each population, measured and weighed, and then tagged with sequentially numbered plastic coated stainless steel wire tags. The tags were attached to the lower (right) shell by drilling a small hole close to the margin of the auricle. Scallops from King Island were released there, and also transported to Banks Strait and released. Those from Banks Strait were treated similarly. The scallops for any treatment were released in one batch, as close together as possible. This experiment was dependent on the recovery of tagged scallops by the commercial fishing fleet and from aimed drags by the research vessel.

At the start of the experiment a subsample was taken from each source population to establish a shell height to shell weight relationship. This was then used to estimate the shell weight of each tagged scallop, and, by difference,the flesh weight from the measured total weight .The flesh weight at the end of the experiment was determined directly. The numbers of scallops released and recaptured at each location are given in Table 2.

Table 2 Number of scallops released and recaptured alive in the release/recapture transplant experiment

Location Caught	Location released	No. Released	No. Recaptured
King Island	King Island	500	0
King Island	Banks Strait	738	27
Banks Strait	King Island	1486	9
Banks Strait	Banks Strait	499	22

Despite considerable fishing effort by the research vessel, and the presence of a small commercial fleet on the release grounds, none of the King Island source scallops were recaptured on the King Island grounds. This considerably reduced the value of the experiment by removing its orthogonality. The recaptures were made at varying intervals so the weight increment of each animal was standardized by the number of days each was free Many scallops had lost weight, and a significant negative relationship existed between initial weight and the time-standardized weight change in both groups of transplanted scallops . Because of this, the data was standardised by dividing by both the initial estimated flesh weight and the number of days between release and recapture. Due to the lack of orthogonality it was not possible to perform a two factor analysis of variance as originally intended. A one factor analysis of variance, however, indicated that there was no significant difference in standardized flesh weight increment between any of the experimental groups (Banks Strait to King Island, King Island to Banks Strait, Banks Strait to Banks Strait).

(iii) Reciprocal transplant caging experiment.

Scallops were taken from the King Island and Banks Strait populations in the same manner as for the tagging experiment and held in arrays of hanging cages for six months. The aim of the experiment was to examine the change in condition of the scallops with respect to source population (King Island, Banks Strait), density (number of scallops per treatment), and cage location (King Island, Banks Strait). The cage arrays were located as close to each source population as possible without interfering with fishing activities (fig. 11), and in water depths of 30 metres to allow access to the cages by diving . Each array consisted of ten cylindrical cages 50 cm in diameter made from 3 x 4 cm nylon trellis mesh. Each cylinder was divided into ten compartments by horizontally aligned partitions made of the same material and spaced 25cm apart. In each array five cages held tagged scallops from King Island, and five held those from Banks Strait. All ten compartments of each of the cages held the same number of scallops, but each of the five cages from any one source held scallops at different densities (2, 6, 10, 14, and 18 scallops per compartment). The ten cages in any one array were suspended vertically 2 m off the bottom and the order of cages in each array was randomized.

a) Relative condition. Estimates of relative condition were made by comparing the observed flesh weights of individuals at the end of the experiment with their estimated weights had they remained in their original wild population. The expected weights were estimated from samples drawn from the wild source populations the end of the experiment. The ratio of the observed to expected flesh weight for both source populatons was examined for density and transplant effects by a two way analyses of variance.

For the Banks Strait source scallops the transplant effect was highly significant; the density effect was also significant, but at a lower level. There was no significant interaction. At the end of the experiment, Banks Strait scallops transplanted to King Island were all in better condition at all densities than their counterparts in the wild source populations. Those caged at Banks Strait also did better than the wild populations, but only at densities of less than six per cage. At both sites there was a progression of improvement in condition with decreasing density.

The King Island source scallops also showed a highly significant transplant and density effects.At the end of the experiment those held at King Island were heavier than those transplanted to Banks Strait and were also in better condition at all densities than the wild King Island populations. Those transplanted to Banks Strait did very poorly at all densities and had lower weights than their counterparts in the wild source population. In these scallops the interactive term was significant . Caged scallops at King Island did better at all density levels than those held at Banks Strait, and the monotonic decline in flesh weight with increased density shown at King Island was absent in those held at Banks Strait.

b) Absolute condition. Efforts were made to select scallops of similar size when setting up the experiment, but because of the different size composition of the two source populations, this was not successful. The mean size of the King Island scallops was smaller than that of the scallops from Banks Strait, and their flesh weight was lower at all shell heights. Because of this, the increase in flesh weight for each scallop was calculated and standardized by its initial weight in the same way as in the tagging experiment reported above.

The results of a three way analysis of variance showed that source, location, and density were all significant, as was the cage location by population source interaction term. The experiment showed an unexpected result in that fifteen of the twenty combinations of source population, cage location, and density showed declines in flesh weight during the period of the experiment. The density effect was usually reflected in increased weight (or decreased weight loss) at lower densities, and this was most apparent in the King Island source scallops held at King Island. The three factors investigated clearly differed in the magnitude of their effects, and their relative importance was as follows:

- the location of the experiment, since all scallop treatments located at King Island appeared to do better there than did their equivalents at Banks Strait;

- the population source, since scallops taken from the King Island source population did better both at King Island and at Banks Strait than did those from the Banks Strait population;

- the density, since the wet weight increase (or reduced weight loss) measured for either population source or location was consistently greater at lower densities.

The significant interaction term suggested that the effect of moving scallops from one side of Bass Strait to the other had, of itself, little effect. It was the region into which they were transported that was most important, for although the King Island transplants did less well than did those left at King Island, the Banks Strait transplants did much better at King Island than those left at Banks Strait.

During the experiment approximately half of the experimental population escaped from the cages and were lost from the experiment. Another 298 died and remained in the cages. Analysis of these individuals showed that they were not distributed evenly between the population sources or the cage locations (Table 3). More died from the King Island populations than the Banks Strait populations, and more from both sources died at Banks Strait.

Table 3. Number of dead scallops in cage experiment.

Cage Location	Source Population: King Is	Source Population: Banks St.	Totals:
King Is	60	38	98
Banks St	143	57	200
Totals:	203	95	298

c) Food levels. Phytoplankton are believed to form a major part of the diet of scallops, and reduced phytoplankton abundance is implicated in the results described above. Examination of the chlorophyll *a* levels at the two cage sites indicates that these levels, although relatively low at both sites, were higher at King Island for all but the last sample taken during the experimental period (fig 15). When examined for the whole year at stations close to the King Island and Banks Strait source populations, chlorophyll *a* concentrations were greater in samples from Banks Strait during the period when scallops were in better condition there. During the period of the experiment, the King Island levels became equal to or slightly higher than those at Banks Strait (fig 16).

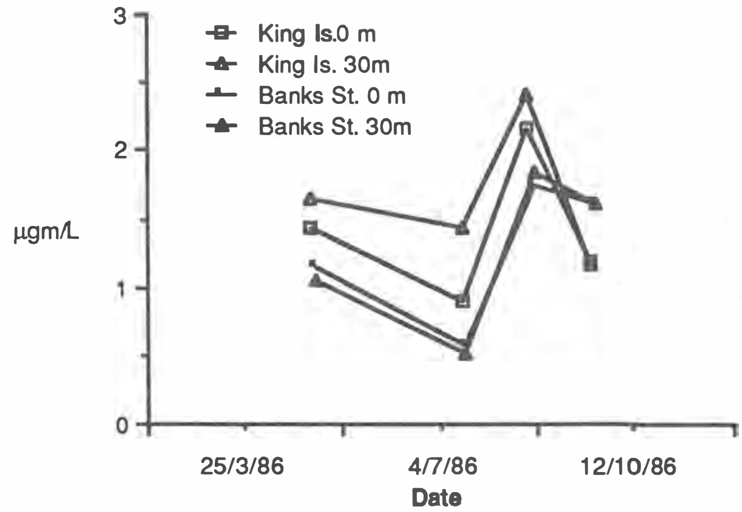

Fig. 15. Variation in chlorophyll *a* concentration at the King Island and Banks Strait cage sites.

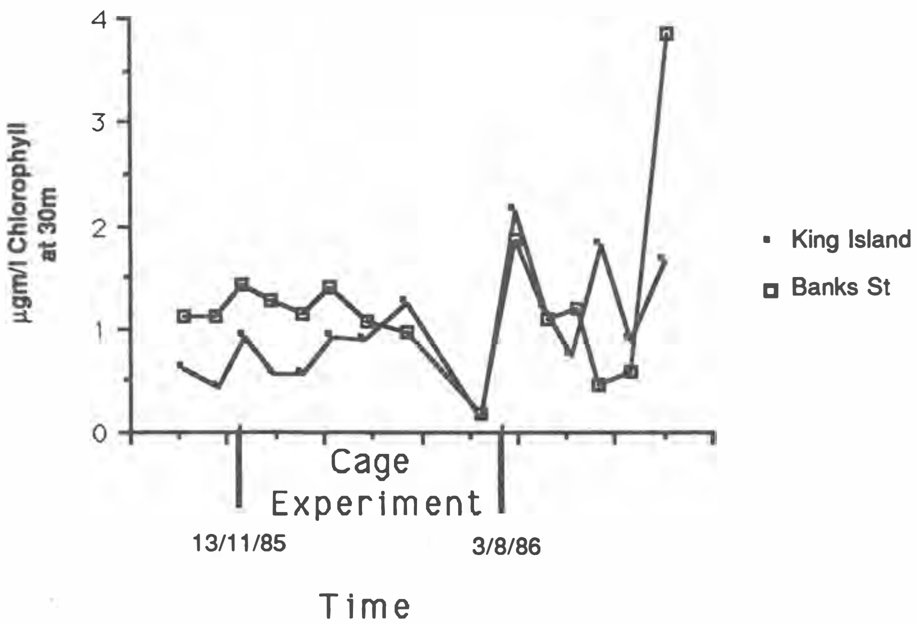

Fig. 16. Variation in chlorophyll *a* concentration at the Banks Strait and King Island fishing grounds.

CONCLUSIONS:

i) These preliminary results indicated that variability in meat weights between populations is marked and that there are discernible temporal and spatial patterns in the distribution of this variation.

ii) Populations showing best condition were located nearer to the the eastern and western margins of Bass Strait, e.g. Banks Strait and King Island. Historical catch data for southern Bass Strait obtained from fisherman's logbooks confirm this general pattern.

iii) Under experimental conditions, scallops in poor condition show higher mortality rates than those in good condition. Howerer, they may also improve their condition when subjected to improved environmental conditions.

iv) In cage experiments, changes in condition were positively correlated with reduced densities and increased concentrations of chlorophyll *a*. This, along with the observed distribution of spatial variability in growth and condition is consistent with the hypothesis that the condition of populations is related to nutrient input into Bass Strait. This is believedto arise from enrichment from deeper waters at the shelf break along the eastern and, to a lesser extent, western margin, followed by advection into the typically nutrient-poor central region.

4. THE INFLUENCE OF RECRUITMENT ON STOCK STRUCTURE.

Tagging studies and modal analysis of shell height frequency distributions from consecutive samples (see below) indicate that the growth rate of the shell declines as scallops approach sexual maturity during their second year of life. This slowing of growth in mature animals leads to a merging of year classes and results in unimodal shell height frequency distributions. To date, direct-aging techniques using shell annuli have proved too unreliable and without some prior knowledge of the settlement history of a population, it is often impossible to determine if the mature scallops on a bed are the result of one or more recruitment episodes.

RESEARCH SUMMARY

As reported above, standard commercial dredges under-sample scallops in smaller size classes and early surveys are likely to have significantly underestimated the contribution of 0+ and 1+ cohorts to the stock structure. Nevertheless, there is some limited information on population structure from surveys prior to the CSIRO study and these provide an indication of the settlement history on a few beds.

The population size structure of scallops on beds located by the then Tasmanian Fisheries Division to the west of Banks Strait during the 1973 survey of Bass Strait, was dominated by a single size mode but the size distributions of samples indicated settlement over at least three consecutive years. Scallops located off Stanley during the same survey were again dominated by one mode but showed no evidence of subsequent recruitment. The King Island beds, which were first surveyed in February 1985, also showed only one mode of unknown age composition and these scallops showed little change in size over the next two years. Survey data suggests that scallops were recruited to the eastern Banks Strait region in all years from 1979 to 1983, but not always to the same beds. Samples taken east of the 20 fathom line during the "Challenger" survey in June 1984 frequently showed a bimodal size structure consistent with recruitment in 1979 and/or 80, and 1981. Scallops to the west of the 20 fathom line settled in late 1982 or early 1983, and these, along with a further settlement in the same region in late 1983, resulted in the beds which produced the bulk of the catch in the 1986 fishing season.

During the CSIRO study, populations throughout Bass Strait were sampled with the dredge/net combination to detect new recruits before year classes had begun to merge. The intervals between samples varied for different populations and ranged from 1 to 12 months between August 1986 and June 1988. The results of these surveys indicate:

- The fishery off Lakes Entrance in 1987 was sustained by a single settlement from the 1985 spawning. No significant settlement has occurred in this area since.

- There has been no settlement on either the King Island or Banks Strait grounds since 1983.

- On the Tasmanian northeast coast, the grounds off Stoney Head were the result of settlements following both the 1984 and 1985 spawnings. When these beds were opened to fishing in 1987 most of the population was still below the minimum legal size for commercial scallops in Tasmanian waters.

- Discrete beds located off Goose Island and Ninth Island resulted from settlement following the 1985 spawning and have shown only minor recruitment in subsequent years.

CONCLUSIONS

i) Historical and recent surveys of Bass Strait indicate that commercial beds may result from single settlement events or by the accumulation of cohorts from settlement over a number of years.

ii) Using the dredge/net combination, changes in the age composition of scallop beds in Bass Strait can be followed if the sampling interval is less than two years.

5. ESTIMATES OF GROWTH, MORTALITY AND REPRODUCTION FOR USE IN YIELD-PER-RECRUIT ANALYSES.

A. GROWTH AND MORTALITY

Historically, all major scallop grounds have been located in the shallow (<60 m) waters around the periphery of Bass Strait where the potential for localized differences in productivity to affect individual beds is high. This study used a combination of regular sampling and modal analysis to determine broad scale patterns in growth variability, and tag and recapture experiments to examine growth and mortality patterns on selected scallop grounds subjected to different hydrological influences.

RESEARCH SUMMARY

(i) Tag and recapture experiments

The tag and recapture experiments were conducted on the commercially exploited beds at King Island and Banks Strait. Scallops were measured and tagged as described above and released randomly over each bed as the research vessel steamed a zig-zag course across the grounds. Six releases were carried out on the Banks Strait ground, and four releases over the King Island ground. Recaptures were made during fishing by the commercial fleet and tags were recovered either directly from fishermen or subsequently from processors.

The methodology involved a multiple release, multiple recapture strategy. The first release location was fished for three weeks after the first release, and thereafter the fishery was closed for about eight months. During the closure, batches of between 1000-2000 tagged scallops were released in each locality each month over a six monyh period. An additional release of double tagged animals was included to examine tag loss.

The tagging data have not yet been fully analysed for either growth or mortality rates. Difficulties have arisen due to the intensity of fishing which resulted in all the recaptured animals being returned within one year,the slow growth of animals at the tagged size, and the high levels of indirect fishing mortality associated with dredging. New and more appropriate analytical methods are being developed and further analysis is currently under way. A summary of the tagging experiments is given in Table 4.

Table 4. Summary of tagging experiments. Release days are counted from 1 January 1985. Fishing took place in Banks Strait from day 281 to day 300, and from day 528 to 730. Fishing occurred from day 308 to 354, and 547 to 789 on the King Island ground.

Banks Strait releases

Release day	# Released	# Recaptured live	# Recaptured dead	#Recaptured condition unknown	% Recaptured live
288	1500	146	1	1	9.7
289	1500	94	4	1	6.3
316	1500	108	8	0	7.2
352	500	22	0	1	4.4
380	1361	206	17	2	15.1
407	2000	203	12	3	10.2
King Island releases					
319	2050	29	2	0	1.4
348	500	0	1	0	0
378	1500	17	4	1	1.1
409	3000	89	4	0	3.0

(ii) Growth estimates from modal analyses.

Growth rates were determined by following the progression of modes in shell height-frequency distributions obtained from consecutive samples. Scallops were collected with the dredge/net combination. This consistently caught scallops down to 10mm shell height and enabled us to reliably locate juvenile scallops less than 6 months after settlement and to follow the changes in modal size with time. The interval between samples varied for different populations and ranged from 1 to 12 months.

Height at age relationships were determined for cohorts where the year of settlement was known. All ages were assigned assuming a settlement date of 1 November. Values for the von Bertalanffy growth parameter (K) were estimated for scallops at Stoney Head and Ninth Island. The size ranges of cohorts after one and two years of growth in Port

Phillip Bay and at five locations in Bass Strait are shown in Table 5.

Table 5. Shell height of one and two year old scallops in Port Phillip Bay and eastern Bass Strait.

Locality	Shell height (mm) after: 1 year	2 years
Port Phillip Bay	50 — 70	71 — 87
Lakes Entrance	45 — 65	64 — 80
Goose Island	34 — 51	52 — 70
Banks Strait	40 — 62	65 — 83
Ninth Island	39 — 57	60 — 80
Stoney Head	30 — 46	50 — 70

The growth rate of scallops in Port Phillip Bay is significantly higher than that at any of the five locations in Bass Strait. The variation in growth among the four south-eastern sites indicates a progressive decline in growth rates with increasing distance west of Banks Strait. This trend is most marked between the populations at Ninth Island and Stoney Head which are only 30 km apart. Growth curves for scallops from Ninth Island and Stoney Head indicate that differences in growth rate first become apparent when scallops are less than 12 months old, and the curves diverge until scallops begin to mature for the first time when about 20 months old.The estimated von Bertalanffy growth coefficients (K) for the two populations are 1.12 for Ninth Island and 0.45 for Stoney Head.

(iii) Mortality

a) Natural and fishing mortality. Estimates of natural and fishing mortality rates based on the tag release and recapture experiments have not yet been completed (see above).

b) Indirect (non-yield) fishing mortality. Indirect fishing mortality was investigated in an area of high scallop abundance during the 1986 fishing season. Most of the fleet fished the area for the first two weeks of the of the season but fishing was discontinued when catches showed evidence of high bacterial contamination. Catches from this area were sampled on the opening day of the season (12 June,1986), again two weeks later, and thereafter at monthly intervals until September, 1986. Catches were sampled by taking a random sample of approximately 0.1 m^3 from a drag and sorting this sub-sample into three categories: live undamaged, live damaged and dead scallops. A damaged scallop was defined as one so badley crushed or broken that it was likely to have been discarded during normal sorting.

An analysis of variance of the proportion of scallops in each category indicated that replicate sub-samples taken from the same catch were not significantly different but significant differences occurred between catches over time. Changes in the proportion of dead, damaged and live scallops scallops in catches sampled over the 100 day period following the start of fishing are shown in fig.17. The proportion of dead scallops continued to increase even after fishing had ceased, and by day 100 over 80% of the catch was composed of dead shell. Opportunistic sampling of the same area showed that by July 1987, no live scallops remained on the Banks Strait grounds.

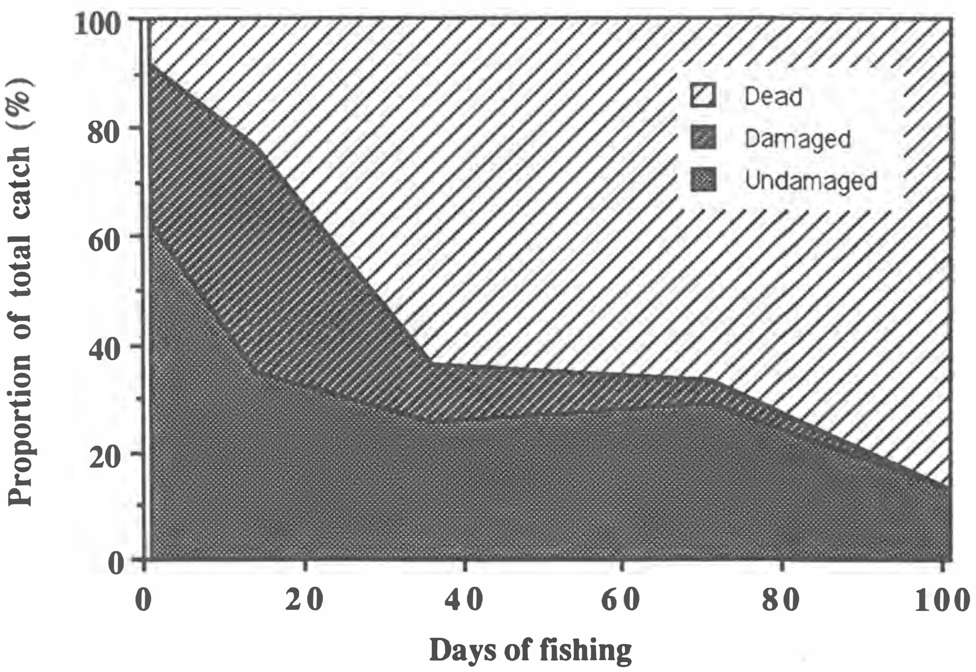

Fig.17. Changes in the proportion of dead,damaged and undamaged scallops in sub-samples of catches from Banks Strait following the opening of the 1986 fishing season.

(iv) Yield per Recruit

Provisional estimates of the age at which scallop populations would maximize their meat weights were calculated for Port Phillip Bay, Ninth Island and Stoney Head and are presented in Table 6. The estimates for Port Phillip Bay are based on von Bertallanffy growth coefficients given in the literature and derived from two tagging experiments which were carried out 20 years apart. Estimates of the natural mortality rate for Bass Strait scallops awaits analysis of the tagging experiments reported in section **5(i)**, however, in the interim, the best estimate of the instantaneous mortality rate has been calculated from tagging experiments in Port Phillip Bay ($M = 0.52$ year $^{-1}$) and this was used here in the calculation of yield-per-recruit estimates. The exponent term 'b', which relates shell height to flesh weight, was calculated from measured shell height/flesh weight ratios for the Ninth Island and Stony Head populations. A value of $b = 3$ was applied to the Port Phillip Bay data.

Table 6. Estimated age at which yield-per-recruit is maximized for scallops in Port Phillip Bay and southern Bass Strait.

Locality	K	b	Age (months)
Port Phillip Bay (1983-85)	1.57	3.00	18
Port Phillip Bay (1963-67)	0.57	3.00	29
Ninth Island	1.12	2.48	19
Stoney Head	0.45	3.47	34

B. REPRODUCTIVE BIOLOGY

Sampling was carried out between July 1986 and July 1987 at King Island and Banks Strait, and between July 1987 and December 1987 off Stoney Head. Each month, scallops were collected using a standard commercial dredge, a sub-sample from which were selected at random for immediate macroscopic examination of gonads. Gonads were classified into one of six maturity stages in the field, each gonad was photographed and then fixed for subsequent histological processing. The remaining sample was frozen and returned to the laboratory where shell height and body component weights were recorded. A gonad index was calculated using the relationship gonad fresh weight x 100/total fresh flesh weight.

Samples from the Banks Strait and the King Island sites showed an increase in the mean gonad index from a minimum in May to a peak in September. This was followed at both sites by a decline in gonad index between September and November, a slight recovery between November and December, and a further decline towards the May minimum after December. The more restricted data set for Stoney Head on the Tasmanian north coast also shows a September maximum.The gonad index data, along with the results of both the macroscopic and histological staging indicate that in 1986, major spawning took place in Banks Strait between October and November. This was followed by some recovery of gonad condition and a lesser spawning between December and January. At King Island a similar pattern occurred but spawning starting approximately one month earlier and the second peak was equivalent to the first in intensity. There was no evidence for two spawning peaks at Stoney Head in 1987.

This study is also investigating the use of stereological techniques to quantify the occurrence of structures in histological sections. It is hoped that this technique will allow the removal of subjective estimates from histological staging techniques and permit statistical analysis of these data. This aspect of the study has not yet been completed.

Estimates were also made of the number of eggs contained in the ovaries of scallops from Ninth and and Stoney Head. The mean number of eggs per gm of ripe ovary was 1.80 $\times 10^6$ (range 1.43 — 2.04 $\times 10^6$) with no significant differences between ages or location. Gonad size, and therefore fecundity, is however, dependent on scallop condition which shows marked regional variation (see above).

CONCLUSIONS

i) The growth rate of *P. fumatus* is extremely variable, particularly so in the first two years before maturity. Growth appears to be directly related to geographical and temporal variability in primary productivity rather to any genetic variability between populations.

ii) Mortality rates are greatly increased in fished populations, due to a large dredge-induced incidental component.

iii) Even if natural mortality is assumed constant, the inherent variability in growth precludes the use of an optimum age to maximize the yield per recruit. In productive areas where growth rates are high, fishing to maximize yield-per-recruit will result in scallops being taken before they complete a major spawning.

iv) Significant spawning first occurs in scallops when they are two years old. Fecundity is directly related to gonad size which is itself a function of scallop condition.

v) Although there is evidence for minor spawning occuring throughout the year, major spawning only occurred between September and January.

6. FACTORS CONTROLLING THE OBSERVED DISTRIBUTION OF SCALLOP BEDS IN BASS STRAIT

RESEARCH SUMMARY.

This investigation consists of an examination of the sediments, hydrography, and distribution of commercial scallop catches in Bass Strait. All sampling and historical data have been collected but await detailed analysis.

(i) Sediments associated with scallop populations in Bass Strait.

Sampling was undertaken to supplement information on the sedimentology of Bass Strait already published by the Bureau of Mineral Resources. Sediment samples were collected with a Smith-Macintyre grab at 10 nm intervals along the Tasmanian north coast, and at selected points off Lakes Entrance. A sampling grid, also at a 10nm spacing, was partially completed off the north-east of King Island, and to the north-east of Flinders Island on the old 'Sisters" grounds.

Samples were analysed for bulk textural properties using the mechanical method. Sediments were predominantly classified as medium to coarse sands, unimodal in size distribution with modal particle sizes in the 1.5-2.5 ø range. .The bulk of the sediments was composed of relic skeletal organic material and lag gravels derived from calcareous algae, bryozoa, foraminifera, and molluscs with subdominant arthropod, echinoderm, and polychaete components. Most of this material has been comminuted and redistributed to its present location by the generally strong tidal currents encountered at most of the sampling sites. A single sample was collected from a muddy environment known to contain scallops close inshore to Table Cape on the Tasmanian north-west coast. The mud component of this sample was of lacustrine origin, presumably originating from nearby river outlets. The scallop population in this area was always sparse and extensive exploratory dredging in 1987 found no scallops.

(ii) Hydrology of Bass Strait.

A data base has been compiled containing all hydrological data relating to Bass Strait held in the oceanographic archives at the CSIRO Marine Laboratories. This has been reformatted into statistical one degree rectangles.

Monthly sampling of a range of water quality parameters at fixed stations was undertaken between September 1985 and September 1987. Sampling at each station consisted of a vertical profile of salinity and temperature, and water samples taken at the surface, 25 m and 45m. The water samples were assayed for nutrients (silicate, phosphate, nitrate) and chlorophyll *a,* and a sample of water was preserved with gluteraldehyde for subsequent analysis of algal composition if required. At this stage all data has been collated and await analysis.

Preliminary runs with a 2-dimensional model of water currents in Bass Strait have been carried out in collaboration with the Division of Oceanography.Wind data provided by the Bureau of Meteorological has been obtained for input into the model..

CONCLUSIONS.

All conclusions are tentative at this stage, but the following appear to hold true:

i) Preliminary observations suggest that scallop beds in Bass Strait lie principally on the periphery of the region, in areas of high current flow and coarse sediments.

ii) Beds which have historically contained scallops in good condition occurred in areas adjacent to regions of reported upwelling.

F. REPORTING

1. TALKS

Verbal presentations of the results of selected parts of the study have been given at a number of industry and scientific meetings.

Industry Meetings:

Professional Fishermen's Association of Tasmania (AGM) 1986/88
Lakes Entrance Scallop Fishermens Association 1986
Port Phillip Scallop Fishermen's Association 1986
Tasmanian Scallop Commodities Group 1987
Scallop Culture and Reseeding Workshop 1988

Scientific Meetings:

5th International Pectinid Workshop 1987
Annual Conference of the Australian Marine Sciences Association 1987
The Australasian Scallop Workshop 1988

2. REPORTS

FIRTA 85/83 Progress Report. 1985
FIRTA 85/83 Progress Report 1986
FIRTA 85/83 Progress Report 1987

3. PUBLICATIONS- to March, 1989

McLoughlin, R. J., Young, P. C., and Martin, R. B. 1988, CSIRO surveys show bleak outlook for Bass Strait scallop fishery. *Australian Fisheries*, 47(1), 43-46.

Young, P. C., 1986, Scallops, the boom or bust fishery. Why are catches so variable? *Proc. Symp. ANZAAS,* Hobart, 4-5 Oct, 1985.

Young, P. C., and Martin, R. B. *in press*, The Scallop fisheries of Australia and their Management. *Reviews in Aquatic Sciencies*, 1(4).

Martin, R. B., Young, P. C., McLoughlin, R. J., and West, G. *in press*, Bass Strait Scallops - 1988 survey by CSIRO. *Australian Fisheries,* 48(3).

APPENDIX

I : DETAILS OF THE GRANT APPLICATION

1. **Title of Proposal:** Bass Strait Scallop Investigations.

2. **Name of Applicant:** CSIRO

3. **Department, Division or Section:** Fisheries

4. **Proposal:** To commence an integrated investigation of the commercial scallop in Bass Strait, with the aim of providing resource assessments to guide and assist the management of the fishery. A research programme was to be established by CSIRO (FIRTA 85/83) with input from the Department of Genetics & Human Variation, La Trobe University (FIRTA 85/50), and the Fisheries & Wildlife Service, Queenscliff Marine Laboratories (FIRTA 83/32). It was proposed that during the three year period from 1 August 1985 to 30 July 1988 the programme would:

   (i) Examine and analyse all biological and commercial data currently available for the fishery.

   (ii) Initiate a coordinated research programme to provide the biological data required for the efficient management of the fishery.

5. **Name of Person Responsible:** Dr. F. R. Harden Jones.

6. **Qualifications of Staff Employed on the Program:**

P. C. Young, B.Sc. Hons. (Lond), ARCS, Ph.D.(Qld)
R. B. Martin, B.Sc., M.Sc. Hons. (Auckland)
R. J. McLoughlin, B.Sc. Hons. (NSW), M.Sc. (NSW)
G. West, B.Sc. Hons (Monash)
S. Kent, Biol. Res. Tech. Cert. (Armidale Tech.)

A number of staff were employed as technical assistants for varying periods of time, with funds from the FIRTA grant. They were:

C. Sprat, M. Palmer, R. Kirkwood and F.Klok.

7. Objectives:

(i) To clarify the status of the commercial scallop of Bass Strait with regard to the number of species exploited, and the degree of reproductive isolation between scallops in the major regions within the fishery.

(ii) To develop methods to assess the standing stock for annual allocation consistent with the rational exploitation of the resource.

(iii) To determine the cause of abnormally small meat weights.

(iv) To see if the stock structure in a region results from single or multiple recruitment.

(v) To refine estimates of reproduction, growth and mortality for use in yield per recruit analyses.

(vi) To determine the factors controlling the observed distribution of scallop beds in Bass Strait

8. Justification, Including Practical Application

The live weight production of scallops from Australian waters in 1982-83 was estimated as a record 34,600 tonnes, the total value of production being $25.8 million. This product is taken mostly from the waters of South Eastern Australia, in particular Port Phillip Bay and Bass Strait, but scallops are also fished along the New South Wales, Queensland and West Australian coasts. All these fisheries have a history of widely fluctuating catches. Almost all the South Eastern catch is composed of individuals of the genus *Pecten*, however in the Bass Strait region three species have been described - *P. fumatus*, *P. albus*, and *P. meridionalis*, all of which are morphologically similar, and although it is thought that they may be one species, there is no evidence available to confirm or deny this assumption.

The Bass Strait component of the fishery increased rapidly during the 1970's, and by 1981 comprised 72% of the Australian landings, (separate estimates were not currently available for the proportion contributed to this by Port Phillip Bay). This increase in landings from Bass Strait was due to the discovery of good beds in the vicinity of Lakes Entrance, King Island, the Furneaux Group and Northern Tasmania, and their subsequent exploitation by both Tasmanian and Victorian vessels. Since 1964 the Victorian Fisheries and Wildlife Division have conducted annual surveys of scallop stocks to provide management advice for the Port Phillip Bay fishery. However similar surveys conducted off Lakes Entrance between 1971-1980 to determine the extent of the beds and the abundance of commercial scallops, showed, when compared with subsequent commercial catches, that unlike the Port Phillip Bay scallops, the survey data and commercial catch data were not consistent. Early work by Fairbridge (1953) and Olsen (1955) were still the only published research work providing general biological information on commercial scallops in South-Eastern waters, and the only detailed work completed to date on reproductive biology was an unpublished Honours thesis by Harrison (1961). Unpublished data relating to growth rates and mortality rates was said to exist for commercial scallops of Port Phillip Bay and Eastern Tasmania. But analysis by CSIRO of growth and mortality coefficients derived from this data indicated that they were too inaccurate for yield-per-recruit estimates of the Bass Strait fishery.

More recently (1984-85), three major areas were closed by the Commonwealth in the Bass Strait region, following reports of small and uneconomically sized scallops. Surveys conducted on behalf of the Bass Strait Scallop Task Force showed that in one area (Banks Strait) the scallops were small because they were young and had small shell sizes. In two other locations (King Island and Lakes Entrance) although the scallops had commercial shell sizes, they had extremely small meat weights, well below those required to make an economic return. The cause of this low meat weight was completely unknown, and whether it would increase with time and relief from fishing pressure was also unknown. Comparison with other bivalve species suggested it could be due to normal seasonal variability, lack of food, or change in the genetic composition of the stock, leading to low growth rates. The area closures were sufficiently large to prevent most of the fishing from some entire ports (e.g. Lakes Entrance) and it has become extremely urgent to determine the reasons for the small meat weights, and if and when they will improve.

The Ad Hoc Technical Committee to the Bass Strait Task Force met to discuss the needs for scallop research in the Bass Strait and concluded that apart from resource surveys, no biological research had been performed in the Bass Strait region, and there was considerable need for the following:

(i) Confirmation that the Bass Strait fishery was exploiting one species and one stock.

(ii) Determination of annual estimates of standing stock available to the fishery.

(iii) Determination of the seasonal changes in condition and causes of unusually small meat weights in Bass Strait scallops.

(iv) Determination of reproduction, growth, and mortality factors applicable to Bass Strait, since those derived from Port Phillip Bay and elsewhere were not applicable to Bass Strait, due to huge variability within the estimates.

(v) In selected areas, to find out if commercial beds resulted from a single recruitment or whether repeated recruitment occurred to the same beds.

(vi) To find out if environmental characteristics are correlated with scallop beds so further exploratory surveys would be stratified within the regions likely to contain scallops.

The Technical Committee also recognized that there was a need for work on the fishing characteristics of the commercial dredge, requested the Australian Maritime College to consider such a study, and noted that the underwater TV requested in the present proposal would be also available for these subsequent investigations.

9. Location of Operations:

Program operations were based at the CSIRO Marine Laboratories, Hobart. The associated studies of the collaborating agencies were, in the case of La Trobe University, based in the Department of Genetics and Human Variation; and in the case of the Ministry of Conservation, Forests and Lands - at the Marine Science Laboratories, Queenscliff.

Sampling of commercial populations, tagging, and field experiments was by the use of a charter vessel based at Devonport. Laboratory analyses of genetic variation were carried out at La Trobe University, whilst histology, data processing, analysis, and reporting was based at the CSIRO Marine laboratories, and at the Marine Science Laboratories, Queenscliff.

10. Proposal in Detail:

I. PLAN OF RESEARCH

Details of the plan are given under project headings.

(i) *Determination of Species and Stock Identity*

Lead Agency - La Trobe University (FIRTA 85/50)

Three scallop species have been described from the Bass Strait area - *Pecten albus, P. fumatus,* and *P. meridionalis.* Although the present management assumed a single species, there was no current evidence that this was the case, and in view of the extreme plasticity of shell shape, examination of genetic variation was the easiest and most appropriate technique to determine the species and stock identity. Preliminary results from La Trobe University had already determined a number of polymorphic enzyme systems in scallops from this region, and it was anticipated that the work would produce a preliminary answer to this question within the first year.

The work was integral to all other studies, since the assumption of a single species was implicit in the rest of the proposal. The sampling was done by CSIRO and MSL as part of their field studies, supplemented by samples from commercial sources and Tasmanian Department of Sea Fisheries. Samples were frozen in liquid nitrogen and transported to La Trobe University for analysis. Where necessary, samples were air freighted in dry ice. More complete details were included in the resubmitted FIRTA 85/50.

(ii) *The Development of methods to assess standing stock for annual allocation*

(a) Analysis of Historical Data.
Lead Agency: CSIRO (FIRTA 85/83)

The Bass Strait Scallop Task Force had commissioned the compilation of all historical catch and effort data from the Bass Strait fishery, and to this end a limited data base had been set up, which amalgamated catch and effort records by location from the records held by Tasmania and Victoria. CSIRO undertook to perform an initial time series analysis of this data to determine if it was possible to correlate stock abundance with environmental variables, including those which are known to be cyclical in nature. The analytical techniques used were to include conventional time series, regressive and multiple regression analyses, as well as more heuristic techniques such as Ivakhnenko's Group method of Data Handling.

(b) Development of techniques for Annual Survey.
Lead Agency: CSIRO (FIRTA 85/83)

In other scallop fisheries the estimation of annual quota allocation has been done by estimating stock size by survey prior to the start of the season. In Port Phillip Bay this is done by divers, and is used to allocate catch quotas. Unfortunately the Bass Strait is too deep and too extensive for diver survey, so some other method is required. This has been done by dredge survey in Georges Banks in Canada, and by remote TV in Britain. Estimation of year class strength requires a knowledge of the relative abundance by age, of scallops in the surveyed population, and this requires an assessment of the escapement of scallops from the sampling gear. There is some evidence that the size composition of samples caught by a single dredge is different from that caught when boats are operating as a fleet, and nothing was currently known about the catching characteristics of the Australian commercial dredge.

Data was to be collected, in the first year of the study, on the catching characteristics of the commercial dredge. Smaller and more efficient sampling gear would be developed specifically for survey work. This gear was to capture with known bias, all age classes on the beds, so accurate assessment of year class strength can be obtained.

An essential piece of gear required for this development was the underwater TV and still camera system which was to be used to investigate dredge action and scallop escapement in waters too deep for diving.

It was envisaged that in 1986 the Australian Maritime College at Launceston would commence a full scale gear technology investigation of the commercial dredge, as part of the Integrated Bass Strait Scallop Investigations and the camera system would be made available for their use.

(c) Spat Collectors.
Lead Agencies: MSL (FIRTA 85/32),
CSIRO (FIRTA 85/83)

The Marine Science Laboratories had set up a series of spat collectors adjacent to the Lakes Entrance fishing grounds. Tasmania's Department of Sea Fisheries had set up similar collectors adjacent to Bass Strait. Although the latter were set up under FIRTA funding to investigate re-seeding of scallop grounds, the data from these can be used to investigate the potential of using spat collection as an index of future recruitment success. If there is a correlation between spat settlement and subsequent recruitment, then spat settlement collectors could provide an index of abundance analogous to the puerulus collectors for the western rock lobster.

It was envisaged that CSIRO would collaborate with Victoria and Tasmania to extend the area of distribution of spat collectors in Bass Strait, and to help calibrate the collectors off Lakes Entrance to match those off N.E. Tasmania. Data on settlement from both areas was to be monitored and related to subsequent stock size determined from commercial sources and selected sampling.

(iii) *The Seasonality and Cause of Small Meat Weights*

(a) Seasonal Variability in Reproductive Condition and Meat Weights.
Lead Agencies: MSL (FIRTA 85/32)
CSIRO (FIRTA 85/83)
La Trobe University (FIRTA 85/50)

The scallop beds off Lakes Entrance contained scallops of commercial shell size but small meat weights, and showed no indication of growth over a 4-month period.The scallop beds off the Furneaux Group contained scallops which were both below commercial shell size and also had small meat weight. It was not known if these scallops were growing as only one survey had been carried out before the CSIRO study commenced.

It was intended to sample these two beds at intervals of one month to collect data on shell size, gonad weight and condition, adductor muscle weight and genetic composition, and to correlate these with seasonal changes in environmental variables. Environmental variables which were to be monitored included temperature, salinity, food levels (measured as chlorophyll *a*), , silt load, etc. Frozen scallops were to be sent to La Trobe University for genetic analyses. Sampling at Lakes Entrance was to take place in 1985-86, and at the Furneaux group in 1986-87.Histological analysis were to be performed at MSL and CSIRO and water analysis at the CSIRO Marine Laboratories, Hobart.

This series of samples was intended to indicate the time of year and environmental correlations to which small meat weights may be related, and determine the relationship, if any, between this and normal growth.

(b) Field Experiments.
Lead Agencies: CSIRO (FIRTA 85/83)
La Trobe University (FIRTA 85/50)

The sampling program outlined above was intended to identify those factors correlated with the occurrence of small meat weights, but not the causes of the phenomenon. The field experiments were designed to investigate the influence of reproduction condition, genetic composition, and availability of food on meat weights.

The approach was to use reciprocal transplant methods to factor-out main variables such as poor and good condition, poor and good food availability, homozygous and heterozygous genetic composition etc., in a series of field experiments with scallops held in lantern cages.

(iv) *To determine if stock structure results from single or multiple recruitment.*

Lead Agency: CSIRO (FIRTA 85/83)

Sampling for this segment was to be the same as for segment (iiia) above, i.e. monthly sampling of shell height distributions to follow changes in modal size. Sampling was to use the commercial dredge and the new sampling gear ((iib) above).

(v) *To determine estimates of reproduction, growth and mortality*

(a) Tag and recapture experiments.
Lead Agency: CSIRO (FIRTA 85/83)

These were to be performed in each of the three years to include:

The commercially fished areas, using the fishing fleet to recapture tagged scallops.

Within closed areas, using the fishing fleet to recapture the tagged scallops when areas are opened.

Within shallow areas, using diver observation and recaptures.

The tagging experiments were to be carried out to determine the range of growth and natural mortality within the Bass Strait Scallop Fishery. These estimates were then to be used as inputs in a yield-per-recruit analyses to determine the optimum size of capture, and the optimum time to open closed areas.

(b) Modal Size Analysis and Direct Ageing
Lead Agencies: CSIRO (FIRTA 85/83)
MSL (FIRTA 85/32)

Using the sampling device developed in (iib) above, CSIRO was to collect a time series of shell height frequency distributions as part of the monthly sampling program associated with activities (iic) and (iiia) above. Direct ageing by observing the growth of spat to recruitment size was to be conducted using material obtained at Lakes

Entrance (MSL) in 1985/86.

(c) Reproduction
Lead Agencies: MSL (FIRTA 85/32)
CSIRO (FIRTA 85/83)

Using the sampling strategy followed in (iiia) above, field staging and histological determination of reproductive activity was to be determined at Lakes Entrance (MSL) in 1985/86, and for other grounds (CSIRO) in subsequent years.

(vi) *Determination of reasons for the observed distribution of scallops,and their relationship to the physical environment.*
Lead Agency: CSIRO (FIRTA 85/83)

This element of the program was to be undertaken in two stages. In 1985/86 an analysis of historic catch and effort data was to be made to locate those areas which previously contained commercial amounts of scallops. These would be correlated with all existing environmental data and relationships, if any, drawn. During 1986/87 surveys of selected areas were to be made to test the implied correlations between the scallop distributions and the variability in the physical environment.

Sedimentological and water quality data was to be obtained from published sources, and also from the cooperation of CSIRO Division of Oceanography and the Victorian Institute of Marine Science, both of whom had worked in the area.

II. FACILITIES AVAILABLE

(i) CSIRO (FIRTA 85/83)

Workshop facilities for design and construction of the sampling device and any associated modifications or electronic equipment.
Hobart VAX computer and CSIRONET for complex analysis of existing and future data sets.
Laboratory facilities at the CSIRO Marine Laboratories, Hobart will be used for:

sediment analysis;
phytoplankton standing stock determinations and particulate carbon analysis;
nutrients analysis.

(ii) MSL (FIRTA 85/32)

Laboratory, data processing, administration, workshop and logistic back-up at the Marine Science Laboratories, Queenscliffe.

(ii) La Trobe University (FIRTA 85/50)

Liquid nitrogen equipment.
University vehicles for collection and transportation of tissue samples
Laboratory facilities for cellulose acetate electrophoresis.
Computer and data analysis facilities.

III. SUPPORTING DATA

(i) Previous work in this or related fields

The Division had an active involvement in scallop research during the early days of the industry in Tasmania. However, this proposal represented a new recent initiative for the Division of Fisheries Research. Dr. P.C. Young, the leader of this group, represented the Division of Fisheries Research on the Bass Strait Scallop Fishery Task Force, which he attended as an advisor. He has extensive experience in marine invertebrate population studies including commercially important species, and an international reputation in a range of fields of marine ecology. Publications that he has authored or co-authored which relate to the present proposals are attached. Of the professional supporting staff, Mr. R.B. Martin has extensive experience with marine invertebrate ecology - specifically echinoderms - and proven abilities to organize seagoing expeditions. Mr. R.J. McLoughlin had investigated the sediment structure of the continental shelf of parts of Australia, and has been associated with a team investigating sediments/biota relationships.

The Port Phillip Bay and Bass Strait scallop research program had been in operation at the Marine Science Laboratories since July 1983. A full progress report of the work to date was submitted with the 1985/86 application for continuation of funds (FIRTA 1983/32). Dr. D. Gwyther was leader of this program and together with Mr. P. McShane, Ms. B. Sause, Mr. D. Burgess and Ms. S. Foley, had formed a team of considerable experience in scallop studies and practical research techniques. Relevant publications are attached.

At the Ad Hoc Technical Committee to the Bass Strait Scallop Task Force, Dr. Gwyther re-examined his original proposal of three-monthly sampling at a number of grounds in the Bass Strait area (primarily with stock size structure and modal analysis in view) favouring more frequent sampling of the Lakes Entrance grounds. Evidence from recent surveys of these grounds together with other information on the current fishing situation suggested that many of the traditional grounds visited by Victorian vessels (especially parts of Lakes Entrance and N.E. Flinders Island) have been fished close to the point of commercially non-viability. And since future viability of these grounds must therefore depended upon new recruitment, the old stock size/age structure was both impossible to determine, and largely of historical interest as far as management of these areas was concerned. For other beds (Banks St., King Island), this was not necessarily the case, but the re-evaluated studies proposed by Marine Science Laboratories within the present integrated proposal, focused on condition, reproduction, spatfall and growth to recruitment for the Lakes Entrance grounds, with the emphasis being on monthly sampling. This would not only provides better sequential data for use by management, for example in the timing of the opening or closing of grounds, but also considerably reduce costs of charter of commercial vessels.

(ii) Publications and Reports of General Relevance to this Submission.

(a) CSIRO

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11. Proposed Commencement Date and Anticipated Completion Date

Commencement date	August 1985.
Completion date	July 1988.

12. Funds Requested (for details see Annex A)

SUMMARY

	Year 1	Year 2	Year 3
	$	$	$
Total salaries and wages	34,456	37,947	62,725
Total travel expenses	4,305	2,350	3,762
Total operating expenses	83,000	142,500	157,500
Total capital items	91,917	-	-
GROSS TOTAL COST	213,678	182,797	223,987
Estimated income	Nil	Nil	Nil

13. Funds to be provided by the Applicant

	Year 1 $	Year 2 $	Year 3 $
(a) Total salaries and wages			
PRS-Max. + 20% Super	51,600	55,556	61,067
ES(II)-Max. + 20% Super.	33,700	35,270	38,659
ES(II)-Max.+ 20% Super	-	-	35,678
ES(I)-step 5 + 20% Super.	25,500	27,335	32,243
Total Salaries & Wages	110,800	118,161	167,647
(b) Operating expenses			
Computing development	2,000	3,000	1,500
Diving boat running expenses	5,000	6,000	3,000
Tags	1,000	-	-
Publication expenses	-	-	1,000
Chemicals, glassware, etc.	5,000	5,000	5,000
Total Operating Expenses	13,000	14,000	10,500
(c) Travel expenses			
International pectinid conference	-	-	10,500
Total Travel Expenses	-	-	10,500
(d) Capital items (relacement cost)			
Photosea 100 underwater camera	33,600	-	-
Nikonos underwater camera system	1,500	1,500	1,500
Spectrophotometer	-	35,000	35,000
Underwater communications unit	3,000	3,000	-
Olympus Vanox microscope	11,000	11,000	11,000
Wild stereomicroscopes (2x/3x)	7,000	6,000	10,000
Diving vessel and trailer	20,000	38,000	38,000
Air compressor, diving gear	2,000	3,000	3,000
Data logger and computer	-	-	5,800
Niskin bottles (3x)	-	3,000	3,000
Buoys and acoustic releases	6,000	-	-
Total Capital Costs	84,100	100,500	107,300
GROSS TOTAL COST	$207,900	232,661	295,947

14. Co-operating Agencies and their Functions

(i) Marine Science Laboratories, Queenscliffe.

Dr. Gwyther of the Marine Science Laboratories had a complementary proposal (FIRTA 83/32). The Bass Strait component of this was integrated with this proposal, as indicated in the body of the submission.

(ii) La Trobe University

La Trobe University submitted a complementary proposal (FIRTA 83/50) to examine the species and stock identity of the commercial scallop of Bass Strait. That proposal was modified to include a genetic analysis of the small meat weight scallop and was integrated into the present proposal as indicated in the body of this submission.

(iii) Tasmanian Department of Sea Fisheries

Tasmanian Department of Sea Fisheries was currently implementing a FIRTA funded study to examine the feasibility of reseeding scallop beds. Their proposal, as it dealt with scallop culture, was outside the scope of the present proposal. Their experiments on spat collecting were relevant however, and active cooperation was planned in the development, deployment and standardization of scallop spat collectors.

15. Similar Work in Australia

To our knowledge, apart from the work mentioned in this submission, no ongoing research had been done on the Bass Strait commercial scallop fishery.

16. Plans for Reporting and Publishing Results

The work would be reported by:

(i) reports to the FIRC Committee;

(ii) interim reports to Australian Fisheries;

(iii) verbal reports to the Scallop Task Force;

(iv) public talks to fishermen from Victoria and Tasmania;

(v) published articles in the scientific and technical literature.

ANNEX A - DETAIL OF FUNDS REQUESTED

		Year 1	Year 2	Year 3
A.	**Salaries and wages**	$	$	$
	1 x Technical Assistant (TA-I-Max)	-	-	18,790
	1 x Technical Assistant (TA-II-Max.)	19,449	19,955	20,249
	1 x Superannuation (20% of salary)	3,945	4,095	4,151
	Leave loading	188	400	400
	Overtime	2,648	4,866	4,767
	Recreation leave (on cessation)	-	-	1,558
	Hard lying allowance (1 x TA-I)	160	275	275
	Marine Survey Allowance (PRS, ES-I,ES-II)	8,066	8,356	12,535
	Total Salaries and Wages	34,456	37,947	62,725
B.	**Operating Expenses**			
	Boat charter and on-costs	73,500	127,500	142,500
	Spat collectors	2,000	6,000	6,000
	TV film cassettes, camera film, development	3,000	3,000	3,000
	TVP service and development	-	5,000	5,000
	Tags	1,000	-	-
	Measuring calipers	500	-	-
	Computing costs, VAX, CSIRONET	3,000	1,000	1,000
	Total Operating Costs	83,000	142,500	157,500
C.	**Travelling Expenses**			
	Fares	2,106	1,090	1,184
	Incidental taxis, etc. $50 per trip	500	600	600
	Travelling allowance	915	660	1,978
	Vehicle hire	784	-	-
	Total Travelling Expenses	4,305	2,350	3,762
C.	**Capital Items**			
	Sediment sieves and shaker	2,000	-	-
	Microcomputer	4,000	-	-
	Remote underwater TV	80,917	-	-
	Diving dry suits (3)	5,000		
	Total Capital Items	91,917	-	-
	GROSS TOTAL COST	213,678	182,797	223,987

ANNEX B

With the integrated approach to Bass Strait commercial scallop investigation, a separation of funds requested by the Department of Conservation, Forests and Lands, Marine Science Laboratories (FIRTA 83/32) into its Bass Strait and Port Phillip Bay components is made necessary. The funds requested in Part 1 apply to those parts of the present proposal for which the Marine Science Laboratories, Queenscliffe, is identified as the lead agency. In Part 2 below, details of funds requested for Port Phillip Bay scallop studies are given.

DETAILS OF FUNDS REQUESTED — 1985/86

Part 1: Bass Strait Component (FIRTA 83/32)

a) SALARIES	$
Overtime and ocean allowance	3,500
Payroll Recreation Leave loading, 10%	350
TOTAL SALARIES & WAGES	3,850
b) OPERATING EXPENSES	
Vessel charter; 12 monthly cruises	24,000
Travelling and accommodation	3,500
TOTAL OPERATING EXPENSES	27,500
c) CAPITAL ITEMS	
Spat collector equipment	2,000
TOTAL CAPITAL ITEMS	2,000
TOTAL FUNDS REQUESTED	33,350

Part 2: Port Phillip Bay Component (FIRTA 83/32)

a) SALARIES AND WAGES	$
S01 (4)	23,988
Technical Assistant	16,750
Technical Assistant	14,334
Workers Compensation, Insurance, Payroll Recreation Leave Loading (calculated at 10% of above)	5,507
TOTAL SALARIES & WAGES	60,579
b) TOTAL OPERATING EXPENSES	-
c) TOTAL CAPITAL ITEMS	-
TOTAL FUNDS REQUESTED	**60,579**