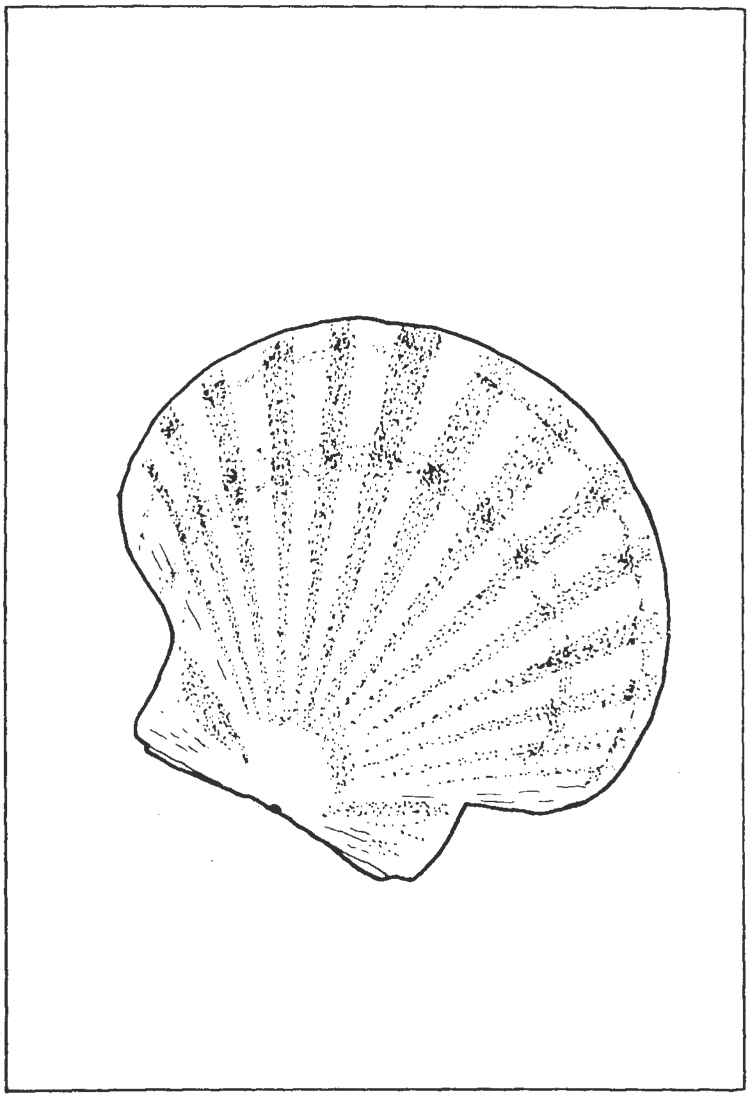
Proceedings of the Australasian Scallop Workshop



Edited by: M.L.C. Dredge, W.F. Zacharin and L.M. Joll

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FOREWORD

There are two distinct scallop fisheries in Australia. In the temperate waters of Victoria and Tasmania and to a lesser extent New South Wales and South Australia, commercial or king scallops (*Pecten fumatus*) are taken by dredge and diving. In tropical and subtropical waters off Queensland and Western Australia, saucer scallops (*Amusium balloti*) are taken by trawling.

In the late 1980s, the status of scallop stocks around Australia had reached a critical stage. Previously substantial fisheries in Tasmania and Bass Strait waters no longer existed. Australia's oldest established scallop fishery in Port Phillip Bay was operating at catch levels well below long term averages. In Queeensland, the *Amusium* stock was showing signs of re^ruitment overfishing. Of the major scallop stocks, only those in Western Australia could be considered to be at a reasonable level. However, even in these stocks, recruitment variability had caused wide fluctuations in catch levels.

At the same time, extremely successful scallop enhancement projects carried out in Japan had created considerable interest in Australia and New Zealand. Stock enhancement programs, based upon Japanese technology, had begun in New Zealand and Tasmania.

The curse of fisheries biology in Australia and New Zealand is the distance between research centres and research workers. There are few opportunities for biologists working in similar fields or with similar groups of animals to discuss their ideas, techniques and results.

It was against this background that we, a group of biologists working on scallops, identified the n d for a workshop in which studies on the status of wild fisheries and enhancement projects could be examined. We were particularly aware of the need for a forum in which current views and theories on factors affecting population dynamics in wild stocks of scallops could be reviewed. The impact of fisheries upon these stocks and the means by which wild stocks were managed were a major area of interest to us. The success of Japanese scallop mariculture and its application in New Zealand and Australia was also a key issue.

The Australasian Scallop Workshop was held at Taroona, near Hobart, in July 1988. A total of 55 people who attended the workshop listened to 27 delivered papers and participated in formal discussions on wild fisheries management and enhancement projects. The topics ranged from taxonomy of scallops to social aspects of scallop enhancement projects. Participants included fishermen, fisheries scientists, managers, and mariculturists, and came from Japan and New Zealand in addition to most Australian states.

A basic function of any worthwhile scientific forum is to document the proceedings. The organising committee of the workshop have set out a core group of 22 papers that cover the most informative areas covered in the workshop. They have been arranged into two major groupings, one dealing with the biology and dynamics of scallops subjected to conventional fisheries, and gear technoloby associated with those fisheries; and the second group of papers covers a wide array of topics associated with enhancement projects in Japan, New Zealand and Australia.

We hope these papers offer a realistic view of the Australasian scallop industry of the late 1980s, and a view of its future potential as a producer of scallops from both wild and artificially enhanced stocks. The papers offer a considerable volume of information on both wild fisheries and enhancement which we hope will be of value to those people who manage fisheries, and to those who intend to culture scallops in the future.

The workshop would not have taken place without the assistance of a number of organisations and individuals. The Fishing Industry Research and Development Committee financially supported the publication of this book, and the Tasmanian Department of Sea Fisheries (now Sea Fisheries Division, Department of Primary Industry) and the Queensland Fish Management Authority gave generous support to organisational matters associated with the workshop. Ms Toni Wilson typed most of the manuscript, and Vicki Martin generously gave her time and expertise to edit certain parts. Jeff Bibby cleaned up some of the artwork, and a number of referees spent a considerable amount of time correcting original manuscripts. We thank all these people and organisations.

Michael Dredge
William Zacharin
Lindsay Joll

December 1989

CONTENTS

SCALLOP FISHERIES MANAGEMENT : THE TASMANIAN EXPERIENCE

William Zacharin
Department of Sea Fisheries
P.O. Box 619F, Hobart
Tasmania 7001.

Abstract

Extensive scallop beds which were discovered in 1972 expanded the Tasmanian scallop fishery into Bass Strait. Catches increased rapidly and new operators flooded in to harvest the increasingly valuable resource. By 1982 the annual catch was approaching 12,000 tonnes (live weight) and fishing effort tripled in two years. The collapse came in 1984 and in 1988 the fishery was closed. Various management strategies in place since 1972 are discussed. Formation of a limited entry fishery and options for the future are presented.

Introduction

Prior to 1972 most Tasmanian scallops were fished from the D'Entrecasteaux Channel, Great Oyster Bay and the inshore north and east coast beds. Vessels participating in the fishery were few and small, most not exceeding 15 m in length. The annual landed catch fluctuated between 1,000 and 5,000 tonnes live weight. Fishing was seasonal, usually May/June to September/October.

In 1972 staff from the Fisheries Division of the Department of Agriculture surveyed 800 nautical miles of Bass Strait searching for new scallop beds. Four areas having scallops in high abundance were discovered (Grant and Alexander 1973). This led the then Minister for Agriculture to release the following policy statement regarding the likely exploitation of the new Bass Strait scallop beds. He suggested :

"a slower rate of exploitation by smaller lighter dredges was considered to be more desirable than an uncontrolled quick decimation of the stock." (Mercury 6 June 1973).

Local interest in harvesting the new resource grew slowly. This prompted the Minister to state:

"unless local fishermen showed more interest in the new scallop beds I will throw the beds open to Victorian fishermen. I am not prepared to see a valuable food resource wasted" (Perrin 1986).

Herein lies a major difficulty faced by fisheries managers to-day and one which proved to be a catalyst to the problems that evolved in the early 1980's over state fishing access rights in Bass Strait waters.

Expansion of the Fishery

By 1975 the Tasmanian scallop fleet , consisting of some 70 vessels, moved northwards from the traditional inshore scallop grounds into Bass Strait. Commercial fishing grounds off Stanley, Bridport and west of the Furneaux Island Group were the target. Fishing lat extended to include the far northwest of Tasmania, King Island and east of Flinders Island by 1978. Vessel numbers during this period remained the same, while commercial landings still failed to return to the levels seen in the late 1950s and early 1960s of approximately 3,000 tonnes (live weight) per annum. The traditional scallop fishing season was still May to October.

With a reduction in catches on the main Victorian beds at Lakes Entrance, Victorian based scallop fishermen began moving south searching for new grounds around Flinders Island. The vast Banks Strait beds were found in 1979 and almost all other fishing became concentrated along the east coast of the Furneaux Islands. Competition between the scallop fleets erupted in the early 1980s as more vessels continued to enter the fishery, lured by high catch returns. These high catches (approaching 12,000 tonnes in 1982, an increase from 1500 tonnes in 1978) depressed the price that processors were willing to pay. Tasmania.. east coast fishermen went on strike, refusing to leave port or to fish for scallops. They sought a 30 percent increase in the landed price. The price rose from $3.00 per kilogram to $3.90 per kilogram as a consequence of this strike.

The fishing at this time was mainly in Bass Strait where the Commonwealth Government had the responsibility for licensing, policing and management (Figure 1).

By 1983 fishing effort was out of control, having tripled in the previous two years, and catches were declining. The scallop fleet was now fishing all year round. Many operators were upgrading to larger vessels and Tasmania still had no licence restrictions on entry to the fishery. Rationalisation of management between Victoria, Tasmania and the Commonwealth was recognised as being paramount in protecting the remaining resource from over - exploitation.

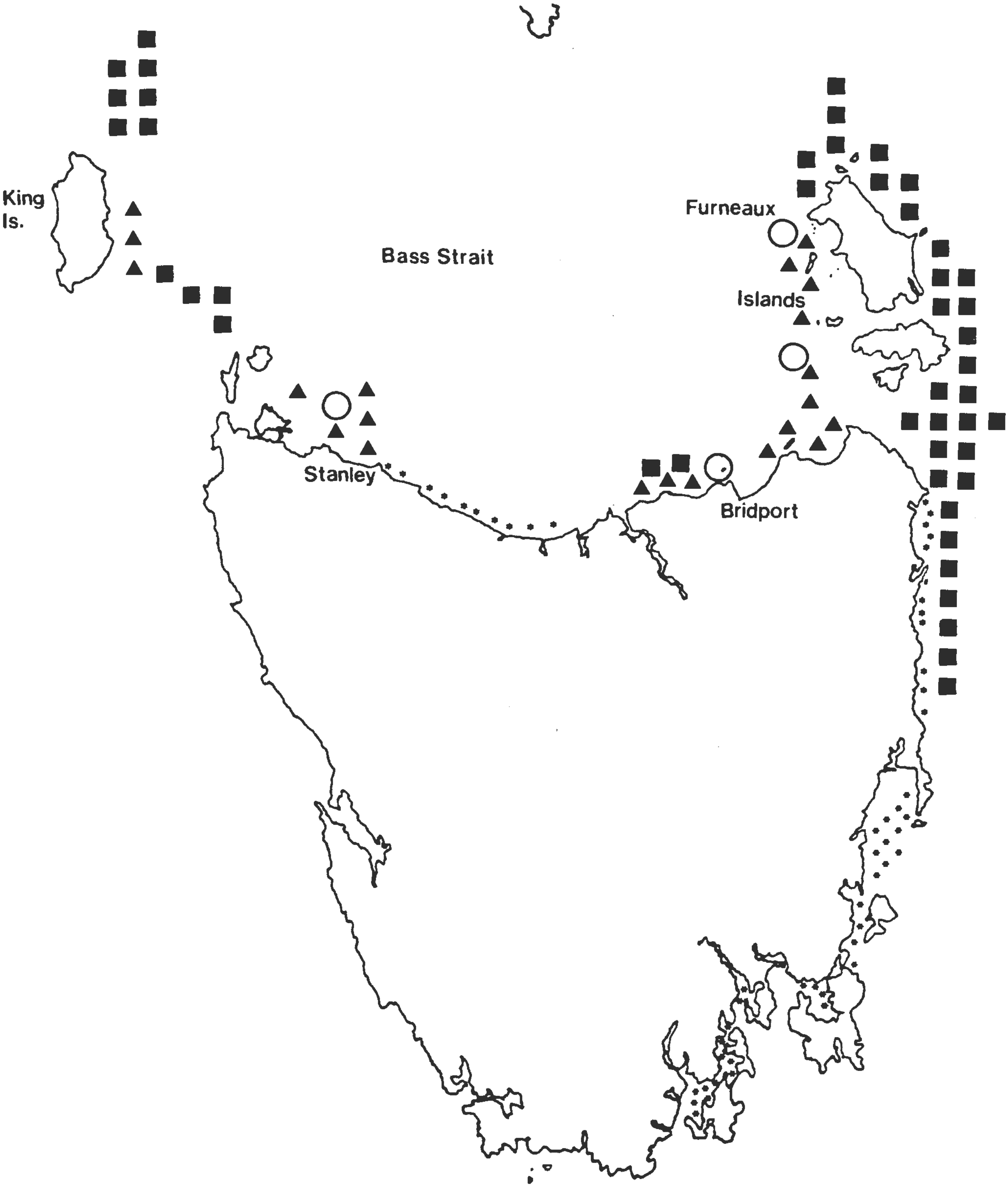

Figure 1 : Expansion of the Tasmanian scallop fishery from a predominantly inshore coastal fishery to a large Bass Strait fishery. Prior to 1972 (•) ; by 1975 (▲) ; complete exploitation by 1983 (■). Open circles show high density areas located in the 1973 survey.

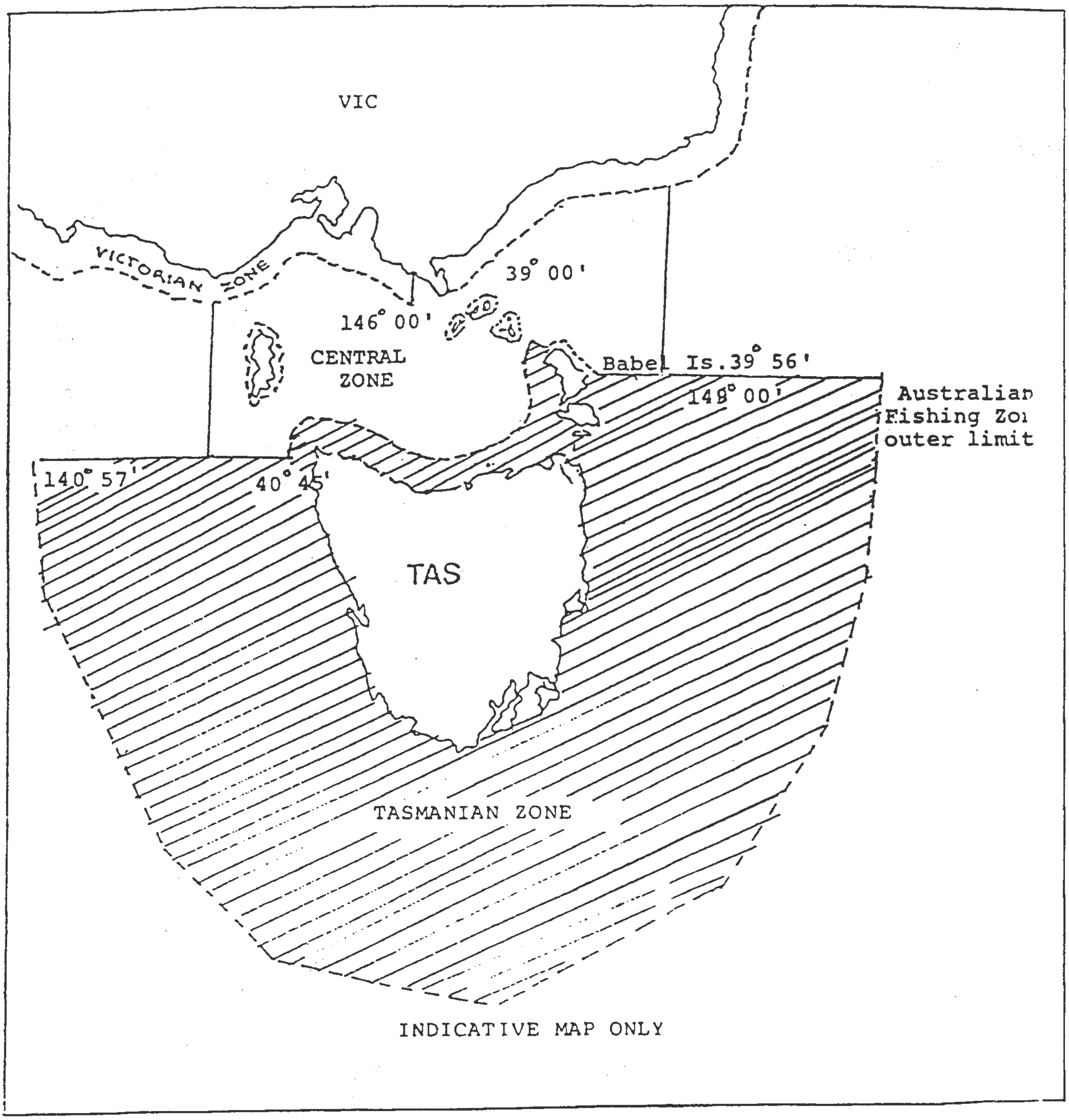

Figure 2. Bass Strait scallop fishery zones as under the Offshore Constitutional Settlement agreement 1986.

In November of 1983 the Bass Strait Interim Management Regime was introduced. Tasmanian participation was limited to scallop fishermen who could meet these criteria :

(1) they had fished for scallops between the 1 January and 31 October, 1983 ; or

(2) they had received approval before 15 November 1983 to buy a new vessel, or replace an existing vessel.

Under the Interim Regime, 97 Victorian and 134 Tasmanian based vessels gained access to the whole Bass Strait fishery (i.e their respective State waters and Commonwealth ·oclaimed waters). The Commonwealth Government then established the Bass Strait Scallop Task Force (BSSTF), consisting of Federal, Victorian and Tasmanian fisheries representatives together with a number of professional fishermen and processors representatives from both states. The brief of the BSSTF was to establish a management regime for the Bass Strait fishery which :

(1) effectively utilised the resource ;
(2) was acceptable to all parties ;
(3) was legally enforceable.

At the Australian Fisheries Council's 15th meeting in July 1985 the final report from the BSSTF was submitted. It included a longer management proposal. The Task Force concluded that "due to irreconcilable management differences" the most rational solution to this fishery as to introduce a management regime which achieved a high degree of separation between the Tasmanian-based and Victorian-based components of the Bass Strait scallop fleet (BSSTF Final Report). The fishery was thus divided into three distinct zones :

(1) Victorian Zone)
(2) Tasmanian Zone) extending to 20 nautical miles from baselines

(3) Central Zone) all waters outside the state 20 nautical miles zones.

Access to the Central Zone was restricted to scallop vessels that qualified for either a Tasmanian or Victorian state licence and had an endorsement of the Commonwealth Fishing Boat Licence. This separation was finalised with the implementation of the Offshore Constitutional Settlement (OCS) in June 1986 (Figure 2).

Limited Entry

Prior to the 1986 season there were approximately 285 licensed scallop vessels.

Under the OCS agreement, the Tasmanian 1986 scallop season was the first time in the history of the 100-year-old fishery that a restriction had been placed on the number of participating vessels. Access to state waters was limited to 187, 134 of which had an endorsement to fish in the Central Zone. Each vessel possessed a fixed unit per trip quota calculated as six units per metre of vessel length. No vessel was awarded more than the industry-agreed maximum of 140 units. This possession quota was necessary to rationalise the harvesting rate as, from 1981 - 1984, much wastage occurred when scallops lay rotting on wharfs because fish processors could not handle the large volume being landed. The quotas we not for conservation purposes but economic purposes, a fact misinterpreted by the scallop fishermen.

This separation of the fishery, together with a reduction in fishing effort, was not enough to prevent the continued slide of the Tasmanian catches to the present all-time low. In 1987 less than 500 tonnes was landed. This represents a 95 percent drop in annual landings in six years. The average annual catch rate decreased from approximately 70 kg hr^{-1} to 9 kg hr^{-1} (Figure 3).

How then should the remaining scallop stock(s) be managed to regenerate the fishery ? The current strategy being pursued is:

All licences are non-transferable in an effort to reduce licence speculation, to provi some stability in the industry. Licence number reduction is happening through natural attrition (as of 30 June 1988 there were 172 licences). In effect, a scallop licence is meant to have no intrinsic value. The possession per trip quotas initially allocated cannot be upgraded. Surveys are conducted between March-May each year to locate areas of juvenile scallops, and to delineate any commercially productive scallop beds. A minimum size limit of eight centimetres at widest diameter applies to the whole Tasmanian Zone fishery.

With the resources available, it is virtually impossible to estimate the abundance of the stock from survey data. However, an indication of the number of commercially viable beds in the zone and the expected initial catch rates can be obtained.

The season usually opens around the middle of June, depending on the condition of the scallops. In 1987 the fishery opened on 14 June and was closed on 1 September as the average

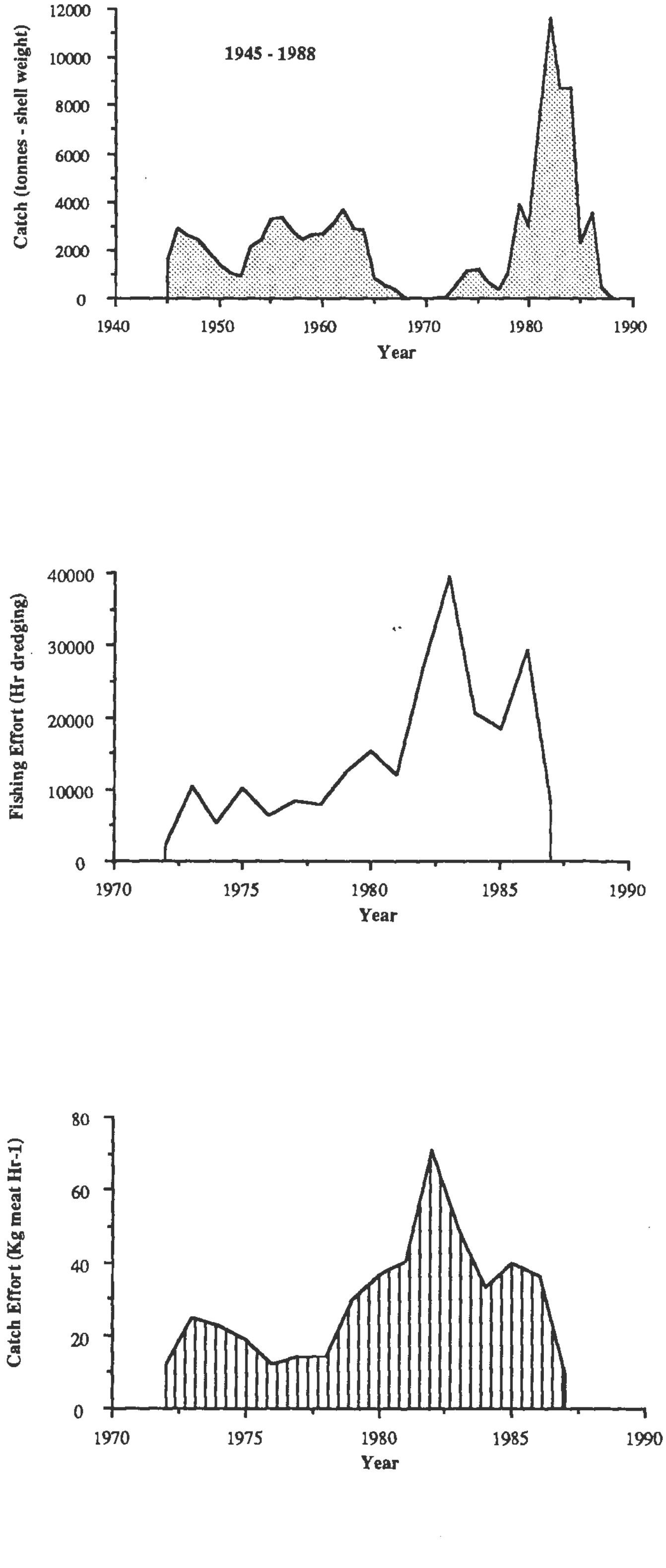

Figure 3 : Tasmanian scallop catch returns, fishing effort and catch effort 1972 to 1987.

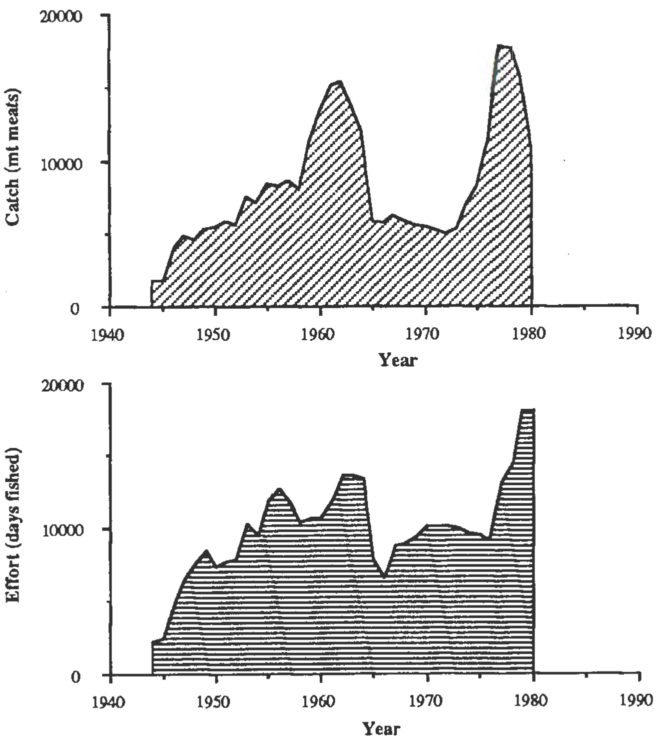

Figure 4 : U.S Atlantic Sea Scallop Landings from the Georges Banks fishery 1945 - 1980. (taken from NOAA, 1982).

vessel catch rate had declined to 3.5 kg hr^{-1}. Surveys carried out in 1987/88 by Sea Fisheries and CSIRO have failed to locate any commercially viable beds in Bass Strait or the Tasmanian Zone. The fishery was closed for the 1988 season and it is not anticipated that commercial beds of scallops will be found before 1990 (Zacharin 1987).

Future management options are varied, with sections of the industry advocating the dismantling of the limited entry system and the dropping of the quota arrangement. Others favour a continuation of the present system but with licence transferability and reduction of quota units. Future directions will depend on the recommendations of the current Tasmanian Fisheries Licensing Review, which was to report in November 1988, and the recommendations resulting from the CSIRO research on the Bass Strait scallop stocks. Victoria and Tasmania also need to work out an acceptable management plan for the Central Zone still under Commonwealth control.

One priority has been to experiment with alternative fishing gear as the present toothed mud dredge causes considerable damage to the beds and the landed catch. It is difficult to advocate the continuation of a minimum size limit when many of the small scallops thrown back are damaged, and anecdotal evidence strongly suggests they do not survive.

The major question now confronting researchers is whether there has been recruitment overfishing or recruitment failure.

Recruitment Overfishing or Failure

Recruitment overfishing is said to occur when the adult population is reduced to some level at which there is a significant fall in the average recruitment. It is extremely difficult to be sure that recruitment overfishing is taking place in this fishery due to the lack of knowledge about any stock/recruit relationship, and when there is a minimum size limit operating which allows the population to reach maturity and spawn at least once before harvesting. However, there is doubt whether the current minimum size of 80 mm achieves this objective at present .

Victoria, which has no minimum size, has also experienced a marked decrease in the commercial catch, but it is no more severe than in Tasmania. Hypothesising, that variation in recruitment due to environmental causes may be a dominant factor in recruitment success even when the parental (spawning) stock size is considerably large. The gross seasonal changes in water temperature and nutrients throughout the central and eastern waters of Bass Strait have been well documented by Harris *et al.* (1987). Their results support the view that gross fluctuating environmental variables in Bass Strait and on the Tasmanian east coast are expected to have a considerable effect on annual recruitment, especially in invertebrate fisheries.

If recruitment is irregular due to these density independent variables, what then would be the most effective and rapid method for regenerating the scallop stocks ? Some other scallop fisheries have adopted a policy of total closure or area closures, strategies which give the best chance of rapid recovery of the stock if density independent variables are not important, according to Hancock (1979) and Wilson (1982).

So, the crux of the current management problem is still : Have the scallop stock(s) been fished below a critical minimum spawning population size at which the average level of recruitment can be expected to fall as a result of a reduction in the frequency of appearance of good year classes ? In other words, has recruitment overfishing occurred and subsequently led to recruitment failure ? Using the commercial catch and catch/effort data from 1972 to 1987 as an estimation of stock size, together with survey data on the frequency of appearance of juvenile scallops (< 50mm) or good year classes, the answer is still not clear. This is partially due to lack of knowledge about the minimum size/age at first maturity.

The spawning population may have been fished below the critical minimum level necessary for rapid regeneration, and a return to catch levels of 4,000 tonnes per annum may take three years or it may take ten years, but it is uncertain. It all depends on recruitment success. Little research has been conducted into factors affecting juvenile scallop mortality. For a disturbing comparison, observe the D'Entrecasteaux Channel doughboy scallop fishery. This became unproductive in 1969. It was subsequently closed in 1970 and did not reopen until 1982. Limited fishing continued until 1985 when the survey data showed catch rate reductions of up to 50 percent. No recruitment was found so the fishery was closed (Zacharin 1986). The small recovery in the scallop stock took 12 years.

A similar event occurred in the Atlantic scallop fishery between 1960 and 1974. Landings fell from 13,000 tonnes to 6,000 tonnes (meat weight) and remained at this level for the next nine years, even after effort had been severely reduced (New England Fish. y Management Council 1982) (Figure 4).

How then should the problem be attacked if recruitment failure is responsible for the resource depletion ?

Research by the CSIRO indicates that recruitment failure followed both the 1985 and 1986 spawnings (McLoughlin *et al.* 1988). However, the spawning stock may have already been fished below the critical minimum level necessary to give "average recruitment". Little information exists on spat settlement or the strength of recruiting year classes before 1984. Only if strong settlement pulses are detected in spat collectors and subsequent recruitment is seen in 1988 and 1989/90 will researchers be able to hypothesise that recruitment failure due to environmental changes, or other factors independent of overfishing (e.g increase in inshore trawling), caused the collapse of the stock(s).

Conclusion

A review of all the biological reports and research todate suggests that a combination of overfishing and recruitment failure has contributed to the situation seen today. It is vital that research continues over the next few years if the stock/recruit relationship is to be better understood. It is vital to know how hard a stock may be fished before "average recruitment" over a short time period (i.e five years) is going to be adversely affected.

The current status of the Tasmanian fishery is that a total closure is in force for 1988/89 and probably beyond, in the hope that the absence of fishing will promote successful settlement and recruitment. If or when the scallop beds regain commercial value, over-capitalisation and over-exploitation must not be allowed to occur again.

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HISTORY OF MANAGEMENT IN THE VICTORIAN SCALLOP INDUSTRY

D. Gwyther
Department of Conservation, Forests and Lands
Marine Science Laboratories
PO Box 114, Queenscliff
Victoria 3225.

Abstract

Scallop fishing began in Port Phillip Bay in 1963. Following the decline of stocks in the bay by 1969 and discovery of beds off Lakes Entrance, the fishery extended into Bass Strait. The development of the Victorian fishery has been marked by a number of significant events. Limited entry was introduced in 1971 to control the rapid expansion of vessel numbers and scallop area endorsements were granted in recognition of participation in the fishery prior to 1970. Other controlling measures, such as daily and seasonal limits on fishing, catch quotas and gear restrictions have been introduced in response to biological, economic or sociological factors. A small but committed scallop fleet has generally meant rational exploitation but problems have been experienced during times of low scallop abundance. This has been exacerbated by uncontrolled capitalisation in the Bass Strait fishery during 1982-83 through the inability to limit catches in Commonwealth waters. Inevitably, stocks were depleted and have not recovered since 1984. Scallop production in Port Phillip Bay has peaked several times since the initial boom in landings during the 1960s and the bay scallop fishery has proven to be the most robust of the south eastern Australian grounds. However, when recruitment is poor, residual scallop abundance is insufficient to support the fleet. Mechanisms for improving viability in an overcapitalised fishery are under consideration, including buy-back and quota consolidation.

Introduction

In its 25 year history, the Victorian scallop fishery has undergone a number of developmental phases. The fishery developed from open access to become one of Australia's first managed fisheries through limited entry. Limited entry and limiting access rights to a common property resource has been the fundamental basis upon which management has proceeded. The set of arrangements by which the scallop fisheries are managed has developed in a trial and error way to meet a changing set of economic, social and political objectives. Given the slow accumulation of knowledge about scallop populations and their environmental and fishery interactions, this development is not surprising. This paper summarises the significant events during the history of development of the Victorian scallop fishery.

The Period 1963 to 1967

Until 1963, the Australian scallop fishery was centred in Tasmania where scallop dredging had been carried out in the D'Entrecasteaux Channel and along the east coast. However, with the decline in the traditional Tasmanian grounds and publicity given to the scallop resources in Port Phillip Bay, a number of operators started fishing in the bay. Production quickly increased as did numbers of operators. There were no regulations which applied to this fishery and any person could enter by being issued with a professional fisherman's licence. There were no restrictions on minimum sizes (until 1965 when a minimum size of 3.75 inches was introduced) and no restriction on season or fishing gear. By 1967, about 300 boats were dredging for scallops in Port Phillip bay and catches peaked at more than 4,000 tonnes in that year.

Amendment of the Fisheries Act

In 1965, the Victorian Fisheries and Wildlife Service warned that the fishery, which had been based on virgin stocks, faced decline and the future of the industry would be dependent upon scallop recruitment success and restructuring of the industry. Nevertheless, new boats continued to enter the fishery. By 1967, the Service considered that the fishery was seriously overfished and tighter controls were necessary. Catch rates had started to decline and fishing was becoming progressively reliant on younger age classes. In December 1967, the Fisheries Act was amended so that boat owners required a scallop licence, renewable for 12 months later in May 1968, limited entry was introduced by offering licenses to those operating at the time and 167 boats were licensed. Thus the fishery became "managed" and the objectives at the time (Sanders 1971) were:

i) to gain stability and optimisation of exploitation giving sustained production ;
ii) to provide a satisfactory income to those engaged in the fishery and ;
iii) to provide a satisfactory quality and price to the consumer.

Thus the Government's management role was directed to the resource, the industry and the consumer. However, there was no provision in the amended Act for actively reducing the number of vessels. The decline in catch rates lasted for four years from 1967 and many boats dropped out voluntarily. By 1969, there were fewer than 100 boats and catches had dropped to 900 tonnes.

Lakes Entrance Fishery

In 1970, commercial beds of scallops were discovered off Lakes Entrance. The beds were in Commonwealth waters so limited entry, introduced for the Port Phillip Bay fishery, did not apply and a number of Lakes Entrance fishermen, who until then had been engaged in other fisheries, commenced scalloping. Scallop licences, valid for Port Phillip Bay (the only scallop licences existing at that time) were granted to 39 Lakes Entrance vessels. This decision was based on the belief that it would have been inequitable for Lakes Entrance fishermen to be denied access to a new fishery immediately adjacent to their port. At the same time, regulatioı were introduced that prohibited any boat equipped for scallop dredging from entering the ports of Lakes Entrance or Corner Inlet unless it had a current Victorian scallop licence. Known as the "dredge and tipper regulation", this had the effect of preventing "unlicensed" scallop fishing in Commonwealth waters off eastern Victoria.

Licence zoning

To prevent an increase in the number of vessels from fishing in areas where they had not historically been involved, a zoning system was introduced in 1971. This divided the scallop fleet into three groups, each with a different geographical fishing entitlement. Entitlements were based on their areas of scallop fishing during the period 1968-71. By an endorsement on the scallop licence, a boat was permitted to fish in Port Phillip Bay only, in ocean waters east of longitude 146^0 only, or in all Victorian waters.

The 39 Lakes Entrance vessels licensed in 1970 were restricted to ocean waters off Lakes Entrance. This was done to prevent boats which had never fished in the bay from increasing effort in Port Phillip Bay. The Port Phillip Bay boats that had not fished off Lakes Entrance by September 1970 were restricted to Port Phillip Bay only. The other bay boats which had fished off Lakes Entrance were given a licence valid for all Victorian waters. At the finalisation of this arrangement, there were 23 (bay only), 61 (all Victorian waters) and 34 valid for waters east of 146^0. No further licences have been issued, although many have been transferred. Through some consolidation of restricted licences, the current numbers are 65 all Victorian waters, 19 bay only and 30 Lakes Entrance only.

Controls in the bay fishery were a combination of daily catch quotas, restrictions on fishing hours, days and seasons, restrictions on dredge width (later mesh size and container specification) and area closures where necessary. Size limits were abandoned in 1979. These measures developed to suit a number of management objectives including rational harvesting and processing, prolonging of supply and reduction of conflict with recreational weekend fishing. Similarly, there were regulations on daily catch quotas for the Lakes Entrance grounds. Daily limits were higher (50 bags per day) reflecting the greater weather dependence and hence uncertainty of fishing in Bass Strait.

High recruitment in Port Phillip Bay in 1981

During the 1970s, the dual management of the bay and Lakes Entrance based fisheries proceeded without undue controversy. However, a massive recruitment to the Port Phillip Bay scallop stocks occurred in 1981 and although there were reasonable beds of scallops at Lakes Entrance, the Lakes Entrance fishermen believed that their catch rates could not compete with the Port Phillip Bay catches. They approached the Fisheries and Wildlife Service seeking entry to the Port Phillip Bay scallop fishery. After much deliberation, 21 Lakes Entrance operators were given permits to participate in the bay fishery during 1981 on the understanding that they remain in the bay all season after which they were to return to Lakes Entrance. While the bay limit was 20 bags per day, the Lakes Entrance limit was increased to 70 for the ten boats which did not come to the bay so that local supply and processing could be maintained. However, the management plan received much criticism when a number of the Lakes Entrance and all Victorian waters operators left the bay to fish at Lakes Entrance. Efforts by Lakes Entrance fishermen to fish in Port Phillip Bay did not become an issue again until 1985.

Expansion offshore in Bass Strait

From 1981 to 1984, there was a rapid expansion of scallop fishing in Bass Strait as new grounds were located off the Furneaux group of islands, Three Hummocks Island and Banks Strait (Figure 1). As these grounds were more distant, involving 12 or more hours steaming time from Victorian ports, the fleet was often away for several days. It encouraged many licensees to upgrade their vessels to improve seaworthiness and crew facilities to fish these grounds effectively. There were many licence transfers as boats changed hands or were replaced. Similar activities occurred in Tasmania and more Tasmanians entered the fishery using larger and more specialised scallop boats. In addition, an entrepreneurial group promoted investment in the scallop fishery and by 1983, were managing a fleet of 60 boats. Some of these were large replacements for old multi-purpose boats, others were new boats to the Bass Strait fishery since neither the Commonwealth nor Tasmanian authorities placed limits on entry to the scallop fishery at that time.

During the 1982-83 period, nearly 2,000 tonnes of meat was landed in Victoria from the distant Bass Strait grounds. However, the serious downturn in catch from the Bass Strait and Lakes Entrance scallop beds which occurred in 1984 (Table 1) resulted in some fishermen experiencing financial difficulties. This was most severe for those who had taken on additional

Table 1. Annual scallop catches (tonnes) at three major grounds in southeast Australia 1970-1989.

Year	Port Phillip Bay	Lakes Entrance	Furneaux Group#	Victoria
1970	18	641	0	659
1971	139	1016	0	1155
1972	978	906	0	1884
1973	814	294	0	1108
1974	219	342	0	561
1975	78	664	0	742
1976	330	120	0	450
1977	70	213	0	283
1978	672	997	0	1669
1979	420	1278	36	1734
1980	1640	857	34	2531
1981	1679	803	57	2539
1982	824	280	713	1817
1983	547	563	1181	2291
1984	844	80	110	1034
1985*	2000	100+	NR	2100
1986*	200	100+	NR	300
1987*	1400	200	NR	1600
1988*	120	100	NR	220
1989*	0	100+	NR	100
Average	650	483	<355	1239

+ indicates the catch is probably slightly greater than the figure shown.
# catch landed in Victorian ports only.
NR no records.
* estimates, based on quotas and number of boats fishing.

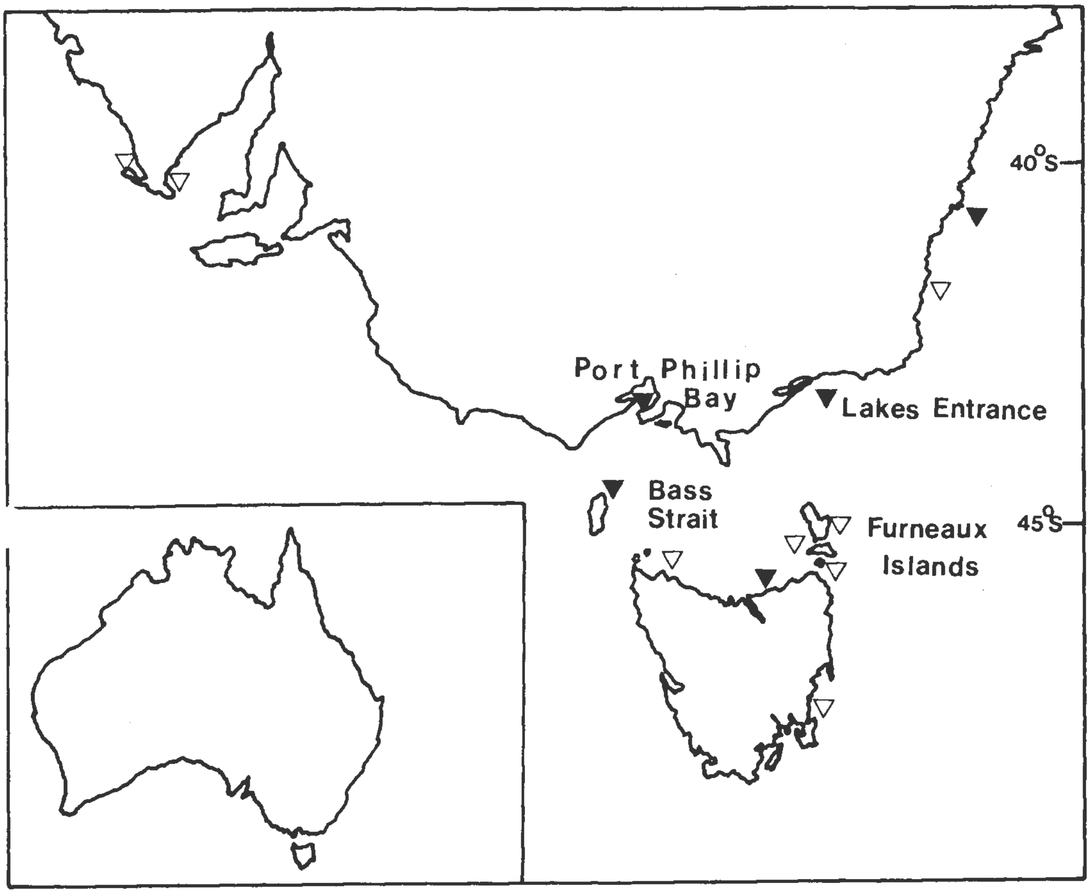

Figure 1. Location of major (▼) and intermittent (▽) scallop grounds in southeast Australia.

commitments but who had no other fishing entitlement other than a Lakes Entrance and Commonwealth Bass Strait scallop licence.

Management of Bass Strait scallop fishery

With the upgrading of Victorian vessels and increases in the size of the Tasmanian fleet, the state fisheries agencies were concerned about excessive capacity and approaches were made to the Commonwealth to introduce controls. In April 1984, an interim management regime took effect whereby access to the Bass Strait fishery was limited to boats which had fished there between January and October 1983. Under this regime, 97 Victorian and 134 Tasmanian licensed boats gained entry to the scallop fishery in Commonwealth waters and restrictions were placed on licence transfer and vessel replacement.

In June 1984, the Bass Strait Scallop Fishery Task Force was established to develop and implement management arrangements for this scallop fishery. The final management plan was introduced in accordance with the Offshore Constitutional Settlement in 1986, with Victoria and Tasmania gaining control of the scallop fishery within 20 nautical miles of their coasts, while the Commonwealth controlled the fishery in central Bass Strait. These arrangements proceeded despite some industry concern; for example, some Victorian operators saw the zoning arrangements as removing their opportunities to fish in what had formerly been Commonwealth waters, less than 20 nautical miles from the Tasmanian coast.

The period 1985 to 1988

When the Bass Strait management arrangements were introduced, survey and spatfall studies indicated that the commercial prospects for the grounds off eastern Victoria wer extremely poor. In contrast, Port Phillip Bay scallop stocks were plentiful and the 1985 season was one of the best on record. As in 1981, an approach was made by a group of Lakes Entrance restricted-licence holders to enter the Port Phillip Bay fishery, and many actually fished illegally in order to bring their plight to the attention of the Minister. A review of commercial fisheries licensing procedures was commissioned, with an initial emphasis on the scallop licensing categories (Arnold 1986). While a number of options for rationalising scallop licences were considered, none satisfactorily overcame differences in equity and access rights which were embodied in the three licences. Instead, exclusive access to the grounds off Lakes Entrance was granted to Lakes Entrance-only licensees for the duration of the 1986 season.

With the decline of the Lakes Entrance and Bass Strait scallop stocks, all 84 vessels licensed to fish in Port Phillip Bay have done so since 1985. While the stocks in 1985 were sufficient to support the entire fleet, the 1986 season was different; recruitment was low and the season lasted less than two months. A recovery in stocks occurred in 1987, with fishing lasting almost the entire season but predictions for 1988 were poor, based on spatfall counts. For a number of years, those in the industry had understood the vulnerability of the fishery, being dependent upon the newly recruited (1+ aged) scallops each season. The lack of recruitment in 1988 gave rise to a season which lasted only three weeks before the grounds were closed to conserve a depleted breeding stock. Recoveries of scallop stocks off Lakes Entrance have been relatively minor, with the fishery lasting only a few weeks in 1987, 1988 and 1989.

Information from research

Research and monitoring activities are undertaken to provide information on stocks and condition of scallops for management decisions. In Port Phillip Bay, annual diver surveys provide estimates of scallop numbers in the bay prior to the season opening and the age composition of the stock in terms of numbers of recruits and residual stock is also determined. At Lakes Entrance, dredge surveys were carried out between 1971 and 1981 but in such an extensive area of ocean, proved of little value in locating beds or estimating stocks and were abandoned after 1981. Surveys of Bass Strait concentrated mainly on known beds to monitor condition of scallops and presence or absence of juveniles. In Port Phillip Bay, the correlation between spatfall and recruitment one year later has continued to provide helpful predictions of variations in recruitment (Sause *et al.* 1987). However, in Bass Strait, the predictive value of spatfall indices has not been demonstrated.

Present management mechanisms

Following a recommendation in the Victorian Commercial Fisheries Licensing Review, the Scallop Advisory Committee was established as a consultative body with Government and industry representation. It is through this committee that research information such as results of surveys or spatfall indices are discussed and recommendations made concerning fishing strategies. Recommendations are made to the Fisheries Management Committee and then to the Minister for final approval. It is also through the Scallop Advisory Committee that strategies for restructuring the industry are developed and discussed. Such plans have included buy-back schemes and various forms of licence or quota consolidation. However, no plan has yet met with general industry approval.

Summary

The main problems facing the Victorian scallop industry at present are the excess fishing capacity and low levels of recruitment. The number of vessels entitled to fish for scallops is more than sufficient to harvest the resource in all but the most productive years. Transfer premiums tend to reflect the optimism generated by these productive years or the average earning capacity over a number of years but in the short term, when the resource is low, the high premiums generate financial hardship. While Port Phillip Bay has proven to be the most stable and enduring of the scallop fisheries of southeastern Australia, it does experience recruitment failures. Operators are reluctant to commit themselves to further expenditure required by any buy-back proposal. However, the present state of the resource indicates that some form of fleet restructuring is desirable if idle scallop boats are not to become a permanent feature of Victoria's fishing ports.

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GENERAL DISCUSSION

Anon. When the split licence concept between Port Phillip Bay and Lakes Entrance was introduced, was there industry support for the idea?

Gwyther: I think it was imposed according to the history of each boat's operations. It was not desirable to have any more boats enter the Port Phillip Bay fishery, so those who had entered the fishery at Lakes Entrance were never allowed into Port Phillip Bay. In practice it worked to the advantage of those who were mobile as they got licences to all of our grounds.

Harrison: I adhere to the economist's doctrine of current market value being market expectations of future earnings. Since the market is still reflecting optimism there are those who are buying who reflect optimism in the future by paying premiums on licenses.

Gwyther: Yes, I think it is future expectations that they are into.

MANAGEMENT OF THE QUEENSLAND SCALLOP FISHERY

P.J. Neville
Queensland Fish Management Authority
G.P.O. Box 344, Fortitude Valley
Queensland 4006.
Present address : Division of Fisheries and Wetland Management
Department of Primary Industries
G.P.O. Box 46
Brisbane 4001

Abstract

The Queensland scallop fishery for the species Amusium japonicum balloti has existed for many years in both Queensland and Commonwealth waters off the Queensland central east coast. The principal fishery exists from approximately Bundaberg to the waters off Mackay, although small pockets of the same species occur in north Queensland waters. Recently, serious industry concerns have risen about the level of fishing effort in the fishery and falling catch rates per unit of effort. The emphasis of these concerns was the continued operation of the trawl fleet on the scallop grounds at very low catch rates. In response to these concerns the Queensland Fish Management Authority introduced a number of management measures. In 1979, the total number of vessel with could use otter trawl apparatus to harvest scallops was limited. In 1984, net length and mesh size restrictions were introduced. A minimum shell size of 80 mm was introduced in November 1984, increased to 85 mm in 1985 and to 90 mm in 1987. A maximum size on the length of vessels was also applied and a compulsory log book system was introduced in order to obtain better information on the fishery. In 1988, a minimum meat count of 130 pieces per kilogram was introduced. The Authority has also funded additional research for the fishery. The major management measures have not been in place for a sufficient period of time to assess their impact on the fishery. Debate is still occurring as to the most appropriate management measure and additional management measures concerning changes to net size, declaration of breeding areas and closed seasons are also being discussed.

Introduction

The Queensland scallop fishery, for the species *Amusium japonicum balloti*, has existed since the mid-1950s in both Queensland territorial waters and waters under the jurisdiction of the Commonwealth of Australia off the Queensland East Coast. The principal fishery is from approximately 22°S to 26°S or from Bundaberg to the waters off Mackay on the Central East Coast of Queensland. Small pockets of the same scallop appear off the North Queensland areas of Bowen, Townsville and Lucinda (Figure 1). The fishery is an inshore fishery with the major areas being relatively close to the coastline in depths of 20 to 50 m. It is fished as part of a multispecies fishery with multi-purpose vessels designed to catch various species of prawn, slipper lobster and other by-catch.

The scallop is trawled by otter trawl nets towed by vessels ranging in size from 10 to 20 m, with engines of up to 400 h.p. (300 kw). The scallop shell is stored on board vessels under dry-refrigeration or salt brine and is shucked in land-based plants.

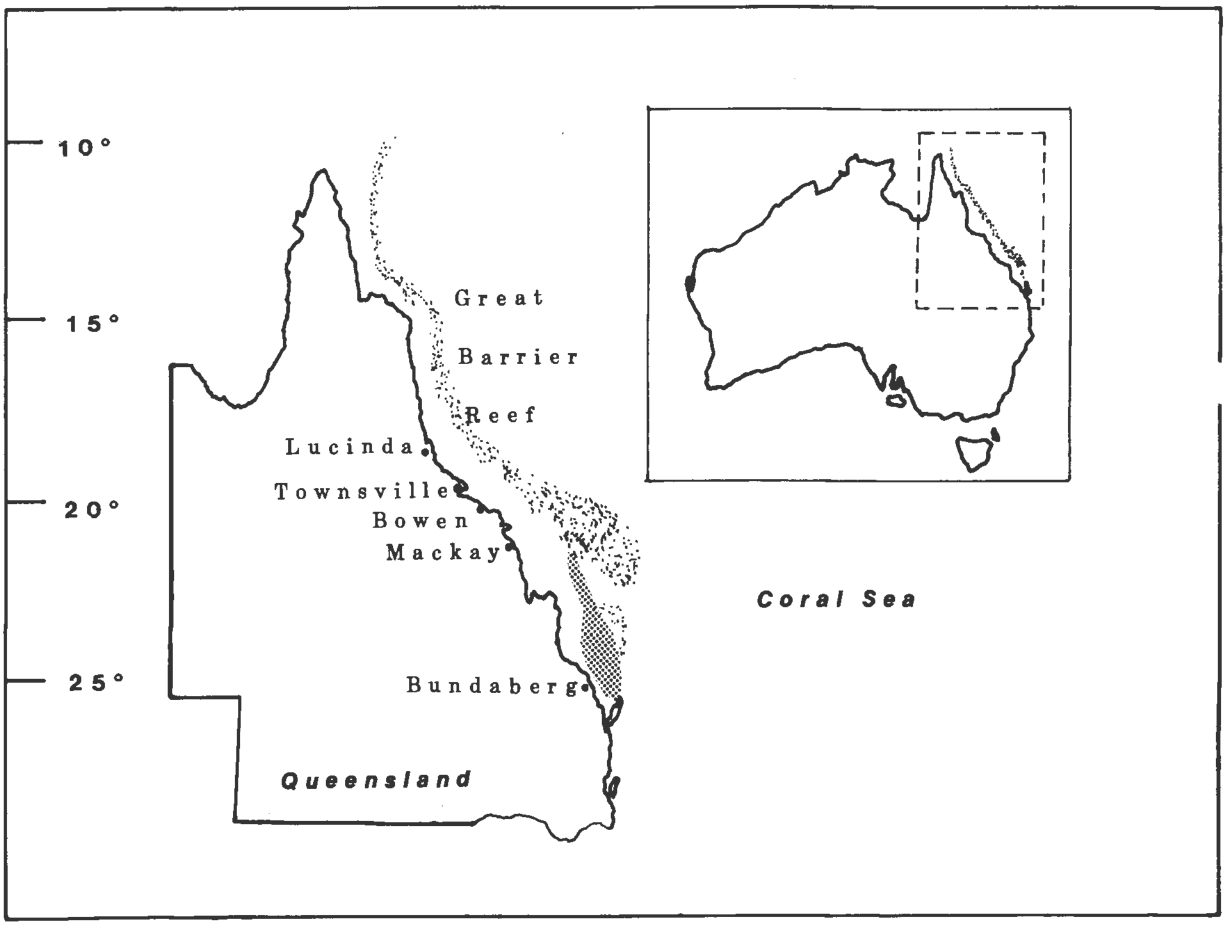

Figure 1. Queensland's major scallop grounds (hatched).

Total production of scallop meat has fluctuated over recent years from 380 tonnes in 1977 to 1220 tonnes in 1982 and back to 450 tonnes in 1987. Gross value is currently estimated at $8 million, with most of the meat exported to South East Asia or the USA.

Following the signing of the Offshore Constitutional Settlement (OCS) for Fisheries on 1 June 1987, the scallop fishery came within Queensland jurisdiction in its entirety and Commonwealth law ceased to apply.

History of Management Policies

When the bulk of the fishery was in Commonwealth waters, there were practically no management measures practiced. The only exception to this was that the Commonwealth agreed to limit the number of trawl vessels which could use prawn otter trawl apparatus in November 1983. This had the effect of placing a limit on the number of vessels which could use otter trawl apparatus for any target species. In October 1984, this restriction on total vessel numbers was extended to scallop fishing vessels.

The Commonwealth Fisheries Notices were primarily designed to duplicate a freeze on the number of licensed otter trawl vessels for the prawn and scallop fisheries, which had been introduced by Queensland for its territorial waters in 1979. The Commonwealth measure was therefore primarily aimed at protection for the prawn fishery and not the scallop fishery. To this end, although the total number of vessels that could engage in scallop trawling was restricted, there was no restriction on the size of nets which could be used in Commonwealth waters, nor any restrictions on protection of the scallop shell, or closed seasons.

Queensland fisheries biologists have been collecting catch/effort data from a sample of vessels engaged in the scallop fishery over a period of some ten years (Dredge this volume). This information has shown that in recent times, the catch per unit effort of the vessels has been significantly declining. This has not been shown by reference to total landings of scallop meat or shell, but has been demonstrated with reference to the catch per unit effort figures, illustrating the significant rise in fishing effort directed at scallops.

The principal cause of this increase in effort has been the significant rise in overseas market prices for scallop meat, leading to continued trawling for scallop even at very low densities and catch rates. Improvements in vessel gear efficiencies and size have also contributed significantly. It followed the common trend that, despite limitations on entry of vessels, effort increased through technological improvements.

Based on this information and representations from sections of commercial fishermen in the fishery, the Queensland Fish Management Authority established a Scallop Advisory Committee in early 1985 to discuss the various management measures required for the industry.

This Committee comprised representatives of the catching sector, the marketing sector, fisheries biologists and Authority management personnel. The Committee has deliberated for some time over first, the necessity for intervention and management, and second, the form that management should take.

The Committee itself initially was not convinced there was a need for intervention. This was based on the argument that, traditionally, scallop fisheries throughout the world exhibit high levels of fluctuation, caused by natural factors influencing spawning, settlement and ea.., growth of the scallop. Also with total landings fluctuating but not necessarily exhibiting a continuous downward trend and with market prices remaining firm overseas, total income to the industry was seen to be in a healthy state. It was necessary for the Authority to be convinced that biological information demonstrated a possible serious threat existed to the regeneration of the fishery.

This data was not available for the fleet, but indications were obtained from the sample data collected by biologists and this was supported in most cases by anecdotal evidence of fishermen themselves. The prime indicator was the catch rates. This led themselves to concerns that, not only was the available scallop being shared among more vessels because of more intensive effort and greater numbers of vessels engaging in the fishery, but that the density of scallops may be so reduced as to threaten their continued regeneration.

The Committee was eventually convinced there was a need for intervention of some form to counter the trend in increasing fishing effort and declining catch rates.

Management Measures

The total number of otter trawl vessels was limited in Queensland in 1979 to 1270 vessels of varying lengths from 8 to 28 m (Hill and Pashen 1985). In 1988 the number has decreased through management measures to approximately 1,100 vessels. There is no separate endorsement on these vessels for the scallop fishery but the vessels traditionally operate in either the prawn fishery or a combination of prawning and scalloping activities.

In 1980, only about 20 vessels of the total possible number considered scalloping to be their main activity (Williams 1980). This number has increased with about 70 vessels conducting significant scallop fishing during the 1987-88 season.

Once Queensland obtained control of the scallop fishery through the OCS. Agreement in June 1987, a number of management measures were then either put into effect or were applied in Queensland and the (previously) Commonwealth waters:

i) a maximum net size was implemented in November 1984 (for State waters only) of 109 m combined head and bottom rope and a minimum mesh of 109 m combined head and bottom rope and a minimum mesh of 82 mm; this mesh was reduced to 75 mm in July 1985 and applied to all waters after July 1987. Prior to this, there was no limit on the size of nets which could be used in Commonwealth waters in the fishery. This restriction was designed to reduce the swept area and control the increasing effort being exerted by the larger vessels in the fishery. The mesh size law was tied into the shell size law.

ii) a minimum shell size of 80 mm was introduced in November 1984, increased to 85 mm in July 1985 and again increased to 90 mm in October 1987. The shell size limitation was introduced primarily to allow the scallop to have the opportunity of spawning at least once before capture. It was also supported on the grounds of market acceptability of meat size.

iii) a compulsory log book was introduced in September 1987 for vessels operating in the central Queensland scallop fishery. This was deemed necessary to collect more information on catch rates per unit of effort for the fishery as a whole, as a guide to future management needs.

iv) a maximum vessel size of 20 m was implemented in November 1984 and continues to apply. This restriction applied to both the prawn and scallop trawl fisheries as a measure to limit swept area.

The introduction of the minimum shell size necessitated the use of mechanical sorting machines on board vessels. These are cylindrical drums with holes cut to size which rotate as shells are fed into the machines. Undersize scallops are immediately returned to the water.

Despite these measures, there is continuing concern about the density of scallop on the beds. Although there is currently no closed season on scalloping, the increase in shell size to 90 mm means that very little shell of that size can be caught on the grounds between April and

September. It is a proxy for a closed season; however, vessels may still trawl for scallops at this time.

Fishermen reacted unfavourably to the increased size limit of 90 mm. Fishermen claimed that scallops from different areas have different growth rates. In certain so-called "wide grounds" and deeper areas off Mackay, conditions were such that the majority of scallops were alleged not to grow to 90 mm even though the meat size inside the shell would be acceptable. Because of this, the Authority introduced a permit system which allowed the harvesting of scallop shell in these areas between 85 and 90 mm and placed observers on board vessels to measure and count the shell.

In addition, the Queensland Fish Management Authority provided additional funds to the Queensland Boating and Fisheries Patrol. This provided additional enforcement of the activi ; of scallop vessels, both with respect to the permit system and to the landings of scallop shell.

On 1 March 1988, the Authority introduced a further measure with the imposition of a minimum meat count of a minimum of 130 pieces of scallop meat per kilogram.

The minimum meat count was one recommended by the industry as a method that is more easily policed and enforced than the shell size and the measure was to apply for the 1988 season. It will require enforcement at the processing level in registered processing plants which are licensed by the Authority to undertake this processing. At this stage it is a voluntary measure to assess the practicality of weighing, measurement and enforcement generally. Legislative support is currently being considered.

An additional management measurement employed during October and November 1. 7 was to ban daylight trawling for scallop shell. This was a further measure to reduce total swept area and to prevent 24 hour fishing on the scallop beds. Industry felt that 24 hour fishing was an undesirable practice without having evidence of the specific effects on the scallop itself. However, this had the effect of advantaging the larger boats against the smaller boats, smaller boats restricted to sheltered inshore waters and the larger boats being able to stay at sea longer and further from port on the more distant grounds.

The fishery itself exists in combination with a prawn fishery and the daylight ban was not popular because of its potential impact on the banana prawn (*Penaeus merguiensis*) fishery which is a daytime trawl fishery. The daylight closure has since been removed in favour of the meat count policy but it remains a management option.

Other Management Measures

In addition to the above management measures, there are current moves to establish scallop seeding areas. These would be small areas into which significant quantities of scallop shell would be placed prior to spawning. Protection would be afforded from trawling in such areas to allow them to operate as a source of scallop spawn for wider areas.

Research is needed into the selection of such areas. Effective means of policing these areas to prevent trawling are also an important consideration.

Further controls such as closed seasons to trawling and limited entry of vessels by special endorsement have been considered but not adopted at this time. The necessity for further management measures will largely be based on research results, data collected from the compulsory log book programme and, possibly, management measures taken to control prawn fishing activities.

Conclusion

Management of the Queensland scallop fishery has been a relatively recent phenomenon with most specific measures only applying for one or two seasons. It has been brought about through increasing concerns of biologists and fishermen themselves for the future viability of their fishery. While recognising the need for management, the industry has suffered considerable internal conflict as to the most appropriate means to provide such management. This has largely been the result of insufficient information about the nature of the scallop itself, limited information on catch/effort data for the entire fishery and the problems associated with both large vessels (13 m - 19 m) and small vessels (less than 13 m) operating under different circumstances in the fishery.

A number of management measures have been recently introduced and these are being monitored to assess their effectiveness. Other measures such as further restrictions on apparatus to be used, closed areas or closed seasons, and refinements of the minimum meat count arrangement are matters that are still under review.

Because of the recent introduction of most measures, there has not been sufficient time to assess their impact. However, with the continued operation of a compulsory log book programme, further data will be available to assist in this review in the coming years.

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GENERAL DISCUSSION

Zacharin: With respect to area closures, every time you draw a line anywhere in the water, you tend to bisect a bed. A major problem when putting in lines is that you've got to examine that whole section and make sure you are not bisecting high density areas. Otherwise it is impossible to keep fishermen outside the lines.

Neville: Once the system is going it shouldn't be quite so bad a problem, particularly if you get to a system where your seeding has a major impact on the stock distribution. If you relied on natural spatfall it can fall in any area and your problem is major. But if you replace scallop in the protected areas the problem is reduced.

Zacharin: What I mean is that if you had a very successful spatfall in one area that was opened in that year and will now stay closed for the next two. Fishermen know that there is this large resource in the area. What will you do then?

Neville: You will have to have a very heavy policing hand, I believe. The intention is to try and work the enhancement operation with scallop fishermen so they see that the whole management approach is in their interests. We have not yet reached this stage. We are still trying to impose the management regime on them but in future we hope that by involving them in an enhancement operation we will not turn on them.

Dredge: Recognition that scallops do have definable stock-recruitment relationships is important. Rather than rotational fishing, the closure of spawning areas is going to become a far more important way of managing scallop fisheries than the bits and pieces type regulations that we have experienced in the past. There is a real shotgun approach in main stream management and area closure appears to be a much tidier approach.

Neville: We were talking before about the possible need to have parent stock at high density for effective spawning. This kind of approach would achieve that. Without current management where we have gear limitations and a size limit and there is fishing over the whole area occupied by the stock and basically the fleet reduces the whole stock in heavy fishing seasons down to reasonably low level. If it's important to have one or two really dense spots then I think this is the better way of achieving it.

Gwyther: I think that if you have a good relationship with fishermen then selective closures should work. I have to support what Zacharin said. Once you draw the line in the water in southern waters then you've got real problems when influential fishermen or processors shake their heads and say that it will never work.

Neville: The other side of the picture is that perhaps if you have one area to fish this year and another for next year and someone fishes in the wrong area his mates may not be too happy with him. Hopefully there might be some peer pressure. If they all join him it's a hopeless situation.

HISTORY, BIOLOGY AND MANAGEMENT OF WESTERN AUSTRALIAN STOCKS OF THE SAUCER SCALLOP *Amusium balloti*

L.M. Joll
Western Australian Marine Research Laboratories
PO Box 20
North Beach W.A 6020

Abstract

The main scallop fisheries in Western Australia are in Shark Bay and in the area of the Abrolhos Islands. Both fisheries commenced in the late 1960s with moderate catches, followed by much reduced catch levels in the mid 1970s. Catches in both fisheries increased considerably in the late 1970s/early 1980s, probably as a result of increases in both recruitment and effort. Changes in processing methods and marketing also improved profitability, which attracted more vessels and further increases in effort. Studies of the reproductive cycle and growth rate in Shark Bay indicated that spawning occurred over the period April/May to December and that most recruits from one year's spawning reached fishable size (approximately 90 mm) by April of the following year and commenced spawning. At current levels of fishing pressure this recruit group forms the bulk of the breeding stock. In order to avoid depletion of the spawning stock in the early part of the breeding season, the opening date is varied according to the strength of recruitment, as determined from pre-season surveys. In the Abrolhos Islands fishery, both the spawning season and fishing occur at different times from Shark Bay. Because of this, only the spawning stock is fished at the Abrolhos. Security of the spawning stock is not an issue in this fishery and management emphasis is on maximising yield and reducing the number of vessels, to increase the share of the catch for the remaining operators.

Introduction

The more common species of Pectinidae occurring off the Western Australian coast include *Amusium balloti* (Bernardi), *Pecten modestus* Reeve, *Chlamys asperrimus* (Lamark) and *Chlamys leopardus* (Reeve). *A. balloti* is distributed from Broome (18°S, 122°E) to

Esperance (34°S, 122°E) (Joll unpub. data) while *C. leopardus* has a tropical distribution, coming as far south as the Abrolhos Islands (29°S, 114°E) (Wells and Bryce 1988) (Figure 1). *P. modestus* and *C. asperrimus* have southerly distributions, with their northerly limit at Shark Bay (25°S, 113°E) (Wells and Bryce 1988). Genetic data from Woodburn (this volume) indicate that the *Pecten* population in Shark Bay is genetically distinct from the *P. fumatus* of S.E. Australia, although *P. fumatus* may occur along the southern coast of Western Australia.

Of these more common species, only *A. balloti* currently supports a commercial fishery, although there was a small dredge fishery for *P. modestus* in Cockburn Sound (near Fremantle) in the period 1970-73 (Heald unpub. data). There has also been interest recently in fishing for *C. leopardus*, which sometimes occurs at high densities in localised patches. Because of the s..mming capabilities of *A. balloti* (Joll in press), the fishery for this species is based on trawling rather than dredging.

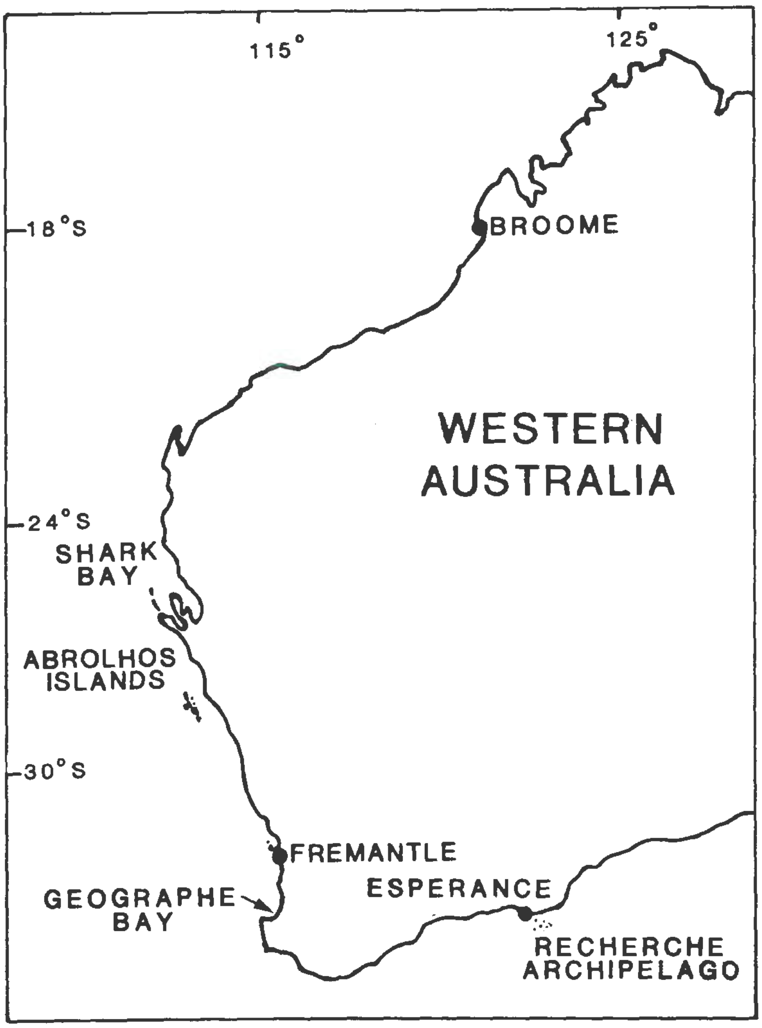

Figure 1. Western Australia, with the position of localities mentioned in the text.

History

Amusium balloti was first recorded in Western Australia in 1904 from trawl catches by the government survey vessel "Rip" (Gale 1905). Exploratory trawling by the research vessels "Lancelin" and "Peron" in the late 1950s and early 1960s revealed potentially commercial quantities of prawns and scallops in Shark Bay (Penn and Stalker 1979 ; D. Wright pers. comm.). However, it was not until 1966 that any landings were reported (Table 1).

Landings in the period 1966-1968 were the result of by-catch by vessels fishing primarily for prawns. In 1969 and 1970 a number of vessels began fishing specifically for scallops, but an apparent recruitment failure caused the fishery to cease operations in 1971. In 1972 scallops were again taken in small quantities by the prawn fleet and this fleet has continued to take a proportion of the total scallop catch. A few specialised scallop vessels operated in 1973 and then in increasing numbers from 1976 onwards. Up to 1978 all catch was landed whole and processed ashore, either by hand or shucking machine, but from 1979 vessels began processing by hand at sea and landing the catch as roe-off, frozen meats.

The greater efficiency of processing at sea, improvements in price due to the higher quality of the product and an apparent increase in the abundance of scallops led to further vessels being attracted into the fishery. This increased fishing pressure resulted in a much higher proportion of the stock being taken by the fishery, with the further result that a higher proportion of the stock did not survive into the older age classes. Because the age composition of the fished stock was lowered, the time period available for the development of larval nematodes in the adductor muscle (Lester *et al.* 1980, Bell 1980) was reduced. This had a marked upward effect on prices, as a much higher proportion of the stock was then acceptable for the export market. Federal export regulations had previously prevented much of the scallop production from being exported, as much of the catch was blemished by the more complete development of the larval nematodes.

The fishery continued to grow in terms of vessels and catch up until 1983 (Table 1), when vessel numbers were frozen and the fleet reduced to 14 vessels pending a review of management arrangements following a four year biological study. The scallop fishery has now been declared a limited entry fishery with the original 14 vessels and operates in concert with the 35 vessels of the limited entry prawn fishery under a catch sharing arrangement.

Table 1. Total scallop landings from Shark Bay and landings by scallop trawlers from 1966 to 1986. Total effort by scallop trawlers 1982 to 1986.

Year	Total Landings1 (tonnes meat)	Landings by scallop trawlers (tonnes meat)	Maximum No. of scallop trawlers	Total Effort2 scallop trawlers (Hr Fathoms)
1966	1.2	N/A	N/A	N/A
1967	N/A	N/A	0	N/A
1968	37.8	N/A	N/A	N/A
1969	272.8	N/A	7	N/A
970	83.2	N/A	14	N/A
1971	N/A	N/A	0	N/A
1972	22.3	N/A	0	N/A
1973	57.4	N/A	3	N/A
1974	31.7	N/A	0	N/A
1975	27.4	N/A	0	N/A
1976	107.5	N/A	2	N/A
1977	158.5	N/A	5	N/A
1978	109.3	N/A	4	N/A
1979	57.0	N/A	3	N/A
1980	101.0	58.6	4	N/A
1981	140.7	74.6	5	N/A
1982	434.7	295.4	13	125 000
983	705.3	640.4	26	235 000
1984	431.2	379.0	14	272 000
1985	232.8	175.0	14	183 000
1986	259.5	211.1	14	161 000
1987	490.9	377.3	14	185 000
1988	731.3	544.9	14	217 000

1 Conversion shell to meat: Landings as shell weight have been converted to meat weight using the approximate relationship: meat weight = 0.2 x shell weight.

2 Effort values: An effort unit of hour fathoms allows for the various head rope lengths used by scallop vessels. 1 hour fathom = 1 fathom of headrope length of net towed for 1 hour.

N/A = Not available.

The scallop stocks in the Abrolhos Islands area were first fished in the late 1960's, but the fishery did not operate over the period 1969-1972 (Table 2). From 1973-1979 the fishery operated intermittently, but from 1980 onwards an increasing number of vessels entered the fishery. This increase in catch and vessel numbers came about for the same reasons as the increases in Shark Bay (i.e. price and operating efficiency improvements, a reduction in the proportion of the catch affected by larval nematodes and an apparent increase in abundance). Following the freeze of the Shark Bay fleet the number of vessels fishing for scallops at the Abrolhos Islands increased rapidly (Table 2) and individual profitability was severely jeopardised. The entry of further vessels was restricted in 1985 and in 1986 the fishery was declared a limited entry fishery with 30 vessels.

Table 2. Annual scallop landings, effort and number of vessels at the Abrolhos Islands.

YEAR	TOTAL CATCH (TONNES MEAT)	MAXIMUM NUMBER OF VESSELS	EFFORT (HR FATHOMS)
1967	4.6	3	N/A
1968	25.9	8	N/A
1969-72	NO EFFORT OR LANDINGS	0	N/A
1973	0.3	3	N/A
1974	4.2	4	N/A
1975	6.7	6	N/A
1976	2.9	4	N/A
1977	0.8	3	N/A
1978-79	NO EFFORT OR LANDINGS	0	N/A
1980	12.3	2	N/A
1981	28.5	6	N.A
1982	47.0	9	N/A
1983	158.2	22	N/A
1984	219.1	40	97000
1985	10.0	27	12000
1986	74.2	28	39000
1987	102.5	27	20000
1988	23.8	24	22000

Smaller stocks and fisheries for *A. balloti* also occur off Dampier, Fremantle, in Geographe Bay and around the islands of the Recherche Archipeligo near Esperance. The fishery off Dampier is intermittent and operates largely as an adjunct to the Nickol Bay prawn fishery. The Fremantle fishery is based on only a few boats and is a mixed-trawl fishery taking scallops, prawns, bugs (Scyllaridae) and a variety of fish using 51 mm mesh trawls. The Geographe Bay and Esperance fisheries also have only a few vessels actively involved, although these fisheries target on scallops using 100 mm mesh trawls. The Fremantle fishery has operated for many years, but the Geographe Bay and Esperance fisheries are more recent developments, having both started with some exploratory fishing in 1984. Access to these fisheries had been controlled under general trawl management plans (Bowen 1985; Anon. 1989) but they have recently been brought under formal management regimes (Millington 1987, 1988; Moore 1989).

Biology

Reproduction

The spawning period of *A. balloti* in Shark Bay was reported by Heald and Caputi (1981) as occurring between December and January, when the animals were approximately two years old. This interpretation of the spawning season was, however, based on macroscopic examinations of the gonad. Studies over the period 1984-1986 using a gonad index (percent total dry weight), as well as microscopic histological examination, showed that gametogenesis begins in March and that the gonad maintains a sexually developed condition until December/January when it enters a regressed phase. Mature gametes are present in the gonad soon after the commencement of gametogenesis and spawning occurs from April/May to December (Joll 1987). The primary microscopic evidence for spawning was the presence of gametes in the major efferent ducts of the gonad. This evidence was, however, supported by estimates of the time of settlement of the earliest recruits by back calculation using daily growth rings (Joll 1988).

The spawning season at the Abrolhos Islands was also studied over the period 1984-1986 using both gonad index and histological methods. These studies indicated that the spawning season at the Abrolhos Islands is approximately three months out of phase with that occurring in Shark Bay. Gonad development commences in June/July and spawning occurs from August until February/March (Joll unpub. data).

Growth

Studies of the growth of *A. balloti* using both tagged animals and modal progression in size frequency samples indicated that growth is very rapid (Joll 1987). Scallops recruited from the earlier part of the spawning season in Shark Bay reach a size of around 90 mm by March/April of the following year and enter the breeding stock for that year. This group also enters a phase of "precocious" sexual maturity, with most animals of around 55 mm or greater in November showing some degree of gonad development. However, this gonad development probably does not contribute in any functional way to recruitment to the stock and its causes and value are not understood.

Recruits derived from later in the spawning season grow even faster than those recruited from the earlier part of the spawning season and also reach sizes around 90 mm by the following March/April. The reasons for this enhanced growth are not clear, although higher water temperatures and a reduced tendency to "precocious" gonad development may be major factors. The net effect of these variations in growth, however is that the bulk of the recruitment in Shark Bay is around 90 mm by March/April of the following year, at which time the animals are 9-12 months old.

Growth at the Abrolhos Islands is also rapid (Joll unpub. data), with the bulk of the recruits from a spawning period (August - February/March) reaching sizes of around 90 mm by the following July and entering the breeding stock at that time.

Adductor Muscle Condition and Meat Recovery

Changes in adductor muscle condition and meat recovery rates are closely associated with the reproductive cycle (Joll 1987). Minimum adductor muscle condition, in terms of both the wet weight of the muscle and the percent dry tissue weight, occur around the time of maximum gonad index (September in Shark Bay, December at the Abrolhos Islands) while the maximum meat condition occurs in the latter part of the regressed phase of the gonad, when the gonad index is at a minimum (March in Shark Bay, June at the Abrolhos Islands).

The changes in the weight of the muscle, as well as the variations in total tissue weight through the development and regression of the gonad, lead to variations in the recovery rate of meat from the whole, live weight. These variations range from around 17% (minimum meat condition, fully developed gonad) to around 25% (maximum meat condition, regressed gonad).

The range of change in the actual wet weight of the meat (as opposed to changes in recovery rate) for an animal of 90 mm is around 20%. This reduction in wet weight will, of course, be offset to some degree by growth over the period from the time of maximum to the time of minimum gonad condition. However, the reduction in the percent dry tissue of the adductor muscle during gonad development causes meat quality to be reduced and increases the likelihood of meat breakage during shucking.

Management

Fishing Seasons

The timing of the fishing season for *A. balloti* has evolved over recent years in response to various pressures. Prior to 1983 there was no legally defined season in Shark Bay, but in 1983 the season was opened on 1 March (to coincide with the opening of the prawn fishery) and closed on 31 August (because of the increase in the number of vessels in the fishery or gearing up to enter the fishery). In 1984 the season ran from 1 March to 31 October, to coincide fully with the prawn season. Since 1984 the closure date has remained tied to that of the prawn fishery, as scallops are an important by-catch for the prawn fishery in the latter part of its season. Scallop vessels, however, have tended to finish before the end of the legally - defined season, as catch rates become too low for them to continue to fish economically.

Because of the importance of the by-catch of scallops to the prawn fishery, the general timing of the Shark Bay scallop fishery has been influenced by the timing of the Shark Bay prawn fishery, although there have been some specific changes in the opening date of the Shark Bay scallop fishery. These changes in the opening date have arisen as a result of a developing understanding of the breeding biology as well as year-to-year variations in stock abundance, determined from pre-season surveys. In 1985, in response to survey data indicating low levels of residual stock and a fairly low level of recruitment, the season opened for one month in March (to take the residual stock in peak meat conditions) and then re-opened on 1 July (to allow the small recruitment the opportunity of several months spawning).

Opening dates in other years have been 15 May (1986), 1 May (1987) and 21 April (1988). The philosophy behind these changes in the opening date has been to maintain a high level of spawning stock for at least the early part of the breeding season. This is because length frequency data and back-calculation of the ages of recruits from growth rings (Joll 1988) indicate that the bulk of the recruitment of the following year comes from spawnings in the early to middle part of the breeding season (April/May - July). Although a relationship between the abundance of the parent stock and the strength of the subsequent recruitment has not been demonstrated, the maintenance of relatively high levels of breeding stock during this period has been felt to be prudent.

The general timing of the fishing season for scallops around the Abrolhos Islands has also been influenced by that of another fishery operating in the same general locality. The very much larger fishery for western rock lobsters (*Panulirus cygnus*) at the Abrolhos Islands (annual value approximately $25 million) operates from 15 March to 30 June and these dates have provided the boundaries for the operation of the scallop fishery since 1984. The reasons for this are: (i) it is cost effective to patrol the scallop fishery using patrol vessels which are in the area at the time for the rock lobster fishery; (ii) the presence of rock lobster fishermen in the area prevents the use and abuse by scallop fishermen of private facilities owned by rock lobster fishermen.

The boundaries set by the operations of the rock lobster fishery and the differences in the spawning season at the Abrolhos Islands has the effect that the Abrolhos Islands scallop fishery only fishes adult scallops in their post-spawning period. The incoming recruitment is not normally vulnerable to fishermen's gear (100 mm mesh) until around the middle of June, but in recent years, when stock levels have been low, most fishermen have fished for only three to four weeks before moving to other fisheries, so that the incoming recruitment to the spawning stock has been protected from exploitation.

Gear and Vessels

Both the Shark Bay and Abrolhos Islands scallop fisheries are limited entry fisheries with 14 and 30 vessels respectively. In addition to the limit on vessel numbers, vessel replacements are also controlled to limit the increases in fishing power generally associated with replacement vessels. The amount and nature of trawl gear used is also controlled. All 14 vessels in Shark Bay are authorised to use twin trawl gear with a maximum of 25.6 m (14 fathoms) headrope length of trawl. In the Abrolhos Islands fishery 18 vessels are authorized to use 25.6 m of trawl while 12 vessels are authorized to use a maximum of 18.3 m (10 fathoms) headrope length as a single trawl. Minimum mesh size of nets is 100 mm and maximum otter board sizes are 2.29 x 0.91 m (7.5 x 3 feet) in both fisheries.

Fishing Times

Scallops are normally catchable by trawling gear on a 24-hour basis. In previous years fishing for scallops in both Shark Bay and at the Abrolhos Islands has been conducted on a 24-hour basis by vessels large enough to carry two crews. From the start of the 1988 season all trawling vessels (both scallop and prawn) in Shark Bay were limited to fishing between the hours of 5 pm and 8 am the following day. This restriction was in response to concern by prawn trawlers about the effects on prawns of fishing for scallops on a 24-hour basis and to support the catch-sharing arrangements between the two fleets by preventing prawn trawlers from fishing for prawns at night and for scallops during the day.

Shell Size

No minimum shell size is set. The size at capture is controlled largely by the minimum mesh size of the trawl nets and the opening dates of the season. The 100 mm mesh nets have a very low efficiency for scallops <80 mm in shell height (Joll unpub. data) but the controls on the opening date usually ensure that most scallops in the population are larger than 90 mm.

Management Strategies

Because of differences in the timing of both fishing and spawning in Shark Bay and at the Abrolhos Islands, the fisheries exploit stocks of different age, reproductive condition and in different phases of the meat condition cycle. In Shark Bay the fishery mainly exploits the incoming recruitment, which is also the main spawning stock, at ages 0+ to 1+ and the main management emphasis is on ensuring that an adequate spawning stock is available. Because of the decreasing meat condition with the onset of spawning, however, it is desirable to take animals as early as possible in the spawning period. Unfortunately, these requirements are somewhat conflicting. Furthermore, the population size required for an adequate spawning stock is not properly understood. Nevertheless, the recent history of the Shark Bay fishery suggests that the levels of breeding stock generated by the current management strategy are adequate. Management strategies, therefore, aim to keep the breeding stock levels within the range of those currently experienced.

At the Abrolhos Islands, only the 1+ post-spawning stock is vulnerable to fishing, although a part of the new recruitment (0+) may become catchable towards the end of the fishing season. Security of the spawning stock is not an issue in this fishery, although in both this fishery and the Shark Bay fishery there is some concern as to the effects of trawling on the survival of recruits. The major management aims in the Abrolhos Islands fishery are to take the maximum yield available from the stock and to reduce the number of vessels in the long term, thereby increasing the share of the catch for the remaining operators.

Conclusion

Scallop fisheries are a relatively recent development in Western Australia. Over the period 1984-88, when both the Shark Bay and Abrolhos fisheries have been fully exploited, catches have varied by a factor of three times in Shark Bay and 21 times at the Abrolhos Islands. These variations have occurred despite management aimed at ensuring the security of the breeding stock and with the greatest variation occurring in the Abrolhos Islands fishery, which only fishes post-spawning stock. It has been assumed that these variations relate to environmental effects on recruitment which affect the success of the larval or juvenile stages, but the environmental variables responsible are unknown at this stage. The possibility of stock-recruitment effects also requires consideration. The future prospects for these fisheries are continued wide variation in annual catch and fishermen must adopt fishing strategies which will cope with this variability. Continued research is needed to identify the environmental effects responsible to variations in recruitment, while recruitment surveys will attempt to improve catch forecasting to enable better planning for the fishery.

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THE NEW ZEALAND SCALLOP FISHERY : A BRIEF REVIEW OF THE FISHERY AND ITS MANAGEMENT

M F Bull
Ministry of Agriculture and Fisheries
Private Bag, Nelson
New Zealand

Abstract

The history of the New Zealand scallop fishery from its beginning in Tasman Bay in 1959 to its present status is briefly described. The fishery currently covers grounds in the Northland, Coromandel and Nelson areas and has the total yield of approximately 3,000 to 5,000 tonnes shell weight per annum. The biology of the species concerned (Pecten novaezealandiae), is briefly covered and the commercial fishing practices described. The current management regime is outlined and a rationale for various restrictions given. Some thoughts on potential benefits and associated risks of moving to a management-system based on rotational fishing of grounds on a three or four year cycle are given.

Introduction

This paper presents a brief history of the development of the commercial scallop fishery in New Zealand and covers some aspects of the biology of the species and the past and present approach to management of the fishery. The New Zealand scallop *Pecten novaezelandiae* is very similar to the commercial scallop of Tasmania and Victoria but there are some differences in both the biology of the species and the management approach in New Zeala..d. Hopefully this brief review will provide a good background for further discussion of appropriate methods of management of the respective Pectinid species.

History of the Fishery

The New Zealand scallop fishery began in Tasman Bay at the northern tip of the South Island in 1959 and over the following ten years spread to cover grounds in nearby Golden Bay and the Marlborough Sounds (Figure 1). Production from this fishery reached a peak of nearly 10,000 tonnes shell weight in 1975 but during the following five years suffered a dramatic decline (Table 1). As a result of concern about declining catches, controls on the issuing of new permits were introduced in 1977 but despite a reduction in boat numbers from 245 to 1976 to 98 in 1979 the decline continued and the fishery was closed for two years in 1981.

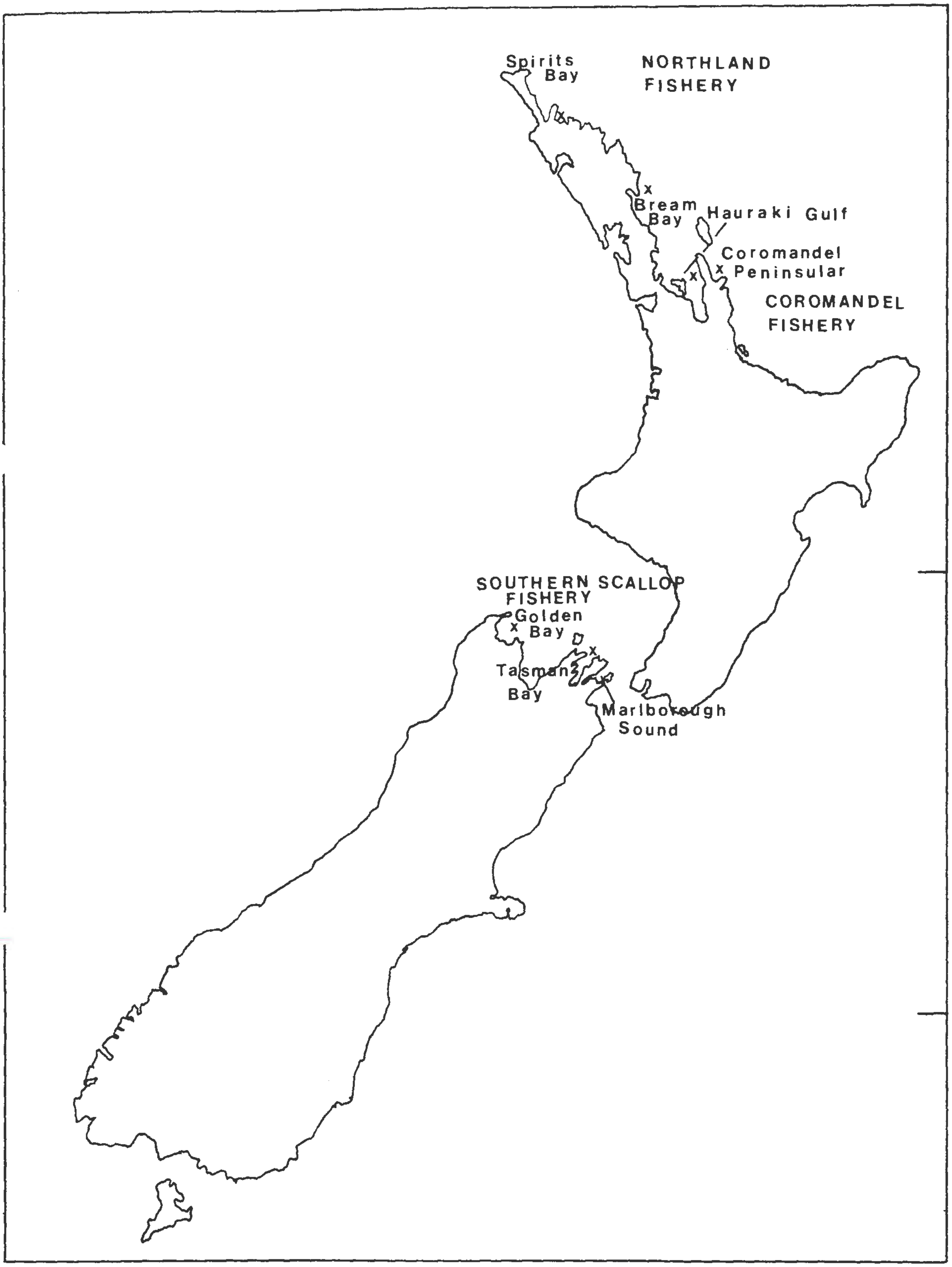

Figure 1. New Zealand scallop grounds. (x) commercial beds.

Since its re-opening in 1983 the Southern Scallop Fishery, as it is now known, has been fished as a tightly controlled fishery with only 48 licences being issued. Yields have been about 2,000 - 3,000 tonnes live weight per year. However data from a recent dredge survey indicate that recruitment over the last two years has been relatively poor and it is expected that for the next two years, at least, annual production from wild stocks will be significantly below this level (Bull 1988). While the northern tip of the South Island remains the main area for scallop fishing in New Zealand, there are now other grounds commercially fished in New Zealand.

In the early 1970s two fisheries were developed on the east coast of the North Island. One, on the Northland coastline from Spirits Bay to Bream Bay is known as the Northland Fishery, and the other, on both sides of the Coromandel Peninsula, is known as the Coromand Fishery (Figure 1). These two fisheries have shown a somewhat more stable production than the southern fishery and in recent years have yielded about 500 to 700 tonnes and 700 to 1400 tonnes respectively (Table 1). Commercial scallop fishing has also recently started in the Chatham Islands, 850 km east of New Zealand at 44°S latitude and it is possible that this could develop into a fishery of a similar scale to the Coromandel or Northland fisheries.

A fishery for a deepwater fan scallop *Chlamys delicatula*, that is similar to the Tasmanian doughboy, was started last year off the south coast of the South Island near Dunedin. Mainly because of small size and low meat yield, the economic viability of the fishery is doubtful and is likely to remain so unless world prices for such scallops increase significantly.

Species Biology

The New Zealand scallop has the typical asymmetric shape of the genus Pecten with convex right valve and flat or slightly concave left valve and is very similar in appearance to the commercial scallop of Tasmania and Victoria. Its range covers the whole New Zealand coastline and it occurs in a variety of habitats from shallow semi-estuarine inlets to oceanic conditions in depths up to at least 90 m. The main commercial beds in the Southern Scallop Fishery occur in an open bay situation in 10-25 metre depth on a soft muddy substrate, while on the North Island beds, the substrate is predominantly hard sand in depths of 15-30 m.

Studies on the reproductive cycle have shown that the species is a serial spawner with individuals usually having a number of partial spawnings over a period of several months. In the southern fishery spat settlement has been observed in all months from October through to April but peak settlement is usually in December or January (Bull 1976).

Scallops in New Zealand do not generally form distinct annual rings on their shells and it is therefore impossible to accurately age them by ring counts as is done with the overseas

TABLE 1. Annual yield from New Zealand scallop fisheries 1959 - 1987

Year	Southern Nelson/Marlborough		Coromandel		Northland	
	Catch tonnes shell wt	Boat Nos. (with landing)	Catch tonnes shell wt	Boat Nos.	Catch tonnes shell wt	Boat Nos.
1959	15	1				
1960	114	6				
1961	104	4				
1962	288	6				
1963	952	17				
1964	764	22				
1965	334	18				
1966	246	21				
1967	106	26				
1968	65	14				
1969	627	25				
1970	640	34				
1971	1,724	49				
1972	1,892	67				
1973	2,566	83				
1974	4,848	96	4	2	40	?
1975	9,969	190	122	?	75	?
1976	4,378	245	80	?	133	?
1977	4,597	189	747	?	133	?
978	1,338	121	1,364	?	113	?
1979	836	98	858	33	150	?
1980	331	61	1,016	?	220	?
1981	0	0	1,081	?	540	?
1982	0	0	1,070	?	721	70
1983	1,801	48	1,380	23	693	?
1984	2,938	48	1,190	23	494	41
1985	1,958	48	710	23	691	?
1986	2,844	48	700	23	472	?
1987	1,752	48	1,098	22	503	39

Southern Scallop fishery = July - June years
Coromandel and Northland fisheries = calendar years
(Source - NZ MAF Statistics Unit)

species. However useful information on growth has been obtained from studies of size frequencies and measurement of tagged scallops. It is estimated that on the commercial beds in the Southern and Coromandel fisheries scallops reach the commercial size of 100 mm shell length approximately two to two and a half years after settlement (Bull 1976; Allen 1985) (Figure 2). As juveniles usually become mature at the end of their first year they have at least one and often two spawning seasons before entering the fishery. With the present heavy fishing pressure on commercial beds most scallops are taken within two years of reaching commercial size and few reach more than five or six years of age.

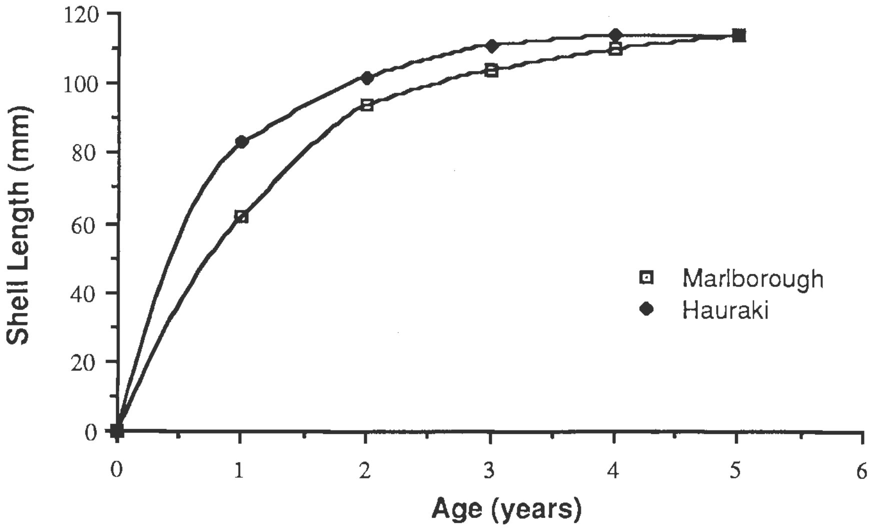

Figure 2. Growth curve for scallops on commercial beds in the Marlborough Sounds (after Bull 1976) and Hauraki Gulf (after Allen 1985).

Fishing Practices

The New Zealand scallop fishery is entirely a dredge fishery with the fleet currently consisting of about 90 vessels most of which range in size from 10 to 15 m. Because of the relatively short open season (two to seven months) nearly all these vessels are involved with some other fishing activity for part of the year such as trawling, gill netting, longlining or rock lobster fishing. However, scallop fishing generally provides 50% or more of their gross income.

Most vessels are privately owned and are run by a skipper and one crew. The type of dredge used depends largely on the substrate of the grounds concerned. In the southern fishery where soft muddy substrate predominates and where scallop densities are often quite low (<1 per 5 m^2), most vessels use a pair of ring bag dredges up to 2.5 m in width with heavy tickler chains. However on the hard sand of North Island beds a single box dredge with rigid tooth bar is more common.

The duration of dredge tows is largely dependant on the amount of scallops or other material being caught, but is commonly about 30 minutes. On recovering the dredge legal size scallops are sorted from the catch and packed in wooden boxes or sacks and undersized scallops and shell returned to the sea.

Marketable scallops are landed on a daily basis and trucked to nearby processing facilities where they are hand-shucked. Only adductor muscle and gonad are retained and the shell and viscera are usually dumped. Meat weight, (i.e. adductor muscle and gonad) recoveries are generally 12 - 20% of total weight with individual meats weighting 10 - 25 g, of which gonad may account for up to 30% or more.

Management Controls

The commercial scallop fishery is one of the most highly regulated fisheries in New Zealand. Within the first ten years of its existence controls had been introduced establishing a minimum size (4", later 100 mm), restrictions on number and size of dredges and an annual five months closed season (February - July).

In the late 1970s strict controls were placed on boat numbers through introduction of non-transferable licences under the controlled fisheries legislation. In the last ten years controls including daylight dredging only and five-day fishing weeks, daily quotas and shortened season lengths have been introduced. In addition, in the southern fishery, annual preseason stock assessment surveys have been carried out and an upper limit on seasonal catch imposed by way of either competitive Total Allowable Catches (TACs) (1979 and 1980), short season length and daily catch limits (1983 - 1985) or individual seasonal allocations (1986 and 1987).

Management objectives and rationale for current restrictions

Currently management of the New Zealand scallop fishery is aimed at the following five main areas:

(i) Prevention of biological overfishing of the stock to ensure long-term survival of the fishery and to prevent reduction of the stocks below a level at which it can maximise its productivity;

(ii) Minimising major fluctuations in landings;

(iii) Maximising the average long-term economic return from the fishery to the country;

(iv) Giving a reasonable long term profitability for participants in the fishery, and;

(v) Minimising conflict between amateur and commercial fishing sectors.

The first of these objectives is currently catered for by the size limit which protects part of the spawning stock and also by the various effort controls including limitations on boat numbers, season length and daily and seasonal quotas which put an upper limit on seasonal take. The size limit also aids stability of the fishery as it is set at a level which can be attained some areas in two years and in others not for three or four. This effectively spreads the fishing of a strong year class over two or three years.

The main value of limiting boat numbers is in allowing participants in the fishery to operate on an economic scale. However a restriction in vessel numbers also allows control on total take when combined with limited season length and daily quota and is of some value in limiting fishing intensity and subsequent destruction of habitat and indirect fishing mortality. The five-day week and daylight-only fishing restrictions are also aimed at limiting fishing intensity.

Regulations to maximise yield per recruit include:

a) The closure of the fishing season during the period when meat yields are at their lowest;

b) A size limit which prohibits the harvesting of scallops before they complete the majority of their early rapid growth phase, and;

c) Daily quotas which prevent wastage as a result of overloading of processing capacity.

Rotational fishing as a possible strategy for future management

While the New Zealand scallop fishery appears to be holding its own under current management controls there are a number of aspects of present management which are far from satisfactory. These include harvesting inefficiencies caused by daily quotas, the need for sorting of undersized scallops, and the high cost and relatively low benefit of the current annual surveys.

An alternative management regime currently being considered is a system involving fishing on a three or four year rotation of the grounds. This system is widely used in Japan and has the major advantage of allowing harvesting with minimum restriction and therefore ıaximum efficiency on the currently open areas while giving maximum protection to stock on the closed areas. The system would seem to be particularly applicable to a fishery where a significant enhancement operation can be carried out. The rotational fishing system can give a clear planning sequence for seeding operations and through seeding, the chances of immediate replacement of harvested stock can be greatly increased. However it may also be possible to run a successful rotational fishing operation without the need for enhancement if the fishing areas can be selected in such a way that there is a good chance of larvae derived from scallops in the protected areas being transported by the currents to neighbouring areas depleted by fishing.

Currently the major obstacles to shifting to a rotational fishing system in the Southern Scallop Fishery are concern about the cost and effectiveness of enforcing temporary area restrictions in an open bay situation and the impact that such a shift might have on recreational fishing activity. Due to enforcement difficulties and the desire of many recreational fishermen ιο fish their favourite local spots. The concept of a rotational fishing system may well be inappropriate for a fishery with a large recreational component. Assuming this is the case, it would probably be necessary to separate physically the commercial fishery from the main recreational fishing grounds by the creation of significant recreation-only zones. As well as protecting recreational interests, such zones are likely to have a beneficial effect on the commercial fishery as management of such zones with a size limit should mean that there is always a stock of adult scallops in the area that can act as back-up spawning stock for adjacent commercial zones.

The implementation of rotational fishing as a trial operation in the Southern Scallop Fishery is being seriously considered at present and may well be implemented in the 1989 season.

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SPAT CATCHES AS AN INDICATION OF RECRUITMENT TO SCALLOP POPULATIONS IN VICTORIAN WATERS

Noel Coleman
Department of Conservation, Forests and Lands
Fisheries Division, Marine Science Laboratories
PO Box 114
Queenscliff, Victoria 3225

Abstract

Monitoring for scallop (Pecten alba) spat has been carried out in Port Phillip Bay, Victoria, Australia, each year since 1983. Quantitative estimates of recruitment to the scallop fishery have also been obtained, and measurements of growth rate have shown that settlement to recruitment takes 15-18 months. A good relationship has been found between the numbers of spat collected and recruitment to the fishery 15-18 months later. The ability to relate spat collection with subsequent recruitment to the fishery probably depends on two factors: the residence time of water in Port Phillip Bay is three to six months, allowing scallops spawned in the Bay to remain there; and the Bay is sufficiently shallow for divers to obtain quantitative estimates of scallop abundance. Spat collection has also been carried out at Lakes Entrance in Victoria. In contrast to Port Phillip Bay, this is an area of open water where it is too deep to use divers to obtain reliable estimates of scallop abundance. At Lakes Entrance, no relationship between spat collection and recruitment to the fishery has been established.

Introduction

The major fisheries for the scallop *Pecten alba* Tate (now generally considered to be a synonym of *Pecten fumatus* Reeve) in Victoria are in Port Phillip Bay and at Lakes Entrance. In both areas, a major problem faced by the fishery is that its success may vary greatly from year to year because of the wide fluctuations in the recruitment of scallops to the fishable stocks each year. To derive an understanding of the factors which influence the success of the fishery and to provide data for managing the fishery, staff from the Marine Science Laboratories have been involved in research to elucidate the biology of *Pecten alba* and to devise means of obtaining quantitative estimates of recruitment to the fishery.

Most research has been carried out on scallops in Port Phillip Bay. Here reproduction occurs during late spring and early summer. The gonads are spent during the summer and develop during autumn and winter. There is some release of gametes during winter and early spring and a major release of gametes in late spring. Spat settlement occurs in late spring-early summer, mostly during December and January (Gwyther 1986; Sause *et al.* 1987a).

Scallops grow to commercial size (a shell height of >70 mm+) in about 15 to18 months, and the fishery is largely dependent on the recruitment of 1+ scallops that are entering the fishery for the first time (Gwyther 1986).

The scallop fishing season in Port Phillip Bay lies within the period April to December, but the exact dates of opening and closing the season depend on the condition and abundance of scallops. In January of each year divers from the Marine Science Laboratories carry out a quantitative survey to estimate the number of scallops available to the fishery in the coming season and to predict whether the coming season will be good or bad (Coleman and Gwyther 1988). It is possible to distinguish the scallops entering the fishery for the first time, as these are smaller than the residual stock remaining from previous years, and so the January survey allows an estimate of the number of scallops being recruited to the fishery.

Since 1983, the annual survey of commercially sized scallops in Port Phillip Bay has been supplemented by monitoring spatfall, and the relationship between spatfall and subsequent recruitment to the fishery has been investigated.

At Lakes Entrance, spat are present in the water over a longer period than is the case in Port Phillip Bay but there is some evidence for a major period of settlement around January to December. As in Port Phillip Bay, growth to commercial size takes 15-18 months (Coleman 1988).

In this paper I discuss the attempts that have been made to correlate scallop spatfall with subsequent recruitment to the fishery in Port Phillip Bay and at Lakes Entrance.

Materials and Methods

The spat collectors used are Netlon mesh bags filled with nylon gill net monofilament. In Port Phillip Bay, where work is on-going, spat are monitored at two sites, off Dromana and off St. Leonards (Figure 1). Both sites are in areas where scallops have in the past been relatively abundant. Each month from September to February six bags (42 x 85 cm containing 300-400 g of net) are set out at each location. The bags are suspended about three metres below the surface in water 13 m deep and are retrieved after two months immersion (i.e. from November to April). Research has shown that these represent the optimum conditions for catching spat (Gwyther 1986; Sause *et al.* 1987b).

After spat bags have been retrieved, the contents are washed on to a 1 mm mesh sieve. The material retained on the mesh is sorted and the scallop spat are removed and counted.

To estimate the abundance of scallops in Port Phillip Bay a survey is carried out in January of each year. Divers collect samples from 60-70 transect sites (each 100 x 1 m) which are selected according to a stratified random sampling strategy (McShane 1983; Coleman and Gwyther 1988).

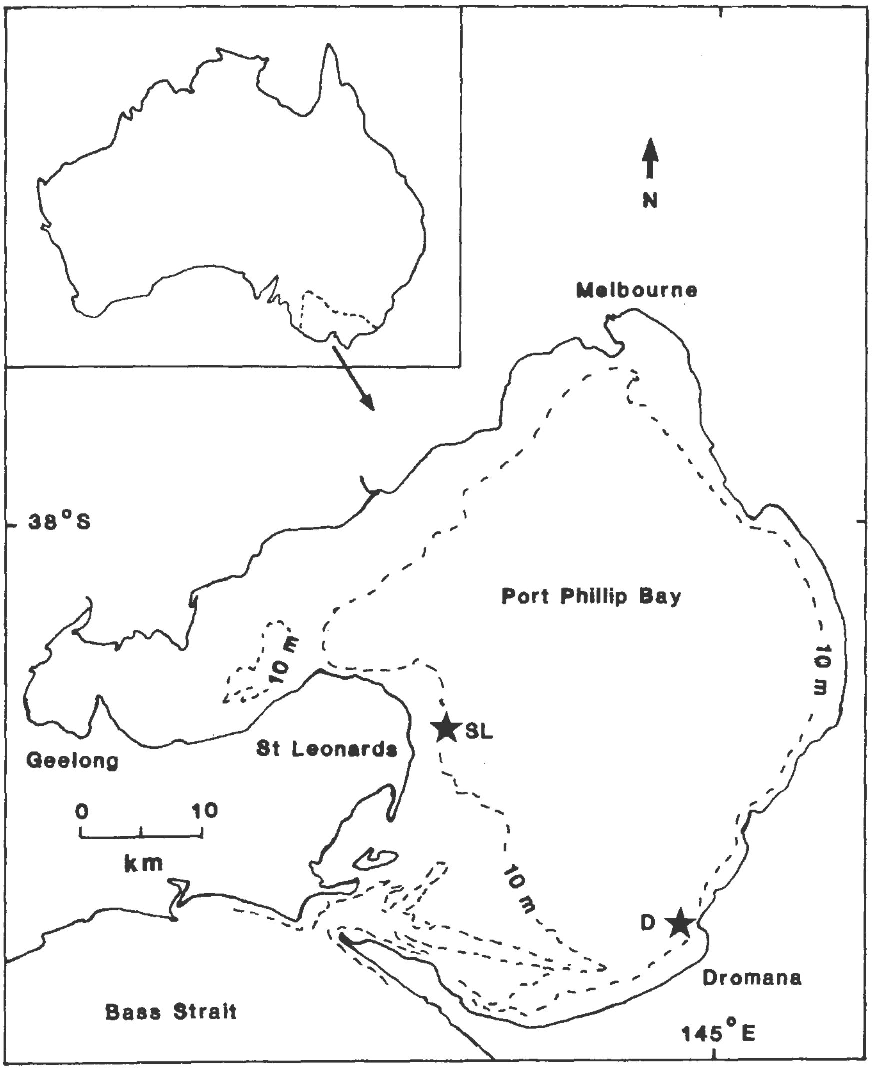

Figure 1. Locations of spat collectors off Dromana (D) and off St. Leonards (SL) in Port Phillip Bay, Victoria.

At Lakes Entrance spat monitoring was carried out from 1985 to 1989. Six bags (90 x 60 cm containing 1,100-1,300 g of net) were set out each month between September and February and were retrieved, and the contents sieved, after three months immersion in the period December to May. Initially sites east and west of Lakes Entrance were monitored, but because of low catches to the east, monitoring was subsequently restricted to the west of Lakes Entrance (Figure 2). The water at this site was approximately 40 m deep and the bags were suspended one above another at 3.6 m intervals in the bottom 20-22 m (Coleman 1987). Relative estimates of scallop abundance around Lakes Entrance were obtained from five to ten minute scallop-dredge tows.

Results

Spat settlement in the collectors in Port Phillip Bay occurs over a very short period. Since monitoring began, almost all the settlement found has been in the bags retrieved in December and January (Figure 3) although small numbers of spat have been found up to April in some years. The number of spat per bag has varied widely from year to year. During the first year of monitoring (1983-84) there were up to 700 spat per bag while over the summer of 1988-89 the maximum number was five spat per bag (Table 1).

Table 1. Comparison of maximum number of spat per bag with estimated number of recruits to the scallop fishery in Port Phillip Bay one year later.

Summer of spat monitoring.	Maximum number of spat per bag.	Estimated number of recruits one year later (millions)
1983-84	700	197
1984-85	100	47
1985-86	600	160
1986-87	20	71
1987-88	15	12
1988-89	5	

The recruitment of scallops to the fishery in Port Phillip Bay has also varied widely, from an estimated 197 million scallops in 1985 to an estimated 12 million in 1989. Patterns of spat collection and recruitment have been consistent; high maximum numbers of spat per bag in one year have been followed 12-18 months later by high recruitment to the fishery, and vice versa (Table 1; Figure 3). Although the correspondence between spat catches and recruitment has been good, it has been exact. Recruitment in 1988 was higher than in 1986 even though spat catches in 1986-87 year were lower than in 1984-85.

During each year of monitoring at Lakes Entrance, scallop spat were present for an extended period (December to May). Highest numbers of spat (up to 1300 per bag) were collected during the summer of 1987-88. There was evidence, from numbers of spat collected, from weight changes in adult scallops and from the spent appearance of gonads, for a major spawning in the period December 1987-January 1988 and for a second, minor peak in spawning during April-May 1988 (Coleman 1988). Spat collections during 1988-89 were extremely poor with no more than 36 scallops per bag being found (Coleman 1989).

Commercial beds of scallops were located following the spatfalls of 1985-86 and 1986-87 and their approximate sizes determined by dredging (Figure 3). Although spat

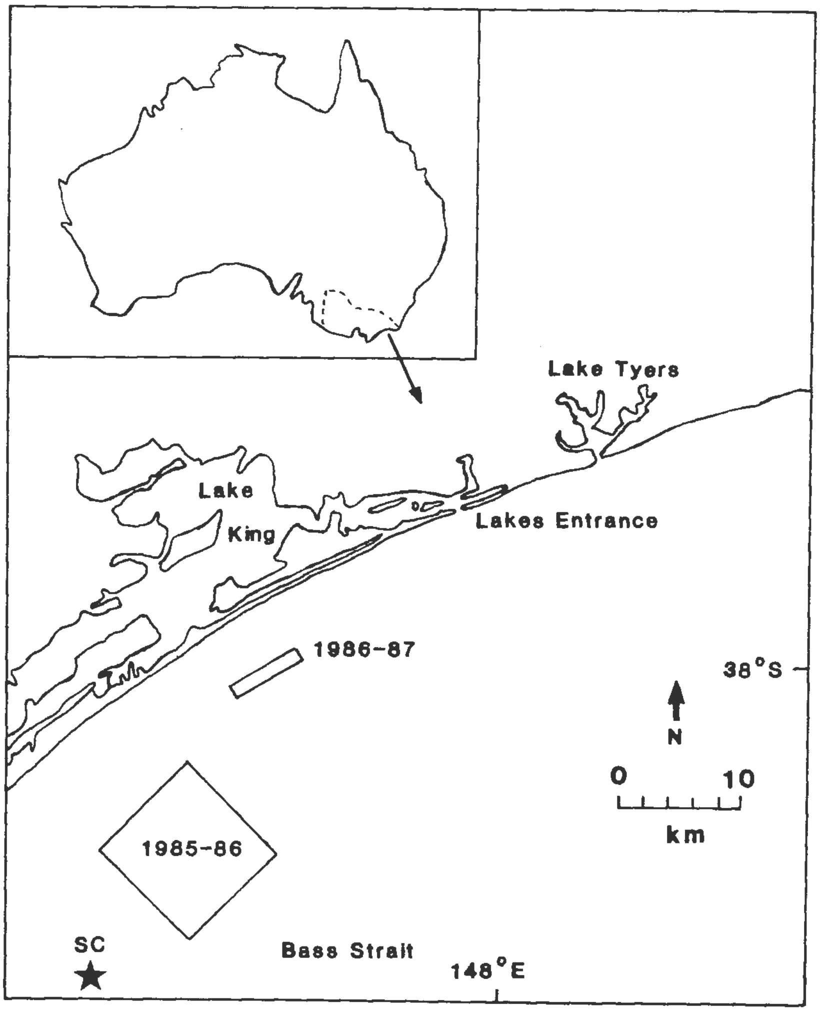

Figure 2. Location of spat collectors (SC) and of scallop beds resulting from the spatfalls of 1985-86 and 1986-87 off Lakes Entrance.

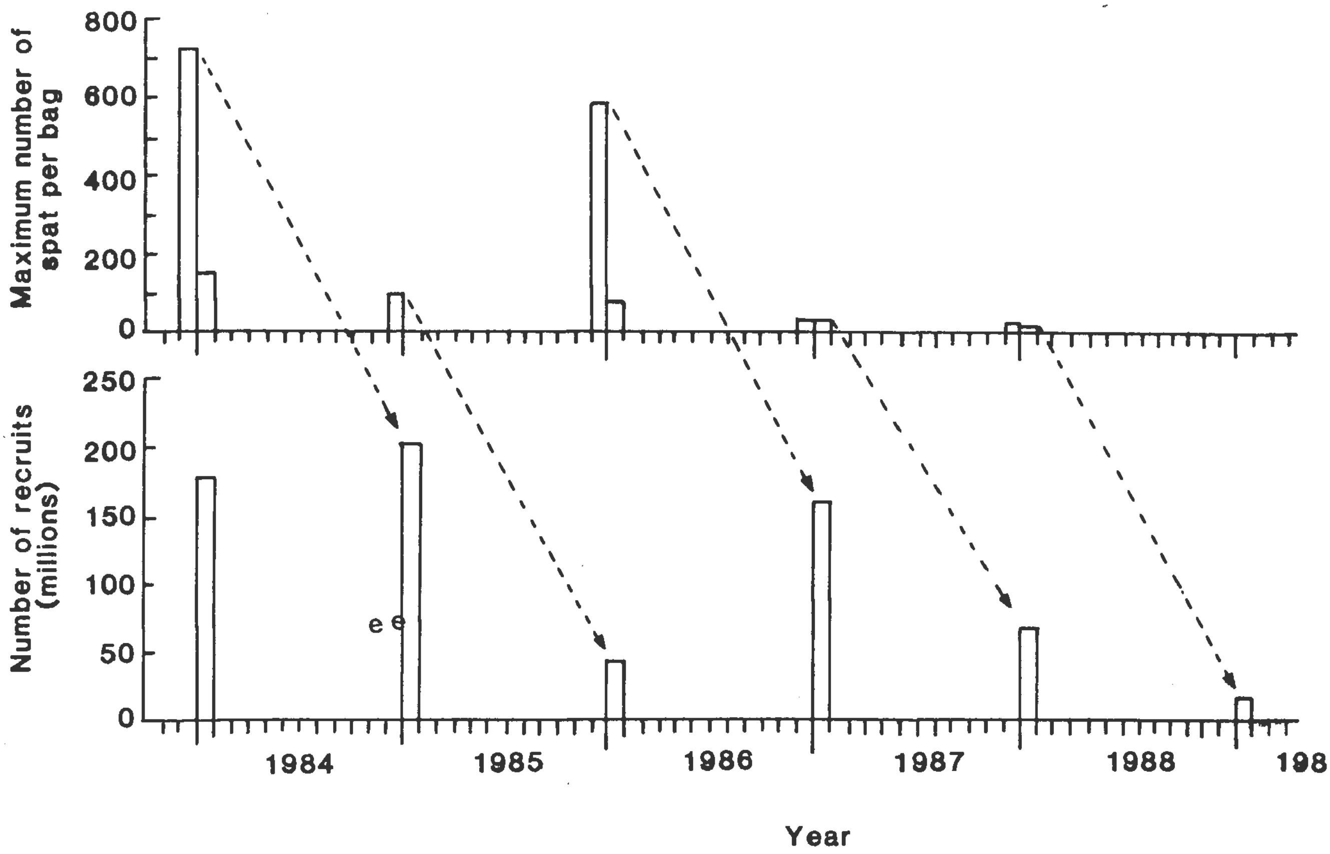

Figure 3. Relationship between spatfall and subsequent recruitment of scallops to the fishery in Port Phillip Bay.

catches were similar over the two summers (up to 600 per bag), the bed formed after the spatfall of 1986-87 was considerably the smaller (Coleman 1988). No commercial beds of scallops were found at Lakes Entrance during 1989.

Discussion

During the years that both spat monitoring and the annual January abundance survey have been carried out in Port Phillip Bay, a strong relationship has existed between the numbers of spat collected and recruitment to the fishery in the following year (Table 1; Fig 3). The relationship with recruitment has been investigated in terms of maximum number of spat per bag, but average number of spat per bag could also be used.

In combination, spat monitoring over one summer and the survey in January of the following summer allow two predictions to be made concerning each scallop season. These are: a general prediction of the strength of the scallop fishery 12-18 months in advance and then, a more specific, quantitative estimate of scallop abundance three months before the season is due to open. Factors which make this possible in Port Phillip Bay seem to be: the residence time of water in Port Phillip Bay is of the order of three to six months (Anon. 1973), allowing scallops spawned in the Bay to remain there; and the area of the Bay, about 1950 km^2, (Anon. 1973). The depth at which scallops are found, mostly about 20 m or less, is such that it is possible to use divers to obtain a quantitative estimate of scallop abundance each year.

The time of spawning at Lakes Entrance is similar to that in Port Phillip Bay, as is the time taken from settlement to recruitment to the fishery. However, during the years the spatfall was monitored at Lakes Entrance, one particular contrast with Port Phillip Bay became apparent. Spat were present throughout summer and autumn even although there was evidence for peaks of spawning in both spring and autumn (Coleman 1988).

Results obtained suggest that the prospects for correlating spat catches with recruitment to the fishery at Lakes Entrance are poor. Spatfall in 1985-86 gave rise to a scallop bed which was fished commercially in 1987, and spatfall in 1986-87 gave rise to a bed fished in 1988 (Figure 2). While similar numbers of spat were collected over the two summers, the bed formed after the latter settlement was considerably the smaller. Spat catches during the summer of 1987-88 were the highest recorded, but no commercial beds of scallops were found at Lakes Entrance in 1989.

The factors which make it difficult, and probably impossible, to correlate spat catches with recruitment at Lakes Entrance, where the scallop beds are in an area of open water within Bass Strait, are the converse of those which make it feasible to do so in Port Phillip Bay. The area over which scallop larvae may be dispersed is much greater at Lakes Entrance than in Port Phillip Bay; and, because of the depth of the water, it is not possible to conduct dive surveys to get reliable quantitative data on scallop abundance.

Acknowledgements

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help and collaboration throughout all of it; and to Dr. Darwin Evan (MSL) for reviewing the original manuscript.

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GENERAL DISCUSSION

Dredge: Do you have any idea what is driving recruitment variability other than the abundance of parent stock at this time?

Coleman: Not with any certainty. In the last couple of years in Port Phillip we had a phytoplankton bloom which led to problems with mussel settlement, and possibly prevented the scallops putting on condition to spawn successfully this year. In other years it is hard to say, but temperature may be a possibility.

Gwyther: Just to add to that one, I'm not sure whether there's a good relationship between adults and spat per bag. What we are looking at is a spat versus recruitment rather than adults versus spat. If we were to do that the relationship is all over the place. There have been years like 1985 which was one of the recent good years when the fishery lasted well into December and therefore scallops had most of that season to reproduce. That summer there was very poor settlement in collectors. In 1986 there was good settlement in collectors but very low adult stocks so one could speculate about an inverse relationship. What I'm saying is we haven't really got a stock recruitment relationship at the stock we've looked at, or that's at least how it appears. Next year when stock levels are down to the point when we're able to name them all we may see some sort of relationship, but at this stage it doesn't seem to be the case.

McLoughlin: Noel, you've shown us that you are still catching different qualities of spat in May. Have you got any thoughts about why we might be getting spat when it is so late in the year?

Coleman: I don't know if this is typical. It was the same in 1987, when we got our best spatfall, or the most spat per bag in those bags we took out in May. The fact they were left until May was accidental. We were supposed to have them out in April but because of rough weather we took them out in May and they were full of spat so we left them down longer this year. But I really don't know why.

McLoughlin: There seems to be a permanent residual population in Port Phillip Bay. Do you have a feeling as to whether it is the areas that haven't been fished or those which are fished all the time are the ones which provide the bulk of the breeding stock.

Coleman: It's probably a combination of both. There are some areas where there are scallops but for various reasons such as unsuitable ground or proximity to shore, they can't be fished. On the other hand our January survey is mainly concentrated on areas that are accessible to the fishery. We know that fishing becomes uneconomical and the fishermen start to think about getting out when the populations reduce to 50 to 60 million scallops. So we work on the assumption that three probably always are residual stock even in the fished areas which is somewhere around about that level. This gives you an average density of about two per square metre or a bit less than that.

West: I'm a little unclear why you'd use maximum of spat per bag in comparisons rather than average numbers of spat.

Coleman: If we use the average we get the same sorts of results.

RECRUITMENT VARIATION IN STOCKS OF THE SAUCER SCALLOP *Amusium balloti* IN THE ABROLHOS ISLANDS AREA

L.M. Joll
Western Australian Marine Research Laboratories
PO Box 20
North Beach W.A 6020

Abstract

Scallop landings from the Abrolhos Islands have varied considerably since the late 1960s. Since 1984 the fishery has been fully exploited and variations in landings reflect variations in recruitment rather than variations in effort. Using two independent estimates of both breeding stock and recruitment, data on stock and recruitment for the past five years were examined. A high degree of variability in the recruitment derived from various levels of breeding stock was noted, but the short run of data precluded a formal analysis. The observation of low levels of recruitment resulting from high levels of breeding stock, however, indicates either that the stock-recruitment relationship may be described by a Ricker curve or that the success of recruitment is subject to a high degree of environmental control.

Introduction

Saucer scallop landings since the late 1960s from both Shark Bay and the area around the Abrolhos Islands have shown considerable variation (Joll this volume). These variations are probably derived from two sources - variations in fishing effort and variations in recruitment, with the recruitment variations arising from either environmental influences, a stock-recruitment relationship, or a combination of these two factors. Since 1984, however, both the Shark Bay and Abrolhos Islands fisheries have been fully exploited (Joll this volume) so that variations in landings have reflected variations in recruitment rather than variations in effort.

This paper examines the available data on the relationship between the abundance of the parental stock and the strength of the recruitment derived from that stock at the Abrolhos

Islands over the period since 1984. Two independent and relatively simple measures of parental stock abundance and recruitment strength are available for Abrolhos Island stocks. Measurement of parental stock abundance in Shark Bay is a more complicated matter, as the fishery operates during the spawning season and the abundance of the parent stock changes during the spawning season as a result of this fishing effort.

Methods

Independent data sources for indices of parent stock abundance and subsequent recruitment at the Abrolhos Islands may be derived from the stock abundance surveys conducted each year in September since 1983, and from the annual catch of the fishery.

(i) Stock Abundance survey data

Measurements of stock abundance have been made at the Abrolhos Islands in September every year since 1983. The surveys have been carried out by the Fisheries Department's research vessel "Flinders", a 20.5 metre twin-rigged otter trawler. The vessel tows twin 10.9 m (six fathom) flat prawn trawl nets with 51 mm mesh wings and 45 mm mesh cod-ends. Trawling speeds in the surveys varied between 1.2 and 1.8 $m.sec^{-1}$ (2.4 and 3.6 knots). All catch rates have been adjusted to a standardised trawling speed of 1.7 $m.sec^{-1}$ (3.4 knots) because of net efficiency changes related to trawling speed (J.W. Penn, unpub. data). Distance trawled varied between 0.6 and 1.2 nautical miles and all catches have been adjusted to a catch per n. mile. Because of the patchy distribution of scallops at the Abrolhos Islands the survey data are expressed as the mean catch rate over the area of a patch, based on between four and ten trawls per patch, depending on the size of the patch.

The patterns of the breeding cycle (August to February/March) (Joll this volume) are such that a survey in September assesses the abundance of breeding stock. Recruitment from this breeding stock is too small to be vulnerable to the normal 100 mm mesh of commercial vessels during the following fishing season (15 March to 30 June). By September, however, the recruits have reached a size at which they are fully vulnerable to the smaller (51 mm) mesh of the survey trawls. By this time they have also become mature and entered the breeding stock. Because of the high level of exploitation during the fishing season, the residual stock component is very small and the new breeding stock is dominated by recruits. The survey data therefore measure the abundance of breeding stock on a patch in any one year and the recruitment to the patch from the previous year's breeding stock.

(i i) Annual catch data

The fishery operates within the period 15 March to 30 June, when scallops have completed their spawning season. This post-spawning stock is fully exploited and the fishery effectively ceases before the end of the legal fishing season. The growing recruit group derived from this spawning stock is, however, protected from exploitation by the fishery because of its smaller size. This recruit group goes on to form the breeding stock for the next breeding season (August - February/March) and is captured by the fishery in the following year. The annual catch therefore provides a measure of the breeding stock at the end of the breeding season while the catch for the following year provides a measure of the recruitment derived from that breeding stock.

Neither of these indices measure actual egg production. However, as the size distribution of animals measured in surveys has remained fairly constant from year to year (Joll unpub. data) the effect of variations in size distribution on fecundity would be minimal. Similarly the size of animals taken by the fishery is fairly constant from year to year, as the fishery operates each year primarily on 1+ animals (Joll this volume).

Results

(i) Stock abundance survey data

The stock abundance values in September by patch for the various patches at the Abrolhos Islands are shown in Figure 1. Survey data for the North Island patch were not available for 1983, but the catch taken from this patch by the fishery in March-June 1984 was more than 70 tonnes (meat weight). Despite the high breeding stock level that this catch would have represented, the recruitment derived from this stock was very low and has remained low ever since. Because of the continuing low levels of recruitment to this patch, surveys were abandoned in 1987. Survey data for the Mangrove Islands patch were not obtained in 1984 due to bad weather, while surveys of the Wooded Island patch did not commence until 1986 as this patch was not previously known to exist. It was included in the 1986 survey because exploratory fishing by commercial vessels late in the 1986 season indicated the presence of a high abundance of recruits in this area.

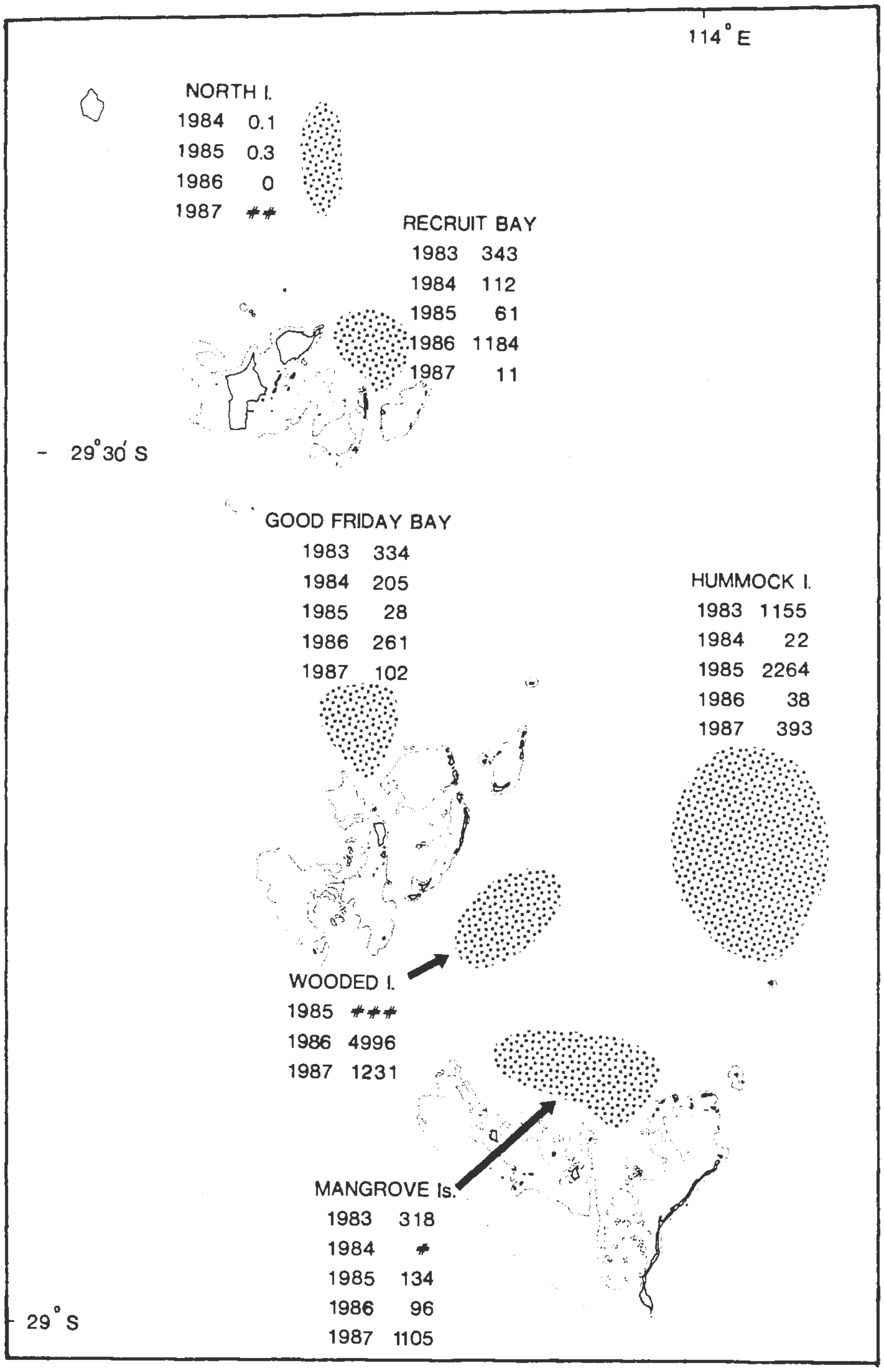

Figure 1. Abundance indices for scallops on the various patches at the Abrolhos Islands (1983-87). The indices show the abundance of breeding stock in one year, which is also the recruitment to the patch from the previous years breeding stock.(abundance indices are catch rate per n. mile at 6.7 m sec^{-1} for 21.8 m headrope length of trawl nets).
#no data due to bad weather ; ##surveys abandoned ; ###not previously surveyed.

(i i) Annual catch data

The annual catches for the whole Abrolhos Islands fishery for the period 1984-1986 are shown in Table 1.

Because the survey data from the various patches are not readily integrated to give a single, overall value for the Abrolhos Islands area, the patches have been reviewed as if they were self-recruiting. The annual fishery data have also been treated as if the population is a unit stock and not supported by larvae derived from a parent stock elsewhere.

The likelihood that these conditions are met varies between the two data sets. For the patch data the small separations between some of the patches suggests that they are unlikely to be isolated from each other. The annual fishery catch data, however, are almost certainly derived from a self-recruiting unit stock. Although conclusive data are not available to support this hypothesis, the separation from other known populations indicate that the population is almost certainly a unit stock. The nearest known populations are in Shark Bay and near Fremantle, approximately 350 km north and south respectively.

Discussion

The relatively short run of data available for both the annual catch and survey data sets precludes any attempt at a formal analysis of stock-recruitment relationships, as data sets of around 15-25 years are generally required to overcome the variability of environmental effects on stock-recruitment data (Ricker 1975). Nevertheless, it is possible to make some

Table 1. Annual Catch Data - Abrolhos Islands Scallop Fishery 1984-1988.

YEAR	CATCH (tonnes meat)
1984	219.1
1985	10.0
1986	74.2
1987	102.5
1988	23.8

preliminary conclusions from the data. The survey data show extreme variability, with the Hummock Island data showing high levels of breeding stock giving rise to small recruitments and low levels of breeding stock giving rise to large recruitments (assuming that the patch is reproductively isolated). The North Island patch data indicate that the high breeding stock level assumed to be present in 1983 (based on the fishery catch of 1984) gave rise to very low levels of recruitment. Furthermore, the low breeding stock values for the North Island patch, indicated by subsequent surveys, have continued to give rise to low levels of recruitment.

Data for stock levels in 1984 or 1985 at the Wooded Island patch are unknown, but the fact that the patch was not known to have produced any significant quantity of scallops prior to the 1987 season, despite active searching by fishermen, indicates that the stock level on this patch was probably very low. In spite of the apparently low breeding stock level in 1985, t patch showed a very high level of recruitment in the 1986 survey. While there was wide contrast in the data for the Hummock Island, North Island, and Wooded Island patches, the data for the Recruit Bay, Good Friday Bay and Mangrove Island patches show much less variability.

In considering the survey data there is always uncertainty as to whether patches are reproductively isolated or otherwise. In the fishery data the probability of the whole population being a unit stock is high. The fishery data, however, also show considerable fluctuations in breeding stock levels and subsequent recruitment, with high levels of breeding stock leading to low levels of recruitment (1984-85, 1987-88), a very low level of breeding stock leading to a moderately high level of recruitment (1985-86) and moderate levels of breeding stock giving rise to moderate levels of recruitment (1986-87).

As noted earlier, the data sets are too small for formal analysis, but the observation of low recruitment resulting from high levels of breeding stock suggests that either a Ricker curve rather than a Beverton and Holt curve (Paulick 1973) may describe the form of the stock-recruitment relationship or that the success of recruitment is subject to a high degree of environmental control.

An earlier investigation of stock-recruitment relationships for a range of exploited invertebrates by Hancock (1973) concluded that among the molluscs investigated the role of the parent stock in determining the success of recruitment was variable and differed between species. In scallops, the irregular recruitment masked any stock-recruitment relationship, probably as a result of environmental factors.

The scallop species considered here shows more regular recruitment than those considered by Hancock (1973), but the recruitment data nevertheless still show considerable variability. The most likely cause of this variability is the influence of normal environmental factors on the success of the larvae or the juveniles, although important environmental variables and their mechanisms of action have not yet been identified. There may also be some fishery-induced mortality causing at least some of the variability. Although the recruit group of *A. balloti* at the Abrolhos Islands is not normally vulnerable to capture by commercial scallop trawls using 100 mm mesh, physical damage inflicted by ground chains, otter boards and heavy cod-ends may lead to mortality of the new recruits, which are interspersed among the adult stock. In years of high stock abundance there are also high levels of fishing effort and the mortality of recruits resulting from this effort may lead to a low survival rate of the recruits into the fishery in the following year. This may be the cause of poor annual catches in e year following a year of high catch.

The data presented here are a 'first look' at the question of a stock-recruitment relationship in *A. balloti*. From the data available, it has not been possible to draw any firm conclusions on the presence or form of a stock-recruitment relationship. Nevertheless, the annual catch figures provide a data set for which there is a high degree of certainty that the population is self-recruiting. This data set will allow the question of stock recruitment relationships and environmental effects to be examined when a longer time series is available.

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HOW FAR CAN A SCALLOP POPULATION BE PUSHED?

M.C.L. Dredge
Queensland Department of Primary Industries
Fisheries Laboratory, Burnett Heads
Queensland 4670

Abstract

The evolution of a trawl fishery for the scallop Amusium japonicum balloti has been followed over a 20 year period from 1969. Effort directed at the species increased rapidly during this period. Production from the fishery peaked in 1982, and has declined slightly since then. Catch rates have declined by a factor of ten since 1978. Recruitment overfishing may be taking place. The scallop fishery is one component of a multi-species fishery in which more than 1000 boats are licensed to fish. Potential effort aimed at the scallop resource is governed as much by the relative economics of fishing for alternative resources as by scallop abundance and price. Consequently, it is extremely difficult to reduce exploitation rates in the fishery by a pre-determined level. Maintenance of an undisturbed broodstock by closing areas to fishing has been considered as an alternative means of managing the fishery.

Introduction

The 1,100 otter-trawlers licensed to fish in the Queensland-managed area between 11°S and 28°S share access to stocks which include ten species of prawn (*Penaeidae*), two species of scallop (*Amusidae*) and two species of slipper lobster (*Scyllaridae*). Numerous other species are taken either as unwanted trash or as marketable bycatch. A basic tenet of the Queensland government's management philosophy has been to allow licensed otter-trawlers access to all of these stocks.

While prawns are the major income source for the majority of trawlers (Williams 1980), scallops have been a valuable secondary income source for many boat owners, and the major source for a small proportion of the fleet. The more valued of the two species, *Amusium japonicum balloti* Bernardi is distributed between 18°S and 27°S, typically in the depth range 20 to 60 metres. The species is consistently fished on the continental shelf between Yeppoon (22°S) and southern Hervey Bay (25°S). It also is taken intermittently between Townsville (18°S) and Mackay (21°S), and off Tin Can Bay (26°S) (Figure 1). Scallops were first trawled in Queensland waters during the mid 1950s (Ruello 1975), but did not become an established or identifiable fishery until the late 1960s. Annual landings in the period 1969 - 1987 have varied between 80 and 1200 tonnes of adductor meat. During the 1970s, annual landings fluctuated with no discernible trend over time. They peaked in 1982, and have declined since that time (Table 1). A broad outline of the fishery has been given in a recent review (Dredge 1988).

A more detailed history of the Queensland scallop fishery will be presented in this paper. Changes in catch rates and effort directed at the major fishing grounds will be examined in relation to the downturn in landings. Management measures aimed at stabilising or increasing the value of landings will be discussed.

Biology of *A. japonicum balloti*

Studies of the reproductive cycle and behaviour of *A. japonicum balloti* have shown that the majority of adults are sexually mature in the period between May and September. Completely spent animals were abundant between September and December. Sexually mature female gonads contained between 3.2×10^5 and 2.6×10^6 mature oocytes and numerous developing oocytes (Dredge 1981). These data were interpreted as indicating that the species has an extended (five month) spawning season, with individuals probably spawning more than once during this period.

Rose *et al.* (1988) described the larval morphology and duration of the larval phase of *Amusium balloti*. Settlement was first observed at an age of 22 days, and at a size of 170 μm. No permanent byssal phase was observed during settlement. The process of larval transport is poorly understood at this time.

Tagging studies that gave data on growth rates and movement in the species were reported by Williams and Dredge (1981). The species was shown to have variable but rapid growth, attaining a shell height (S.H.) of 85 mm within six to nine months. Sexual maturity was attained before scallops reached an age of one year, and the maximum life span appeared to be about three years (Heald and Caputi 1980). Tagged scallops in the size range 36 - 111 mm

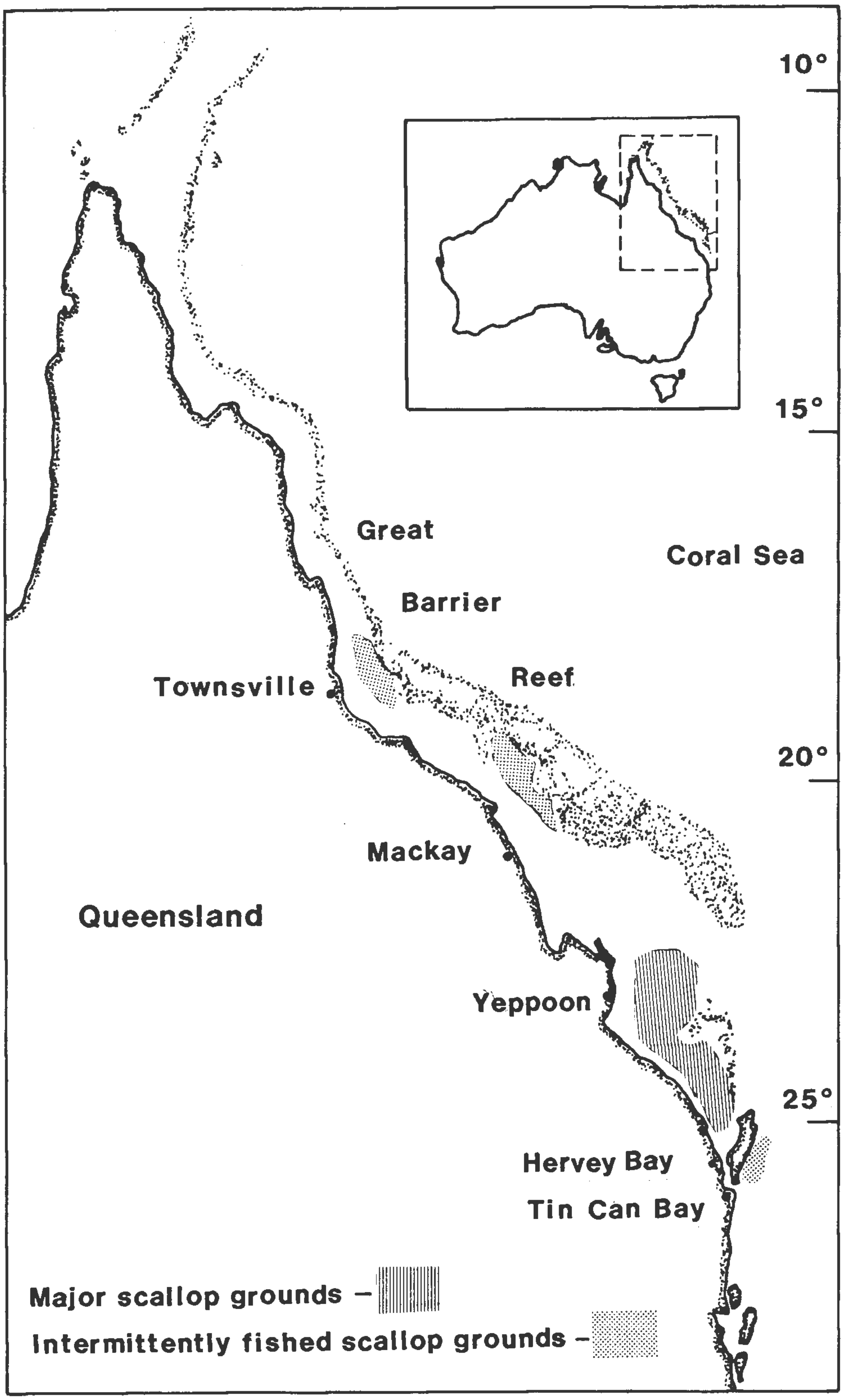

Figure 1. Queensland scallop grounds.

(S.H.) at liberty for periods of up to 121 weeks moved no more than 17 km. Most recaptured tagged scallops did not move from their release point. Tag returns were used to estimate natural mortality rates, with an instantaneous rate of 0.020 - 0.025 week^{-1} being given by Dredge (1985a).

The species occurs in extensive beds, which are separated by areas of low or zero scallop density. The maximum known density of scallops, estimated by combining maximum catch rate data with known gear efficiency (Joll and Penn in press), is 1 m^2. In 1987, trawlers consistently fished beds down to a catch rate of less than 500 scallops per hour, equivalent to a density of approximately one animal per 150 m^2.

The Fishery

Several hundred tonnes of scallop were trawled from the Wide Bay area, in the late 1960s, and off Cape Capricorn in 1972-1973. Grounds in Hervey Bay, wide of Yeppoon, and adjacent to the Capricorn-Bunker Group were opened up successively, and by 1980 there was little trawlable ground between 22°S and 25°S on the continental shelf that had not been searched for scallops (Dredge 1988).

Most scalloping in the period between 1969 and 1980 was carried out by prawn trawlers which worked on the scallop grounds as a secondary fishery. Effort directed at the stock was relatively low during this period (Table 1), and was insufficient to allow searching of all grounds suitable for scallops in each year.

Between 1970 and 1985, four major changes in the scallop fishery took place. Each had the effect of increasing effort in the fishery and, in combination, caused an apparent overfishing problem.

i) In the period 1970 - 1980, changes in vessel design, numbers and gear configuration led to substantial increases in the fleet's potential fishing power. The Queensland fleet increased from 500 to 1300 trawlers in this period (Hill and Pashen 1985). While no documented records on average vessel size or power for that period remain, there is no doubt that both increased considerably. In 1970 'large' trawlers of the time were 14 metres in length, powered by 100 kwatt motors, and towed a single 25 metre headrope length trawl. By 1980, larger trawlers in the fleet exceeded 20 metres in length, were powered by 250 kwatt engines, and towed trawls with a headrope length of 80 metres. One consequence of the increase in size (and capitalization) in the fishery was an increase in average time spent at sea by fishermen. Data from a voluntary log book programme

(Dredge unpub.) show that between 1976 and 1979, participating trawlers worked, on average, 90 - 120 days per year. In 1987, participating boats worked on an average of 160 nights per year.

ii) Changes in trawl gear configuration have been an important factor in the increase of effective effort in Queensland trawl fishery in the period 1970 - 1980. Otter trawlers initially equipped with single trawl nets were converted to two net - four board configuration by 1972. In 1978 - 1979, a three net - two board configuration was developed, and adapted to a four net - four board layout by many fishermen. Each of these changes lead to a substantial increase in effort because of the increase in total net size which could be towed. These changes occurred in both the prawn and scallop fishing sectors of Queensland's trawl industry.

Table 1. Annual landings, catch rate, estimated effort and price of scallop meat in the Queensland scallop fishery.

Year	Total catch (adductor weight)	Mean catch rate (kg/m headrope hour fished)	Effort (boat hours trawled)	Scallop price ($A, indexed to 1980)
1976	70	0.85	3000	-
1977	380	1.44	11000	-
1978	950	1.28	25000	-
1979	250	0.62	14000	-
1980	530	0.34	43000	5.87
1981	660	0.33	53000	4.58
1982	1220	0.38	86000	4.99
1983	880	0.66	38000	4.50
1984	900	0.30	81000	5.59
1985	660	0.13	107000	7.54
1986	700	0.13	116000	8.41
1987	450	0.11	77000	8.58

Source - Dredge (1988)

iii) Profitability in the prawning sector of the fishery appeared to be high in the early 1970s, and the trawler fleet increased in numbers during this period. By 1978 - 1979, many prawn trawlers, particularly those operating from north Queensland ports, were operating at a loss. However, profitability in the scallop fishery remained relatively high (Hill and Pashen 1985). Consequently, more trawlers were deployed in the scallop industry, initially on a part time basis. By 1981, a number of boat owners had constructed 20 m trawlers (the maximum length allowed in Queensland at that time) that were designed and operated as scallop trawlers. These boats contributed to the massive increase in effort directed at the scallop stock observed between 1978 and 1982 (Table 1).

iv) In 1985, scallop meat prices increased in value, both in absolute and real terms. The price rise persisted in the following two years, allowing scallop fishing operations to remain viable at catch rates that would have been uneconomic prior to 1985 (Table 1). The effect was to allow the fishery to maintain high levels of effort, and leave lower residual stock densities. Average catch rates declined by a factor of more than ten between 1978 and 1987.

Season Characteristics of the Fishery

The saucer scallop fishery was primarily an off-season fishery for prawn fishermen until the 1980s, and seasonal catch reflected the non-availability of prawns as much as seasonal abundance of scallops (Dredge 1985b). Proportions of annual landings taken each month are given in Table 2. There has been considerable variation from year to year. Between-year comparisons (Kolmogorov-Smirnov tests) of the proportion of each year's landings taken in each month (Table 3) demonstrate this variation. There was no significant variation in seasonal landing patterns between 1978 and 1980, and between 1986 and 1987. The similarity in seasonal landings between 1986 and 1987 can be explained in terms of a pulse fishery. Fishermen leaving the northern prawn fisheries in August and September search and fish for residual 1+ scallops in the early part of the season (September - November). They then target young of year (0+) scallops spawned during the past winter as they grow to legal size (90 mm). Total monthly landings and average monthly catch rate decline (Figure 2) and by February, most of the year's scallop harvest has been taken. In the absence of reliable ageing techniques, such a scenario is hypothetical, but fits with existing catch and effort data. The contrast between monthly catch rate data from 1977 - 1980 and that of 1987 - 1988 (Figure 2) supports the concept of a lightly exploited fishery becoming more heavily exploited.

Stock Assessment

The decline in total landings observed in this fishery has been attributed to recruitment overfishing (Dredge 1988). Such an observation is consistent with the observed decline in catch rates, total catch, and known residual densities of approximately one animal per 150 m^2 after fishing (Dredge 1988). Because scallops are sedentary and patchily distributed, structured stock assessment models (sensu Deriso 1987) can not be used to determine the relationship between effort and exploitation rates. Defining the relationship between spawning stock size and subsequent recruitment levels is difficult, if not impossible, because of the difficulty in determining the population level of spawners. Likewise, estimating fishing and total mortality rates in such a population presents particular difficulties because the relationship between stock size and catch rate is unclear. In these circumstances, conventional structured assessment models have little relevance to scallop stocks.

Spatial modelling of the stock

An alternative means of considering changes in stock size over time can be carried out using spatial modelling techniques. The stock can be depicted as occurring within an area divided into grids. A proportion of these grids contain scallops at high density, the remainder of the grids being areas that support only low densities of scallops. Fishing effort can be allocated to the grids. If a perfect knowledge of potential catch rate achievable from each grid is

Table 2. Proportion (%) of annual landings taken per month between 1977 and 1987.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1977	1.9	0.1	0.1	0.1	0.4	2.6	6.5	22.4	13.3	11.7	21.0	20.0
1978	9.5	5.3	1.0	4.1	3.3	8.7	10.1	7.2	12.4	16.8	12.2	9.3
1979	24.4	3.9	4.5	4.9	1.9	3.4	3.6	13.9	14.9	4.6	9.0	13.7
1980	8.9	6.6	2.5	5.9	6.5	8.0	7.4	7.8	8.9	14.6	9.0	13.7
1981	1985	no	data									
1986	7.6	9.1	2.3	2.3	0.1	1.6	3.5	7.9	16.6	19.9	18.7	10.4
1987	14.0	10.0	6.3	2.6	8.2	2.0	2.6	3.5	7.7	17.8	12.4	12.8

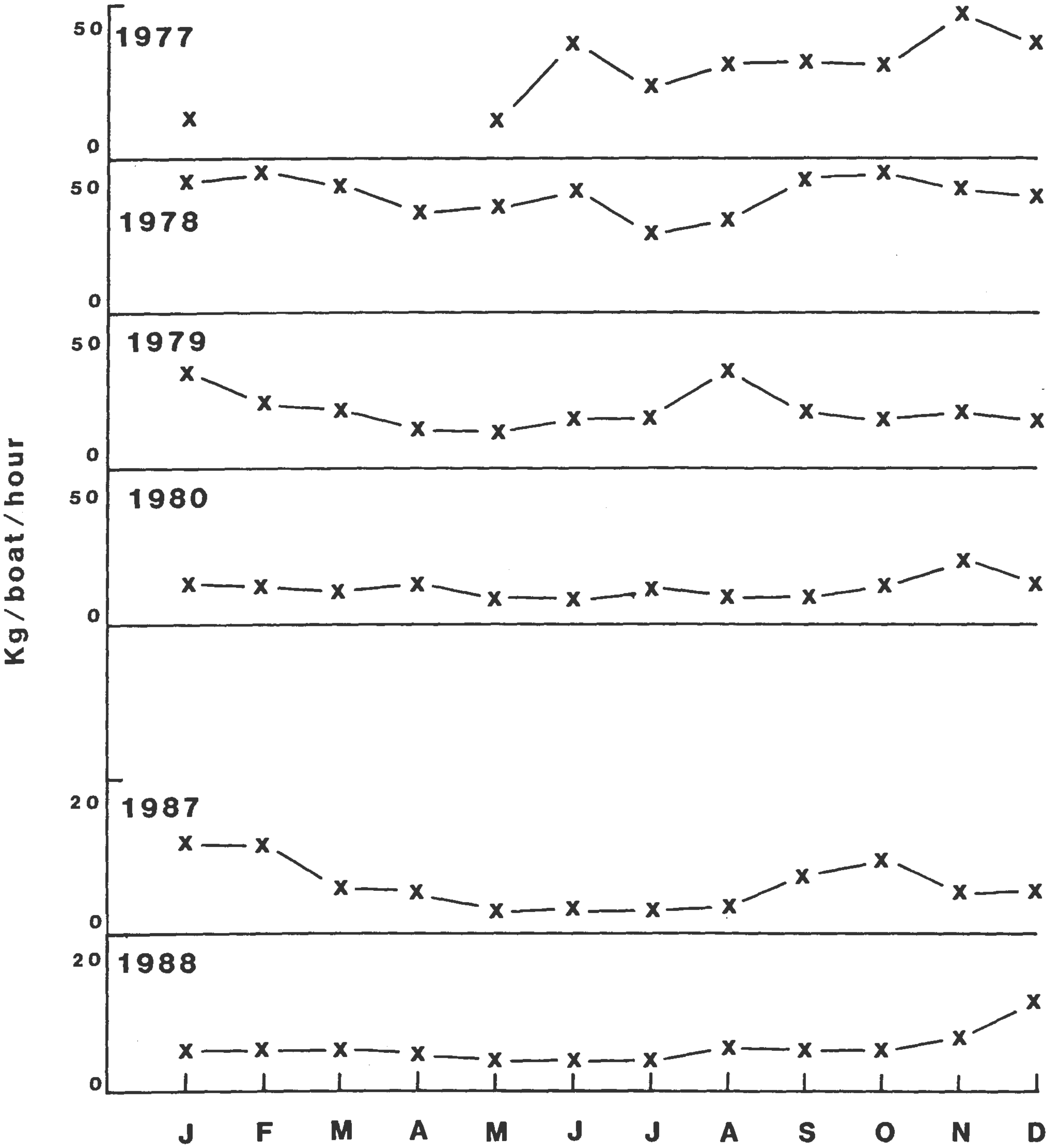

Figure 2. Monthly catch rate (kg adductor meat/boat/hr) between 1977-80 and 1987-88.

Table 3. Statistical comparisons of the proportion of annual landings taken in each month (Kolmogorov-Smirnov tests).

Year	1977	1978	1979	1980	1986	1987
1977		* *	* *	* *	* *	* *
1978			* *	NS	*	*
1979				*	* *	* *
1980					* *	*
1986						NS
1987						

NS Differences not significant

* P <0.05

* * P <0.01

assumed, effort can be allocated to the grid with greatest scallop abundance. This fishing effort harvests scallops for a given time, either daily or weekly. At the end of this time period, the harvest and remaining abundance of scallops in the grid is calculated. Scallop density in each grid is recalculated and the fishing sequence is repeated for a full year. A new set of recruits is then fed into the system as larvae which are dispersed throughout the entire area occupied by the stock. They are allowed to grow and die through natural mortality, and when large enough, fished. Total catch, catch rate and survivors from each year's fishing can be monitored. stock-recruitment function can be constructed and built into the model, and the effects of varying effort levels or other management strategies can be gauged by varying various input parameters in the model. Walters and Hilborn (pers. com.) set up a model incorporating these parameters, during a recent training school. The model consisted of a scallop population occupying 50 grids, five of which attracted 100 times the number of recruits per grid as the remaining 45. Effort levels were determined on the basis of swept area, using estimates of effort and gear size given by Dredge (1988) as a proportion of total area in which scallops are caught off Queensland's south and central coast. Effort was limited by abundance. When scallop density dropped below a given threshhold, fishing ceased. A Ricker-type recruitment function, which used landing data from the Queensland fishery in the period 1976 - 1987 as an estimate of spawning stock-size was forced to follow recruitment trends (based on landing statistics) during the period. Weekly fishing effort was allocated to the grid in which scallops were most abundant.

When the model was run over a 30-year period, total abundance, recruitment, and effort in the first ten years followed known statistics. The downward trend in abundance continued, and by year 15, both the stock level and catch rate had stabilised at a level of less than 5% of maxima (Figure 3). The fishery model was then manipulated by eliminating fishing from one of the high abundance grids after 20 years. The model predicted a rapid recovery in recruitment, high and stable scallop abundance and fishing effort and low catch rates (Figure 3).

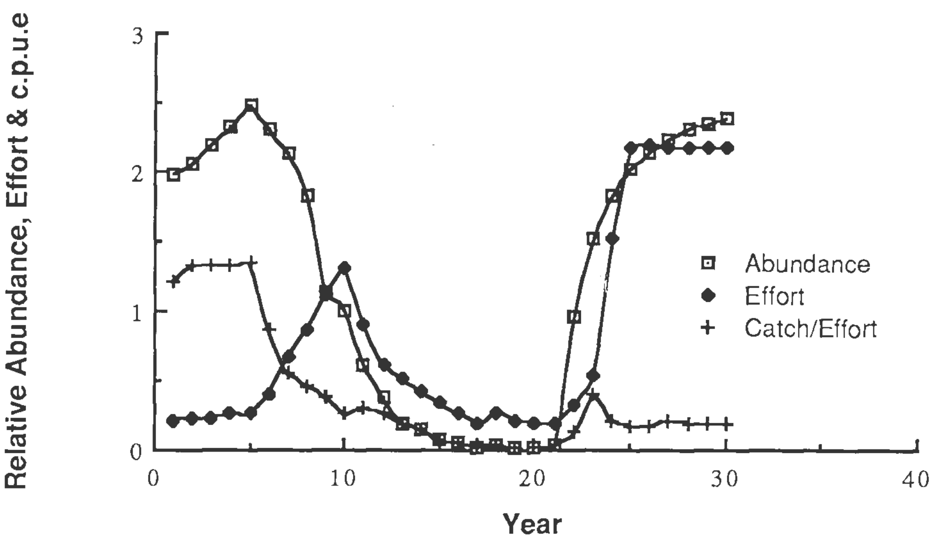

Figure 3. Output from a spatial model of a scallop stock, with no fishing effort applied to one grid after 20 years.

Discussion

The history of Queensland's scallop fishery between 1977 and 1987 has been one of increasing effort directed at the stock by trawlers whose efficiency has improved with time. At the same time, the value of scallop meat has arisen, allowing trawler operators to fish at scallop densities which previously would have been uneconomic. Consequently, the residual stock is fished down to such low levels that reproductive success may be impaired.

A substantial proportion of the catch is thought to consist of 0+ animals, taken prior to their first spawning. While fishing scallops at this age gives optimum yield per recruit (Dredge 1985a), the fishery has the potential to reduce the population substantially prior to spawning and consequently affect subsequent recruitment.

The potential threat to the industry has been recognised, and a series of measures designed to reduce effort in the fishery have been implemented (Neville this volume). Initial attempts included limitation on the size of vessels working in the Queensland east coast fishery, and restriction upon the combined headrope and footrope length. A ban on daytime trawling in what has traditionally been a 24-hour-a-day fishery reduced effort quickly, but had complex social effects in the fishery. Smaller vessels in the fleet were regarded as being unduly penalised by this measure, and fishing grounds adjacent to sheltered anchorages were fished very heavily. Given the basic tenet of management in the Queensland fishery - that all trawlers have access to all stocks - there is no guarantee that these measures will reduce total effort in the fishery. Effort directed at the scallop stock will be as much affected by the price and availability of penaeid prawns as by the price and availability of scallops.

The spatial model of the fishery indicated that by protecting areas in which high densities of scallops occurred, the annual catch could be stabilised at a level close to the maximum observed. This model, like any other, can be faulted as being simplistic. It does, however, offer the opportunity of investigating alternative management regimes. One such manipulation indicates that the concept of 'brood stock protection areas' may be of value for heavily fished sedentary animals. In Queensland, serious consideration is being given to closing a number of small areas to trawling for this purpose. The concept has considerable attractions as a management tool. Provided suitable areas are selected, the survival of an undisturbed breeding population is guaranteed. The population should not be affected no matter what levels of fishing pressure are applied to the remainder of the grounds, and should reseed them. Major drawbacks to the system include opposition from fishermen who do not want to lose fishing grounds, difficulties in effective policing of the grounds, and an imperfect knowledge of the transport pattern of larvae from the broodstock protection areas to other fishing grounds. Actual implementation of the scheme has not been finalised. However, it seems a worthwhile experiment in an attempt to stabilise or increase landings in the Queensland scallop fishery.

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VARIABILITY IN SPATFALL AND RECRUITMENT OF COMMERCIAL SCALLOPS (*Pecten fumatus*) IN BASS STRAIT

P. C. Young, R. B. Martin, R. J. McLoughlin, and G. West
Division of Fisheries, CSIRO Marine Laboratories,
GPO Box 1538, Hobart
Tasmania 7001.

Abstract

The fishery for the commercial scallop, Pecten fumatus, in Bass Strait has been characterised by marked interannual variability in catches, which can be related to the sequential discovery and exploitation of new beds, and recruitment failure on previously fished beds. In this study, the size of the spawning stock, as indicated by the mean annual meat weight caught per hour fished within 1° latitude x longitude grid cells, was found to be positively correlated to the mean number of spat settling on artificial collectors located within the same cell. Independent estimates of the abundance of juvenile scallops (less than one year old) showed no such correlation with the catch rates of adults in the same cell. It is postulated that while the size of the population of larvae competent to settle is related to that of the parental stock, the number actually settling on the bottom is dependant upon some, as yet unknown, characteristics of the physical and biological environment at the settling site.

Introduction

Although fished commercially in the D'Entrecasteaux Channel since the 1920s, *Pecten fumatus* has been fished elsewhere in southern Australia for little more than two decades. Since 1964, the scallop beds in Port Phillip Bay have supported an almost continuous fishery in which variations in the size of the annual catch have, at least in a general way, been related to the level of recruitment to the beds and, in recent years, to the abundance of spat settling in artificial collectors (Sause *et al.* 1987). Similar variations in catch abundance of *Placopecten magellanicus* in Canada described by Dickie (1955) were thought to be due to environmental factors and indirect effects of fishing, such as erosion of epifauna and substrata for settlement (Caddy 1979). In Florida, catch fluctuations in *Argopecten gibbus* had been ascribed to reproductive failure (Moyer and Blake 1986), and to temperature-induced mass mortality (Allen and Costello 1972). However, the large fluctuations in annual landings that characterise the southeastern fishery outside Port Phillip Bay (Figure 1) appear to relate more to the progressive discovery and exploitation of new beds as the old resources became exhausted (Young and Martin [in press]).

Although independent estimates of stock size and recruitment are not available for the Bass Strait beds, a number of surveys have examined the distribution and the size composition of scallop populations in the area both before (Sanders 1966; Grant 1971; Grant and Alexander 1973), and after fishing (Zacharin 1985 a, b; 1987). The pre-fishing surveys indicated a widespread resource in southern Bass Strait, but by 1985, commercial scallop populations in the region were fished only in Banks Strait, off Lakes Entrance, and a few scattered beds in estern Bass Strait. In 1985, closures in force on the Bass Strait grounds were partially lifted and fishing was permitted in restricted areas of Banks Strait for a period of three weeks. By June 1986, both the Banks Strait and King Island beds were judged by the managers to hold scallops of commercial size and most of Bass Strait was again opened to fishing. Effort was concentrated on the highly productive Banks Strait grounds, with some fishing on the less extensive beds off the north-east of King Island. Fishing in Banks Strait ceased at the end of December 1986, by which time almost all scallops on the grounds had either been caught or killed by repeated dredging. Subsequent surveys confirmed that the beds in Banks Strait had been fished to extinction and are devoid of recruits (McLoughlin *et al.* 1988; Martin *et al.* 1989).

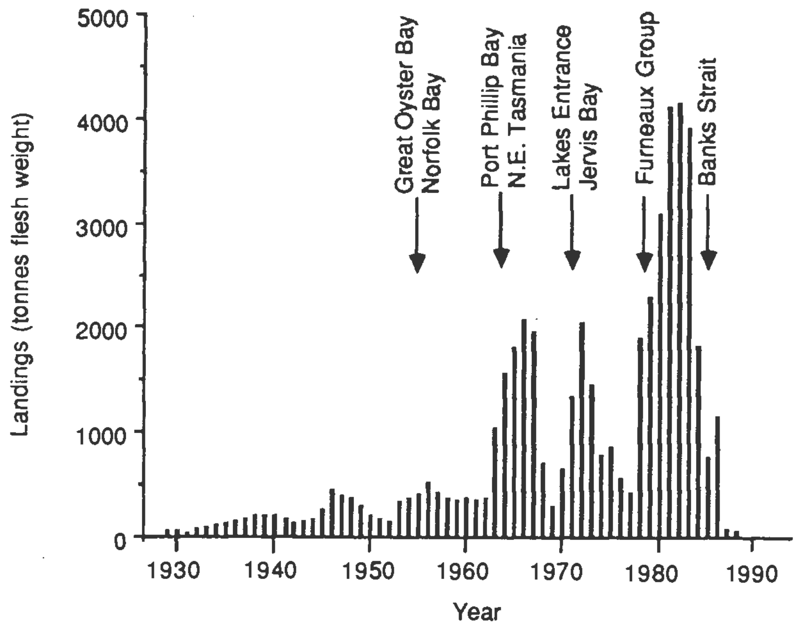

Figure 1. Commercial catches of P. fumatus from southeastern Australia. The years when new beds were first exploited are indicated.

With little information available on either the fishery or biology of *P. fumatus* in Bass Strait, catch failures could not be explained. The age, distribution and abundance of spawning adults, the timing and duration of spawning, the longevity and mobility of larvae, and the distribution and abundance of spat, were all unknown. To address some of these questions, CSIRO staff undertook an investigation of the reproductive ecology of the commercial scallop in Bass Strait to establish the time and duration of spawning, the distance over which larvae might be advected, and the relationship, if any, between the size of the parental stock and any subsequent recruitment. This paper presents some of the preliminary findings of this research.

Materials and Methods

Adult Spawning Stock

An index of the size of the spawning stock was calculated from catch statistics obtained from the log book returns submitted by fishermen to the Victorian and Tasmanian fisheries management authorities. Catch locations were standardised by conversion to a 1° latitude x 1° longitude grid (Figure 2), and catch statistics were calculated for each cell within the grid. The flesh weight caught per hour fished was used as an index of the stock size, as this takes into account the number of drags per hour and the size of the catch in each the drag, both of which change with the abundance of the resource. Between July 1986 and July 1987, gonad condition was examined in monthly samples of 100 scallops taken from beds off northeast King Island in western Bass Strait (grid cell 8), and in Banks Strait (grid cell 18) in eastern Bass Strait. Visual (macroscopic) staging, histology, and gonadosomatic indices based on wet weights were all used to define the timing and duration of spawning but only data relating to the first of these techniques is presented here.

Spat Settlement

The distribution of settling larvae and the time of settlement were determined from the occurrence of spat on artificial collectors deployed at six widely separated locations in Bass Strait (Figure 2) after both the 1985 and 1986 spawning seasons. Collector arrays were located as close as possible to existing or previously fished beds, in water depths between 45 and 50 m. Full details of the spat collection bags, their deployment and retrieval are given in McLoughlin *et al.* (in press). Collectors were in the water from before scallops began spawning until after significant settlement could no longer be detected (from September 1985 to April 1986 in the first year, and from August 1986 to April 1987 in the second year). After a collector line was retrieved, the contents of each bag were washed into a 500 μm mesh net and the retained catch frozen for subsequent sorting, identification and measurement in the laboratory. As the number of *P. fumatus* spat settling in collector bags varies with depth (Dix 1981; Hortle and Cropp 1987; Sause *et al.* 1987), height effects were removed from the analysis by only including bags set at between six and eight metres above the sea bed.

Juvenile Distribution and Abundance

Between October and December 1986, and January and August 1987, all beds known to have produced commercial catches of scallops in the past were sampled for juvenile scallops. Juvenile scallops are defined here as settled scallops less than 50 mm shell height. Modal analysis of samples from wild populations had previously shown these were usually less than one year old, and thus could be identified as emanating from the previous year's spawning. Sampling was carried out with a standard 4.2 metre mud dredge fitted with a trailing small ıesh net. The dredge/net combination has been shown to effectively retain scallops as small as 10 mm shell height that would otherwise pass through, under or over the dredge (McLoughlin *et al.* 1988). All tows were of ten minutes duration at a speed of approximately 1 m s^{-1}, and all scallops caught that were less than 50 mm in shell height were counted and measured. Catches from each year were averaged separately within each grid cell.

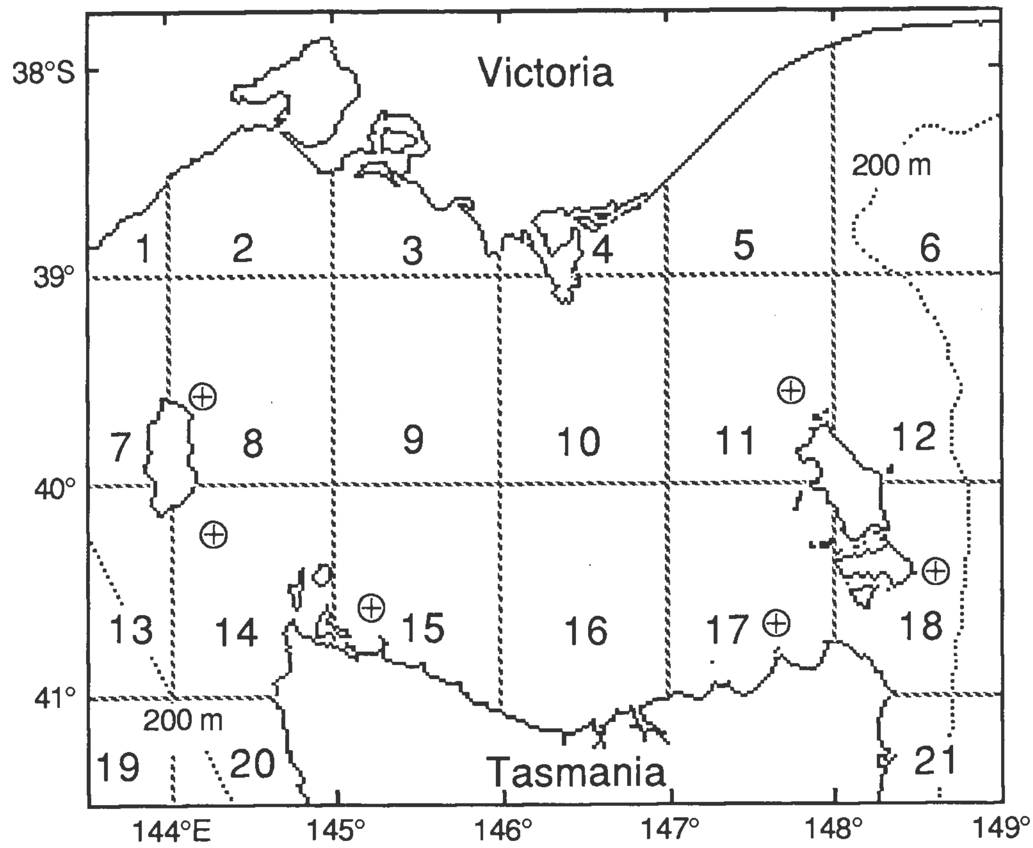

Figure 2. The distribution of grid cells (1° longtitude x 1° latitude) and the location of spat collector arrays (+) in Bass Strait.

Results

Adult Spawning Stock

In 1985, fishing in Banks Strait (grid cell 18) accounted for 74% of the total hours fished and 86% of the catch. In 1986, fishing in Banks Strait accounted for 65% of the total effort in Bass Strait, but an additional 19% of fishing took place on the beds off King Island (grid cell 8), the two locations together producing 88% of the year's catch (Table 1).

There were significant differences in the percentage of ripe individuals in monthly samples taken from the beds in Banks Strait and off King Island. In samples from Banks Strait, there was a clear annual cycle in gonad condition and clear evidence for spawning synchronicity (Figure 3a). No ripe scallops were detected in the July sample but by October, 85% were in spawning condition. Between October and January the percentage of ripe individuals in samples declined rapidly and remained low until the following June. While a similar general trend was apparent in samples taken from the beds off King Island (Figure 3b), it was less marked.The percentage of ripe scallops in samples rose to 67% in September, fluctuated between 15 and 40% from October to April, and then declined in May and June. No samples were collected after July 1987, as by that time the delayed effects of fishing had reduced the density of scallops at the sampling locations to such low levels that adequate samples could not be obtained.

Spat settlement on Artificial Collectors

The number of spat settling on collectors varied considerably with location. After the 1985 spawning, settlement was highest off northern Tasmania (cells 15 and 17) and lowest off the northeast of King Island (cell 8). Peak settlement was between September and January, with spat settling earlier in the collectors in the east than in the west (Table 1; Figure 2). With the exception of the array in cell 11, where a second peak occurred in December, major settlement at the eastern sites was concentrated in September and October. In western Bass Strait, settlement occurred between November and January and only at the array off north-west Tasmania (cell 15) was there more than one clear settlement peak.

The pattern of settlement after the 1986 spawning was similar to that observed in 1985 (Table 1). Spat abundances were again highest off northern Tasmania and lowest off King Island. Settlement was highest between October and January and, as in 1985, was earlier in the east than in the west. In the east, three settlement peaks (October, November, January) occurred at the collector site in cell 17, and two (October, January) in cell 18. In the west, a single settlement peak occurred in December in cells 14 and 16, and in January in cell 8.

Table 1. Total commercial catch, mean catch rate of adult scallops, mean number of juveniles, mean number of spat settling in artificial collectors, and the period of spat settlement for each 1° grid cell during 1985 and 1986. (– indicates missing data)

Grid cell no.	Commercial catch ($kg\ hr^{-1}$)	(t flesh wt)	Juveniles (no. $drag^{-1}$)	Settled spat (no. bag^{-1})	Settlement period (no. of peaks)
			1985 Spawning		
4	–	–	0.0	–	–
5	–	–	4.8	–	–
6	23.2	1.0	0.0	–	–
7	–	–	0.0	–	–
8	29.4	18.8	0.0	34	Nov (1)
11	–	–	1.0	65	Oct–Dec (1)
14	38.6	37.8	–	60	Dec (1)
15	16.4	13.7	0.0	101	Nov–Dec (2)
16	25.6	9.8	–	–	–
17	38.7	13.1	87.0	262	Oct (1)
18	54.0	646.8	0.0	62	Sept (1)
21	13.7	14.0	–	–	–
			1986 Spawning		
1	17.3	5.1	–	–	–
2	10.5	7.5	–	–	–
5	20.3	1.0	–	–	–
8	19.0	106.1	0.0	38	Jan (1)
11	7.0	3.1	0.3	30	Nov (1)
14	16.5	8.6	–	14	Dec (1)
15	53.1	34.3	0.5	620	Dec (1)
16	31.8	14.4	2.0	–	–
17	43.3	48.2	2.3	153	Oct–Jan (3)
18	47.9	919.5	0.0	117	Oct–Jan (2)
21	30.1	14.7	–	–	–

Juvenile Distribution and Abundance

Juvenile abundances were low in both years and none were recorded at most sampling sites. Apart from a single individual taken in grid cell 11, recruitment following the 1985 spawning was limited to areas off Lakes Entrance (grid cell 5) and northeast Tasmania (grid cell 17). Juvenile scallops were found in four of the six grid cells surveyed after the 1986 spawning, but no significant catches were made (Table 1).

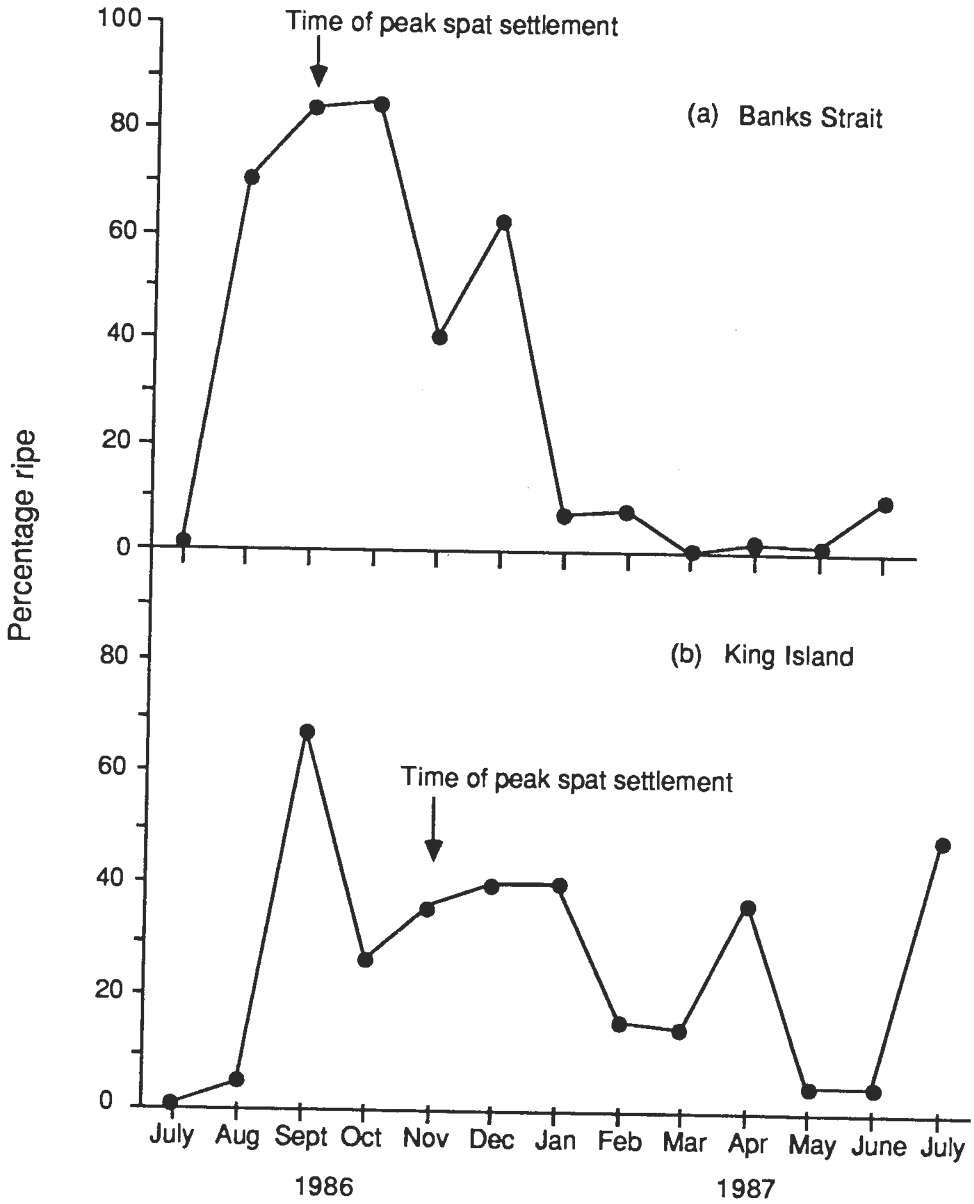

Figure 3. Percentage of scallops with ripe gonads in samples taken between July 1986 and July 1987 from (a) Banks Strait (grid cell 18), and (b) off the northeast of King Island (grid cell 8).

After the 1985 spawning, large numbers of spat settled on collectors at two sites off the north coast of Tasmania (grids 15 and 17), and the marked differences in the timing of settlement suggests that the larvae settling at each site may have come from different spawning stocks. In the next year, spat settlement on the same collectors overlapped in time, which suggests that these larvae may have originated from a single source, such as the Banks Strait beds, and dispersed westwards along the north coast of Tasmania. Both the timing and the numbers of spat settling indicate that little dispersion northwards occurred in either year. When settlement data from both years were plotted against the mean catch-per-hour in each grid cell, the mean number of spat on the collectors and their variance generally increased with increasing catch rate in the same cell (Figure 4 a). Stabilising the variance by transforming the mean number of spat per collector to log e results in a significant linear relationship (Figure 4 b, R^2 = 0.442, $p < 0.05$). This gives credence to the view that larvae may not perse widely and the number achieving the pediveliger stage may be related to the size of the nearby adult populations.

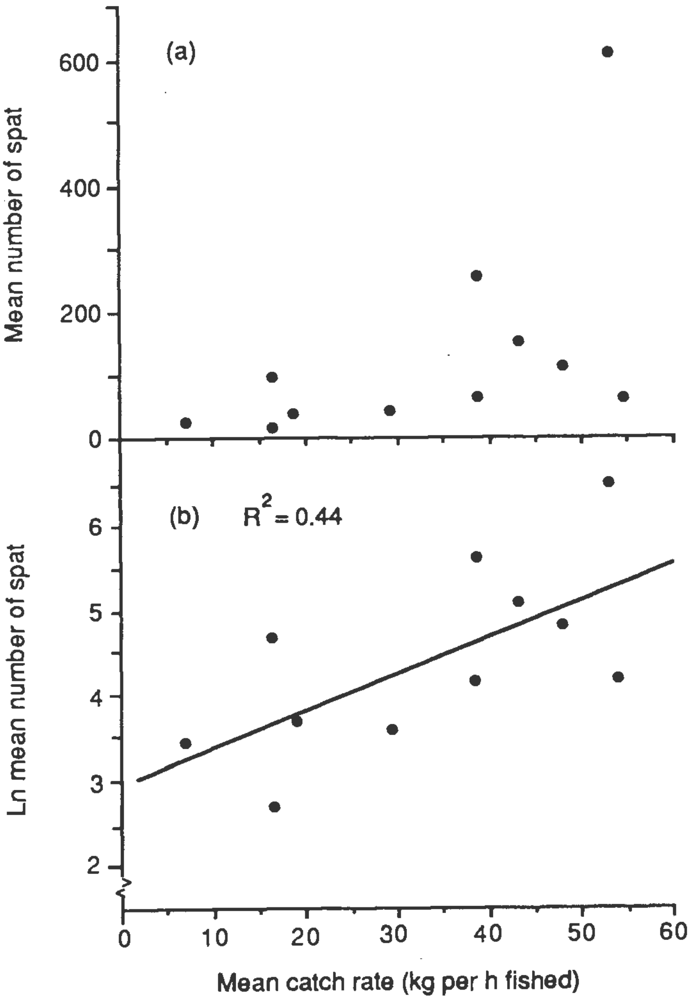

Figure 4. Relationship between the mean commercial catch per hour and (a) the mean number of spat per collector in the same grid cell, and (b) the natural logarithim of the mean number of spat per collector in the same grid cell, in the same year. Data for 1986 and 1987 combined.

Discussion

Some individuals with ripe gonads were found over much of the year, and some spat settled on collectors throughout the experiment, which indicates that *P. fumatus* in Bass Strait has a protracted spawning season. However, most spat settled over a restricted period that followed an increase in the percentage of ripe individuals in adjacent populations. This peak settlement period in spring and early summer broadly corresponded with that found in previous studies undertaken in this region (Dix 1981; Hortle and Cropp 1987; Hortle 1983).

The number of juveniles settling on the sea bed was extremely low in both years. In the 12 months after the 1985 spawning, relatively large numbers of juveniles were found in grid cell 17 where large numbers of spat were also found on collectors.After the 1986 spawning, however, few juveniles were found anywhere in Bass Strait, and there was no association wi. the numbers of spat that had settled on nearby collectors. When data from both years were combined, the number of juveniles showed no correlation with either the number of spat settling on collectors (R^2 = 0.05), or the catch-per-unit effort of adult scallops (R^2 = 0.02) in the same grid cell. This implies that, as well as controls on the production and survival of larvae to metamorphosis, there are additional controls on the settlement and survival of recently settled juveniles on the sea bed. These may include the sometimes adverse small-scale hydrodynamic processes (Butman 1987), the absence of suitable settlement substrata (Culliney 1974), and predation by crabs, lobsters, oyster drills, and starfish on settled juveniles (Morgan *et al.* 1980).

The vertical distribution of larvae approaching metamorphosis and their hydrodynamic environment, may be crucial components in the successful settlement of invertebrate larvae (Butman 1987). Spat abundance in collectors was found to be consistently higher in collectors placed in the bottom third of the water column. This distribution may reflect the relative abundance of larvae at different heights in the water column, or be an artefact of greater water flow through the collectors in the mid-water region. It is not known if *P. fumatus* larvae can regulate their position in the water column. An extensive literature based on small-scale laboratory experiments in still water attests to the ability of invertebrate larvae to actively select suitable substrates on which to settle (Meadows and Campbell 1972). Under natural conditions, however, even average current velocities may cause turbulent mixing that could prevent larvae from reaching the sea bed or result in transport rates over the bottom that could inhibit active searching for suitable substrates.

The widespread failure of scallop beds in southeastern Australia to show significant recruitment following commercial exploitation suggests that fishing results in some change to the settlement environment. The destructive effects of current fishing techniques on exploited 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.

In summary, research to date suggests that the recruitment of scallops in Bass Strait may be influenced by several factors operating at several levels. There is the initial requirement of a suitably large parental stock with high effective fecundity that results in the production of larvae in sufficient numbers to ensure that many survive and reach the pedivelliger stage. The formation of a scallop bed may then be the result of local topographic effects that in some way alter current flow, allowing larvae to settle passively on to suitable substrata on the sea bed. In such a case, active habitat selection would play a secondary role in , settlement process, perhaps operating at a scale of millimetres or centimetres. Support for this hypothesis comes from the results presented above, and 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.

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ALTERNATIVE DREDGE DESIGNS AND THEIR EFFICIENCY

William Zacharin
Department of Sea Fisheries
P.O. Box 619F, Hobart
Tasmania 7001.

Abstract

Scallop dredge designs differ markedly around the world. Europeans have been experimenting for more than forty years with gear in an effort to increase efficiency and reduce incidental damage to the catch. Fishermen in southern Australia still use a toothed box dredge that is a variation on the Baird dredge. Efficiency, estimated at less than 10%, is much lower than dredges in use in Europe and America. Preliminary investigations of efficiency using Japanese Keta-ami dredges in Australia have been encouraging.

Introduction

Many different scallop dredge designs have been experimented with and adopted by scallop fisheries worldwide. In this paper, the literature on scallop dredge design and efficiency is reviewed. Efficiency of gear used in present scallop fisheries and preliminary results of a 12-month project into Japanese dredge designs are presented.

In southern Australia scallops are still harvested using the modified Baird or toothed mud dredge. Little research has been conducted on gear technology in this fishery since the introduction of the Baird type dredge in the 1960s (Hughes 1972). Even at the time of its introduction fishermen were concerned at the damage being done to the scallop beds when incidental catch damage greatly increased. However, the toothed mud dredge gained wide acceptance as it operated well in water deeper than 30 metres. Without its introduction, expansion of the scallop fishery out into Bass Strait may have been retarded. The box dredge was beneficial in promoting expansion of the fishery, but may have been detrimental to the fishery's viability in the long term.

Most of the world scallop fisheries in Scotland, England, France and Canada use dredges that are much smaller in size, weigh considerably less, and collect the catch using a flexible chain or net mesh bag of varying length and mesh diameter.

These dredge designs resulted from development over many years by fisheries researchers and industry in searching for more efficient and less damaging fishing gear. In Australia fishermen have been content to use what ever is available. Little funding has been made available for technological research; industry has been content to continue using the toothed box dredge with diesel or hydraulic self-tipping gear (Figure 1a).

Scottish Dredge Design and Efficiency Tests

Scallop dredge designs in the United Kingdom have undergone continued testing over the past 40 years, but until Baird (1955) began observing and estimating the efficiency of English scallop dredges in the 1950s, little changed in dredge design. Baird estimated that the dredges were only catching 5-20% of the scallops in their path. He subsequently designed the "Baird" dredge with its characteristically pronounced pressure plate on the front of the toothbar. This improved the efficiency of the dredges to between 24-33% on sandy bottom (Chapman *et al.* 1977). However, the Baird dredge was superseded in the early 1970s and later dredges were built without pressure plates (Franklin *et al.* 1980).

Chapman *et al.* (1977) conducted efficiency trials on the Scottish standard fixed-bar dredge and a new spring-loaded toothed bar that was introduced into the scallop fishery in favour of the Baird dredge. Their results showed that the efficiency of Scottish scallop dredges [illegible] low, even for the capture of larger marketable-sized scallops (> 80 mm). Overall the fixed toothbar dredge caused less damage and was more efficient. All the trials were conducted over sandy bottom. The spring-loaded dredge is popular with fishermen in areas of rough bottom as it does not collect as much rubbish. This effectively decreases sorting time and therefore fishing time. These trials seem inconclusive as different bottom types were not considered in estimating dredge efficiency.

Research into efficiency was continued by Strange (1978a, b;1979) using a lighter fixed toothbar dredge. He attached a trash vent to some dredges in an effort to reduce the incidental rubbish collected. Results showed that the standard dredge with fixed toothbar outfished dredges with spring-loaded toothbars or dredges with trash vents. Strange also recognised the importance of keeping the toothbar angle of attack constant.

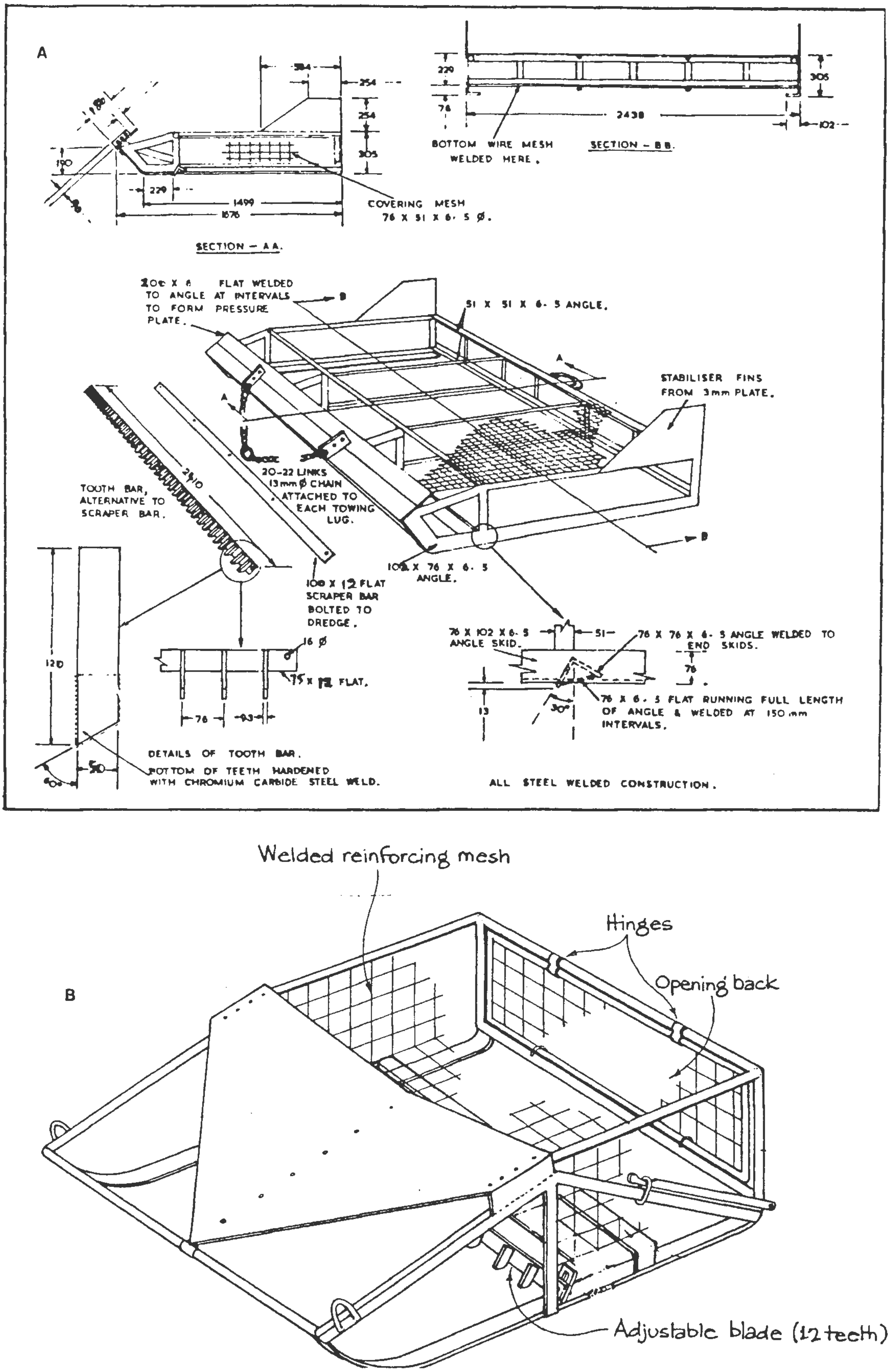

Figure 1. A - Victorian toothed mud dredge as shown by Hughes (1972). B - modified Baird dredge in use in Tasmania in the 1960s.

Recent work on dredge efficiency by Howell (1983) using the Scottish dredge with spring loaded toothbar has shown that smaller but more numerous dredges are better able to conform to the contours of the bottom and fish more efficiently than wider dredges with fixed toothbars (Figure 2).

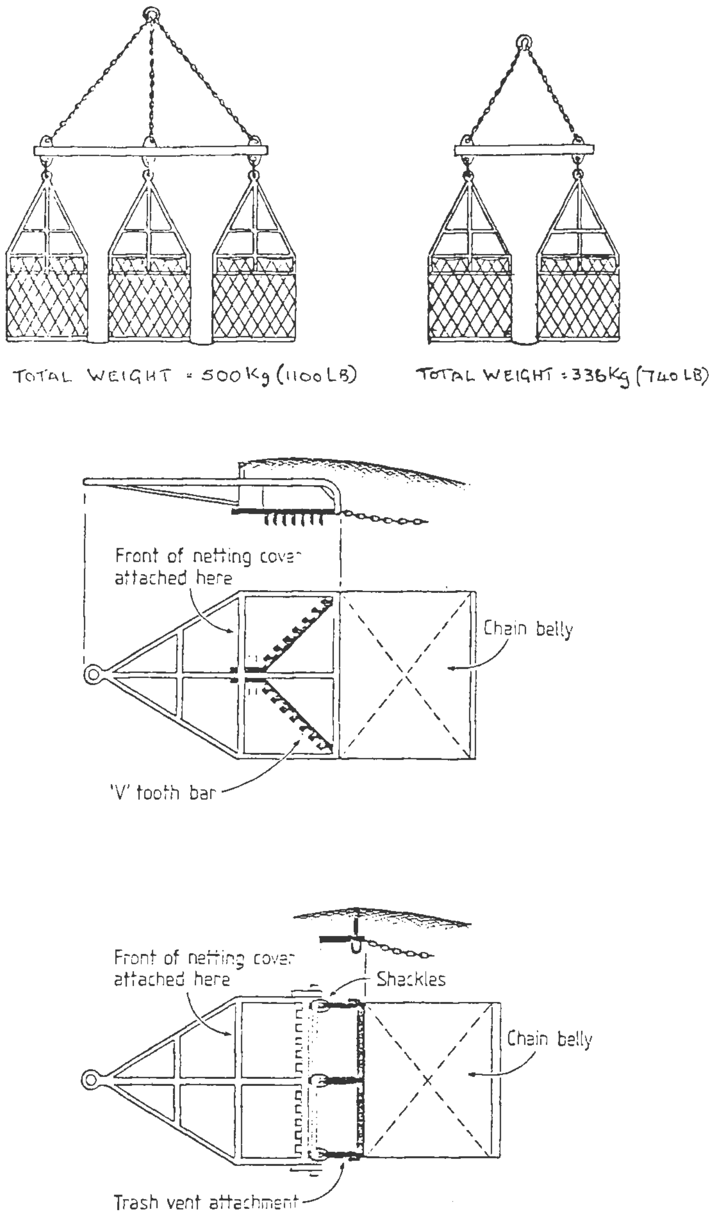

Figure 2. Scottish dredge designs and deployment apparatus as shown by Strange (1978, 1979).

Canadian Dredge Designs

Caddy (1973) studied the effects of two types of dredges on a scallop ground from an underwater submersible. One was a 2.4 m offshore dredge, weighing 0.6 tonnes with a bag knit from 76 mm steel rings and the second consisted of a gang of three Alberton inshore dredges. These are considered to catch less rubbish on rougher ground by fishermen. Caddy estimated that the efficiency of the offshore dredge was approximately 15% and that incidental mortality to uncaught scallops was in the range of 15-20%.

French Dredge Designs

Two distinct types of dredge are used in France. The most common, a regular or insho. dredge, incorporates a rectangular frame used to open a catch bag with a metal ring base and net top. The other, an offshore dredge, is distinguished by having a sloping pressure plate above the toothbar. Both dredge types have an average width of two metres and weigh about 200 kg. Dupouy (1982) observed that the dredge with a pressure plate was slightly superior to the one without, attaining an efficiency of 35%. The Saint Brieuc offshore dredge is the most efficient yet reported (Table 1).

Table 1. Comparative table of dredge efficiency for various scallop species and dredge designs.

Type of Dredge	Weight (kg)	Country	Species	Efficiency (%)	Reference
Rake	90	Scotland	*Pecten maximus*	20	Baird (1955, 1959)
Spring	110	Scotland	*Pecten maximus*	13	Chapman *et al.*(1977)
Baird Offshore		Scotland	*Pecten maximus*	30	Rolfe (1969)
Digby bar	300	Canada	*Placopecten magellanicus*	5 to 12	Dickie (1955)
New Bedford	350	Canada	*Placopecten magellanicus*	8 to 10	Caddy (1968)
Toothed drag	200	France	*Pecten maximus*	30	Dupouy (1978)
Saint Brieuc	200	France	*Pecten maximus*	35	Dupouy (1978)
Toothed mud	750	Australia	*Pecten fumatus*	10	Young *et al.*(pers. com)

taken from Dupouy, H. (1983)

Australian Mud Dredge

Preliminary results from studies conducted by CSIRO personnel indicate that the toothed mud dredge takes approximately 10% of scallops in its path (Young pers. comm.). Underwater observations using a video camera show that a wide rigid frame does not maintain the toothbar in contact with the bottom, even at slow speeds. Unless the toothbar angle of attack is constant, efficiency decreases and scallop damage increases.

With the downturn in the scallop catches in 1985, the incidental damage to the catch became more significant, and Tasmanian scallop industry representatives approached the Department of Sea Fisheries to carry out trials on alternative fishing methods. The result of .is request was a 12-month FIRTA-funded project into gear design.

Methods

Two alternative gear types were investigated and compared with the Australian mud dredge. These were the Queensland trawl nets and Japanese Keta-ami dredges. Siebenhausen scallop nets, used in the fishery for *Amusium balloti* were obtained from Queensland, and fishing was conducted using a double rig comprised of two 22 m headrope length nets. Trawl shot duration was for a maximum of 30 minutes.

Japanese Dredges

Two different types of Japanese scallop dredges were transported to Tasmania. The αιedges, Keta-ami dredges, differed in their robustness and toothbar width. The larger had a width of 2.6 m and the smaller, 2.0 m. Construction was based on the bottom topography in the area in Japan from which they originated. The general design consists of a horizontal tooth bar supported on teeth between 50 and 60 cm in length. Trailing behind the toothbar is a catch-bag with a chain mail bottom and synthetic mesh netting top. The sides taper towards the rear of the catch bag similar to the wings in a small trawl net. A tickler chain is connected to the forward edge of the catch bag and this has two functions: it keeps the bag open, and with speed or warp adjustment, determines the composition of the catch (Figure 3).

Dredges were deployed from the rear of a commercial fishing vessel using a wire cable of 9 mm diameter. Depth to wire ratio was 4 or 5:1 at a towing speed of 3.0 to 3.5 knots. A number of comparative trials were conducted deploying the Keta-ami and a 2.5 m toothed mud dredge at the same time.

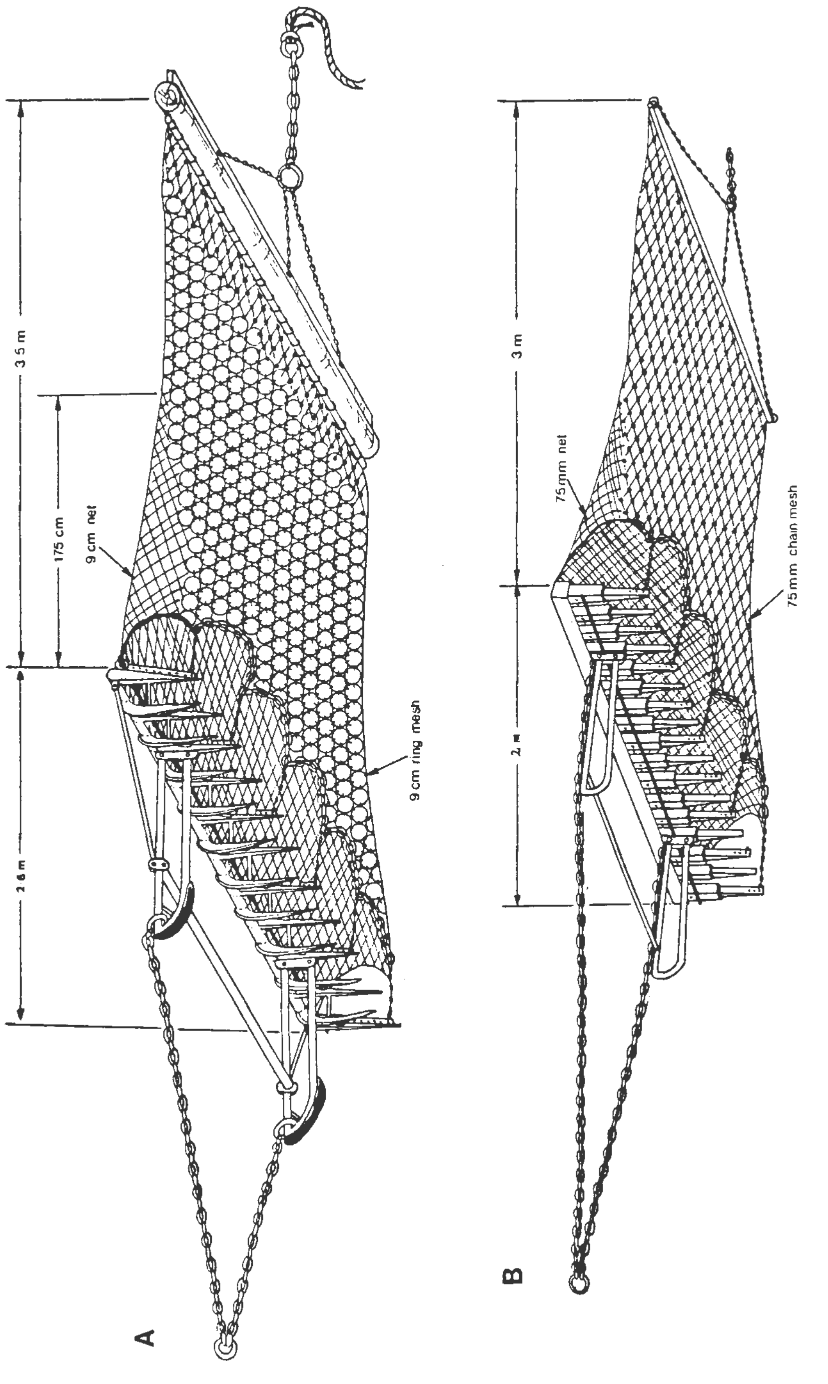

Figure 3. Japanese Keta-ami dredges. Type B has proved to be the most successful in southern Australian waters.

Results

<u>Trawl gear</u>

Trials using trawl gear were conducted for 30 days. Scallops were taken in only seven shots, either as a consequence of low scallop density or gear failure. The most successful trawl yielded 468 commercial scallops (Table 2).

Results showed that Queensland scallop nets will catch scallops in southern Australian waters even when the terrain is very different and the swimming ability of *Pecten* much weaker than *Amusium*. Difficulty in shooting this gear over much of the scallop grounds soon became apparent as rocky outcrops were a major hazard.

Table 2 : Scallop fishing trials using Queensland Siebenhausen scallop nets.

Shot No.	Duration (mins)	Warp Ratio	Speed (knots)	Depth (m)	Catch	By-catch
1	10	4:1	2.0	38	40c	2 flathead
2	10	4:1	2.0	40	468c 2000d	gurnards rays
3	10	4:1	2.0	40	63c	3 flathead
4	15	4:1	2.0	40	254c	rays, flathead gurnards
5	15	3:1	2.5	34	107c	flounder,rays
6	10	3.5:1	2.5	26	37c	200rays flounder flatheads
7	30	4:1	2.5	34	354c	100rays 2 flathead

c - commercial scallop *Pecten fumatus* ; d - doughboy scallop *Chlamys asperrimus*

Dredges

Paired tests indicated that the Keta-ami dredges took more than five times the catch of a toothed mud dredge. In the most successful comparative ten minute drag, the Keta-ami dredge caught 1,242 scallops to the mud dredge's 245 scallops. In every comparative drag undertaken the Keta-ami consistantly outfished the mud dredge. The incidence of damage to scallops taken in the Keta-ami dredge was less than 15% of that observed in scallops taken by the toothed mud dredge (Table 3).

Table 3 : Some comparative drags between the Japanese Keta-ami dredge and Toothed Mud dredge. Incidental damage to scallops using the Keta-ami dredge was under 2%, where with the mud dredge catch damage could be as high as 12%.

Drag	Keta-ami		Mud dredge	
No.	No. Scallops	No. damaged	No. Scallops	No. damaged
1	188	3	16	2
2	597	2	59	4
3	1242	4	245	12
4	352	2	91	5
5	1076	11	237	8
6	664	6	80	3
Mean	686.5	4.7	121.3	5.7

Discussion

The toothed box dredge is no longer used in most of the world's scallop fisheries. Research has shown that rigid dredges cannot adequately follow the contours of the seabed. This results in low catch efficiencies and damage to the remaining scallops on the bed (Young pers. comm.).

Trials using Keta-ami dredges are most encouraging. The comparative efficiency tests between the Keta-ami and the mud dredge show the Keta-ami will catch a greater number of scallops, with incidental shell damage being lower.

There is growing concern that dredge damage to juvenile scallops is having a significant effect on recruitment. Reducing this damage is possible by using more efficient and less damaging gear, such as the Japanese Keta-ami dredges. However, the mud dredge has one advantage over the Keta-ami in its rapid deployment and retrieval using automotive self-tipping gear. This reduces fishing time considerably and fishermen do not have to handle heavy gear that could be dangerous in rough seas.

Although gear handling time is increased, using the Keta-ami the corresponding increase in catch per shot results in the Keta-ami dredge catching more scallops per hour dredging.

Designs in other countries have shifted towards dredges with flexible catch bags made from heavy netting or steel ring mesh. These have a greater catch efficiency and cause less incidental damage to the scallops (Caddy 1973 ; Dupouy 1982 ; Strange 1978).

Japanese dredges tested in southern Australian waters are more efficient than the toothed mud dredge currently in operation. Incidental damage to the catch is greatly reduced. It is hoped in the near future that the toothed mud dredge will be banned and a modified Japanese Keta-ami dredge will be used to replace it.

Acknowledgements

The data presented in this paper are from the 12-month FIRTA-funded study entitled "Development of Alternative fishing practices for the harvesting of wild and reseeded scallop beds in Tasmania (87/69). Keta-ami dredges were supplied by the Overseas Fisheries Co-operation Foundation of Japan.

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TRAWL-INDUCED MORTALITY OF JUVENILE SAUCER SCALLOPS, *AMUSIUM JAPONICUM BALLOTI* BERNARDI, MEASURED FROM VIDEO RECORDINGS AND TAG RECOVERIES.

M. Dredge
Queensland Department of Primary Industries
Fisheries Laboratory, Burnett Heads
Queensland 4670

Abstract

Incidental gear-induced mortality of scallops, which can be significant in dredge fisheries, has not been previously described in equivalent trawl fisheries. Video camera recordings of scallop abundance and analysis of tag recovery data were used to evaluate the effects of trawling in a trial area occupied by juvenile saucer scallops, Amusium japonicum balloti. Results from the video recordings were inconclusive. There was significant variation in counts of scallop abundance between video film observers. A decline in scallop abundance after the trail area had been trawled may have been caused by scattering rather than trawl-induced mortality of the juveniles. Results from a tagging experiment were more conclusive, with returns from scallops that had been subjected to trawling being lower than those from an untrawled control. The tagging study also gave information on size specific mortality/vulnerability which could not be obtained from video recordings.

Introduction

The Queensland trawl fishery for scallops (*Amusium japonicum balloti* Bernardi) developed rapidly between 1977 and 1987. Effective effort directed at the stock increased by a factor of 14 during this period, while catch rates declined consistently. Total annual landings have declined since 1983 (Dredge 1988). Trawl-induced mortality of pre-recruit scallops may have been a factor contributing to this decline. The fishery now operates for 12 months a year, taking animals larger than 90 mm shell height (S.H.), the legal size limit. The trawls used in this fishery are normally made from 90 - 120 ply 75 - 87 mm mesh. Consequently scallops smaller than the legal size are vulnerable to capture.

Quantitative data on age composition of animals in the fishery are not available, but late 0+ and early 1+ animals are thought to make up a large proportion of landings. *Amusium japonicum balloti* spawns during winter and spring (Dredge 1981), and young of year scallops can be found in trawl catches from July onwards each year. These juveniles may occupy the same geographic location as older scallops, and be subject to fishing operations. Juveniles in the path of trawl gear may be passed over by the otter boards or ground chain of the trawl if they do not swim in response to the trawl gear's presence. Those that do swim either pass through the meshes of the trawl or are retained, brought to the surface, and subsequently discarded. Scallops which survive this process are characterised by a prominent ring or banding on the shell's surface (Joll 1988) (Figure 1), the location of which indicates the scallop's size when caught.

Incidental mortality of scallops in dredge fisheries can be significant (Naidu 1988, Equivalent trawl-induced mortality of juvenile scallops has not been previously described. But if incidental mortality is appreciable, there is justification for attempting to reduce it, given the potential loss to the fishery.

This paper reports an introductory study on the effects of trawling on juvenile scallops. Two techniques were used to assess survival of juvenile scallops in an area subjected to trawling. Underwater video camera recordings were used to estimate pre- and post-trawl scallop density in a trial area. Return rates from a scallop population that was subjected to trawling have been compared to those from an a less heavily trawled controlled population in order to assess trawl-induced mortality. The quality of results from these two techniques has been compared.

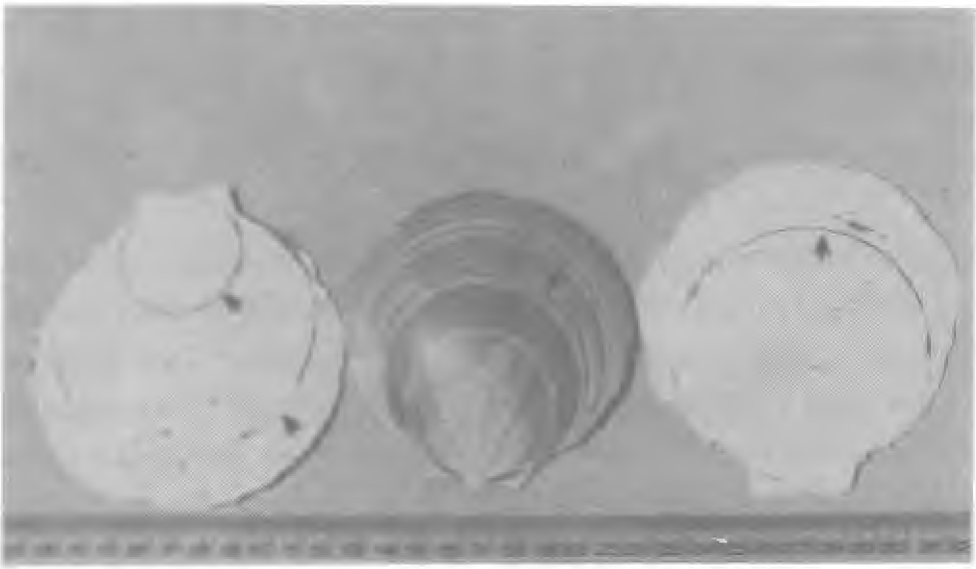

Figure 1. Left and right valves of *A. japonicum balloti*, showing scarring and pigment flares caused by trawl gear.

Materials and Methods

Trial Site

A rectangular trial site, 800 by 250 m, located at 23°42'E, was buoyed at each corner with the aid of gyrocompass bearings and radar-measured distances. Depth at the site was 26 m, and the substrate was a uniform mud-sand mixture. Juvenile scallops in the size range 30 - 80 mm S.H. had been found in the area during a preliminary search.

Pre-treatment

A total of 446 scallops in the size range 35 - 81 mm trawled from an area well away m the test site was measured (S.H., to the nearest mm), tagged with coded Dymo-tape labels glued to the shell's surface, and released in the trial site on 11/11/87.

The night after this release took place (12/11/87), ten counts of scallop abundance were made in the trial site. An 8 mm colour video camera housed in a water-tight casing, mounted on a 3.0 m wide beam trawl frame and illuminated by a 250 watt, 240 volt light source was used to record scallop abundance. The camera and frame were towed over the 800 m axis of the trial area at speeds of 40 - 50 m min^{-1}. On completion of each pass, the camera was retrieved, the video tape replaced, and a new run commenced. The film was viewed by two observers immediately after the completion of each run, and a further three observers, working independently, following completion of field work. Observers were asked to count all scallops seen, and note numbers of dead shell and living animals.

Treatment

Immediately after the completion of the initial series of video counts, the trial area was trawled using commercial scallop trawl gear with open cod ends. The trawl equipment consisted of a pair of 18 m headrope length Seibenhausen nets made of 90 thread by 400 denier net. A nine mm short link chain connected to the footrope by 120 mm long drop links was used as ground-gear. The nets were spread by 2.1 x 1.2 m flat otter boards, and towed at a speed of 5.4 km $hour^{-1}$ (three knots). Trawling was carried for 1.5 hours at night and then repeated 12 hours later, during daylight hours. Trawling was distributed evenly over the trial site. There was sufficient effort expended to cover the site on each of the two occasions that trawling trials took place.

Post-treatment

Three hours after trawling had been completed on the test area, ten more counts of scallop abundance were made with the video camera system. On the day after this second set of video recordings of scallop density were obtained (14/11/87), a control group of 448 scallops was tagged and released in the trial site. Tagged scallops were recaptured by the research vessel and by commercial trawlers which worked in the trial area within six months of experimental work being completed. Each recaptured scallop was identified by its coding and measured.

Data Analysis

Estimates of scallop abundance made from video camera observations were compare using split-plot analysis (Cochran and Cox 1957), with pre- and post-trawling abundance being treated as one source of variation, and inter-observer variation as a second.

Size composition of tagged scallops released in the test area before and after trawling were compared using t tests after size frequency data had been examined for skewness. A multi-dimensional log-linear analysis of deviance (GENSTAT) was used to examine the effects of size at release and treatment (trawling) effects upon recapture rates. Time at liberty for recaptured scallops from the control and treated groups was compared using a t test.

Results

Abundance measurements using video recordings

Summaries of the 20 sets of counts made by four observers are given in Table 1. There were significant differences in counts of scallop abundance both as functions of treatments (before and after trawling) ($F=5.69$, $P<0.05$) and between observers ($F=57.90$, $P<0.01$). There was a significant decrease in the number of scallops recorded by all observers following trawling of the test site.

Counts of dead scallops and scallop shells recorded from video camera tapes are summarised in Table 2. These counts were significantly skewed, and so were transformed [log e (x+1)] for further split-plot analysis. There was no significant difference in numbers of dead shell observed before and after trawling ($F=0.18$, $P>0.10$) but the difference between observers was significant ($F=29.14$, $P<0.01$). All observers noted that there was no way of judging whether scallops had been recently killed from their appearance on the video image.

Table 1. Mean (standard error) of scallop counts from ten sets of video camera observations before and after trawling.

Observer number	Before trawling	After Trawling
1*	33.2 (3.34)	24.4 (2.51)
2	41.4 (3.34)	32.3 (3.63)
3	50.6 (4.56)	31.1 (3.74)
4	27.5 (2.35)	14.1 (2.16)

* Two observers counting together.

Table 2. Mean (standard error) of dead scallop shell from ten sets of observations before and ter trawling.

Observer number	Before trawling	After Trawling
1*	0	0.6 (0.43)
2	1.4 (0.70)	1.7 (0.73)
3	1.1 (0.79)	1.7 (1.10)
4	4.0 (0.60)	3.2 (1.31)

* Two observers counting together.

Table 3. Summary of scallop tag returns.

	Control		Trawled	
ıe out (days)	Number released	Number recaptured	Number released	Number recaptured
0-30		0		0
31-60		43		21
61-90		26		20
91-120		7		7
121-150		5		7
151-180		0		3
Total	448	81	446	58

Table 4. Analysis of deviance between treatments and size groups for tag returns.

	Residual df	Residual deviance	Change df	Chi-square
Initial model	17	35.67		
Modifications to model				
Size	9	7.66	8	28.01**
Treatment	8	4.43	1	3.23*
Treatment by size	0	0.00	8	4.43NS

* P< 0.10
** P< 0.01

Tag Returns

There was no significant difference between the size compositions of tagged control and treated (trawled) scallops. (t=1.70, P>0.10). A total of 139 tagged scallops (15.5% of those released) were recaptured. Summaries of tag returns, in terms of numbers returned from the control and treated (trawled) groups against time at liberty are given in Table 3. Results from the analysis of deviance are summarised in Table 4. There was a highly significant difference in the rate of return as a function of size at release (P<0.001), while the interactive (size-treatment) term was statistically non-significant (P>0.5). The much higher return rate of larger scallops (Figure 2) may reflect higher survival rates or increased vulnerability of larger scallops to trawl gear.

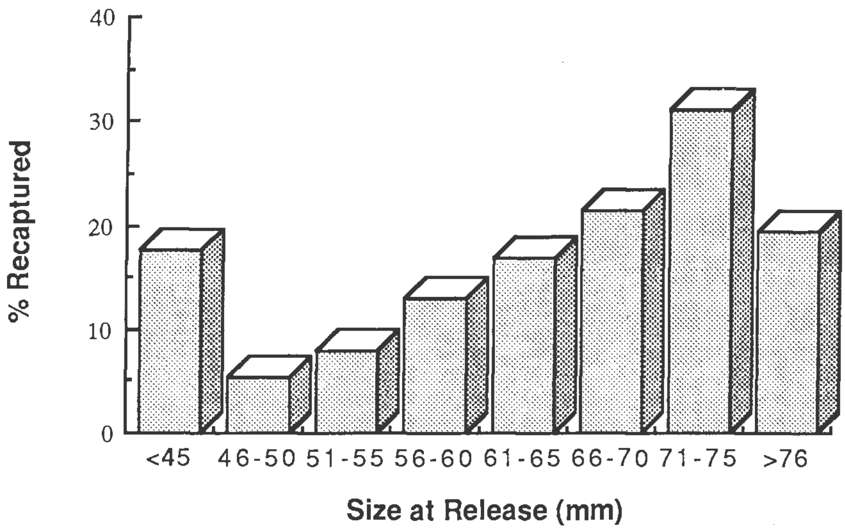

Figure 2. Recapture rate of tagged scallops (%) as a function of size at release (S.H., mm).

The difference in tag return rate between the control and trawled group was significant only at the 0.10 probability level ($P=0.077$). The difference in time at liberty was significantly different ($t=2.71$, $P<0.05$), with the average time at liberty for the control group being 57.9 days, and for the trawled group being 76.2 days.

Discussion

The two techniques used to assess trawl-induced mortality generated superficially similar results in that both techniques suggest that trawling over juvenile scallops reduced survival. These results need qualification. While results derived from video camera observations indicated that there were fewer live scallops in the test area following trawling, there was no commensurate increase in the number of dead scallops observed. This may have been a consequence of the observers' inability to distinguish between recently killed scallops and older shell remains on the video film image. Equally, the reduction in numbers may have been due to the trawl gear moving scallops away from the trial area. Scallops may have been temporarily held in the wings or body of the net during the trawling operations, and dropped from the net outside the test area. Scallops on the periphery of the trial area may have moved from the area in response to repeated trawling nearby. The difference in average time at liberty between trawled and untrawled tagged scallops suggests there was some difference in behaviour or vulnerability between the two groups. These alternative hypotheses cannot be tested using available data. The significant variation in counts of scallop abundance between observers in these trials gives rise to concern over the accuracy of quantitative data obtained from video camera recordings.

The tag return data gave a far less qualified indication that trawling may induce some mortality on juvenile scallops, although the significance of the probability level associated with the difference in recovery rates was marginal. There are no obvious reasons why returns from the trawled group of scallops would be lower than from the control group other than through treatment (trawling) effects. Tagging data also gave some additional data on the differential survival or vulnerability of scallops as a function of their size at release. The higher recovery rate of larger sized scallops suggests that smaller animals may be most vulnerable to trawl induced mortality, or less vulnerable to trawl gear.

While video cameras have a great deal to offer in the way of mapping local (fine-scale) distribution of scallops, and *in situ* behavioural studies, there are difficulties associated with their operation in the field. The problem of variation between observer's skill or experience level has been discussed. The equipment is not easy to use in the field. Handling a three metre bean trawl frame heavy enough to keep the camera and casing on the bottom during filming involves the use of a substantial boat, fitted with a good winch. In the present trials, an 18 m research trawler was used. The boat was extremely difficult to control at the very low speeds required for effective filming. Consequently, near calm weather was required for field operations. The camera and underwater casing, while reasonably robust, were designed to be hand-held and therefore had to be handled with a great deal of care when being deployed. The costs, in terms of boat time and labour, should be considered carefully before underwater video cameras are considered as a tool for field observations.

To fully quantify the extent of trawl-induced mortality upon juvenile scallops requires additional work. But there is evidence which suggests that fishing practices may need modification if trawl-induced mortality of juveniles is to be minimised in the Queensland scallop fishery.

Acknowledgements

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PROBLEMS WITH APPLYING YIELD-PER-RECRUIT TECHNIQUES TO THE MANAGEMENT OF THE BASS STRAIT SCALLOP FISHERY

R. B. Martin, P. C. Young and R. J. McLoughlin
Division of Fisheries, CSIRO Marine Laboratories,
GPO Box 1538, Hobart
Tasmania 7001.

Abstract

The commercial scallop, Pecten fumatus, in Bass Strait shows marked inter-population variability in growth rate and condition (meat weight) over spatial scales of as little as 30 km. Populations with higher meat weights were located close to the eastern and western margins of Bass Strait. Harvest strategies designed only to maximise yield have resulted in faster-growing populations being fished before the majority of scallops have completed their first major spawning. An alternative strategy involving a trade-off between yield and egg production is suggested to reduce the potential for recruitment failure.

Introduction

"Yield-per-recruit" models combine estimates of growth and survival to predict the yield over the lifespan of a cohort. In addition to estimating changes in cohort biomass, they can also be used to calculate a minimum size for recruitment into a fishery. Despite the importance of such estimates for the management of exploited stocks, only two scallop fisheries in Australian waters – those for *Amusium balloti* in Queensland (Dredge 1985) and *Pecten fumatus* in Port Phillip Bay (Gwyther and McShane 1988) – have been analysed with a yield-per-recruit model. In the *P. fumatus* fishery in Bass Strait, size limits and area closures have been imposed without prior estimates of the yields that would result from such strategies, and without considering the spatial and temporal variations in either growth or mortality rates that might result from regional or local differences in productivity.

This paper presents evidence of variability in growth and condition (meat weight) in scallops throughout the Bass Strait region and examines the implications of this variation for a yield-per-recruit approach to the management of the Bass Strait fishery.

Materials and Methods

Sampling

Scallops were collected with a 4.2 m scallop dredge fitted with a trailing small-mesh net (McLoughlin *et al.* 1988). The dredge/net combination consistently caught scallops down to 10 mm shell height and enabled us to reliably locate juvenile scallops less than six months after settlement. The intervals between samples varied from one to twelve months for different populations. The locations of sampling sites are shown in Figure 1. No sampling was undertaken in Port Phillip Bay.

Shell Height and Age Relationships

Growth rates were determined by following the progression of modes in shell height-frequency distributions obtained from consecutive samples. Data for Port Phillip Bay were taken from Sause *et al.* (1987). Height-at-age relationships were estimated 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 (Figure 1).

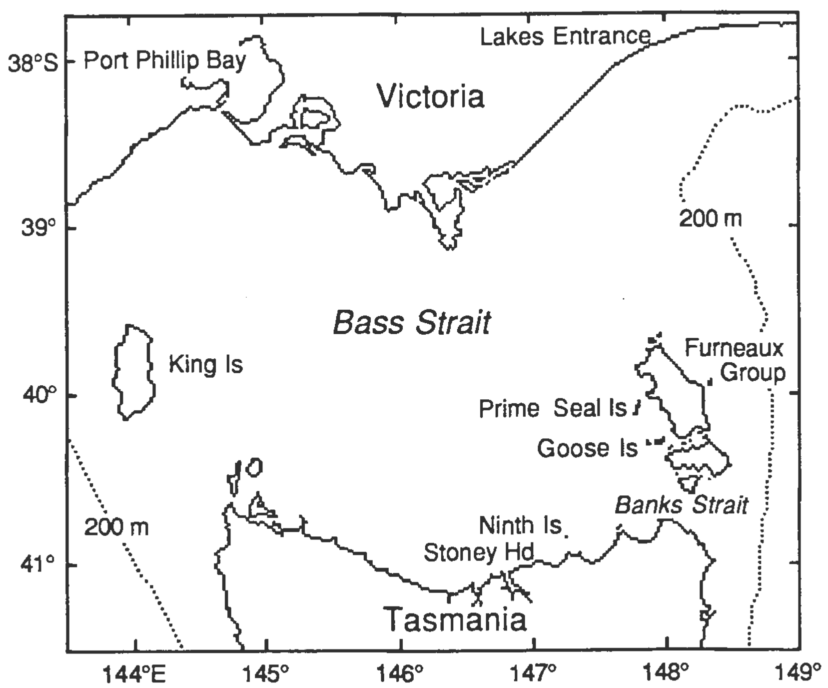

Figure 1. Locality map, Bass Strait.

Condition

Spatial variation in condition was examined by comparing meat weights (adductor muscle + gonad) of selected populations during the period of peak gonad development in September 1987. The relationship between meat weight and shell height was determined from a least-squares fit of a linear regression to $\log_{10}$ -transformed data. The allometric growth coefficient (b), and the meat weight of a 'standard' 80 mm scallop were estimated for each population.

Yield-per-Recruit

Estimates of the age at which cohorts would maximise their meat weight were obtained using Equation (4) of Alverson and Carney (1975) with 'b' values other than 3 where these were available. An instantaneous rate of natural mortality of 0.52 $year^{-1}$ (Gwyther and McShane 1988) was applied to all populations.

Fecundity

The fecundity (the number of mature eggs per ripe ovary) of individual scallops was estimated from wet gonad weights using previously determined conversion factors for the number of eggs per gram of ovary, and the proportion by weight of ovarian tissue in whole gonads. A two factor analysis of variance indicated that neither the number of eggs per gm of ovary nor the proportion of ovarian tissue in the gonad differed significantly ($P > 0.5$) between populations or age classes.

Results

Shell Height at Age

The size ranges of cohorts after one and two years of growth in Port Phillip Bay (Sause *et al.* 1987) and at five sites in Bass Strait are shown in Table 1. The growth rate of scallops in Port Phillip Bay was higher than at any of the Bass Strait sites. The difference in growth rates among the four southeastern sites showed a progressive decline with increasing distance west of Banks Strait. This trend was 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 indicated that significant ($P < 0.01$) differences in growth rate first become apparent when scallops are only nine months old, and the curves remained different over the range of the data (Figure 2). The estimated von Bertalanffy growth coefficients (K) for the two populations were 1.12 for Ninth Island and 0.45 for Stoney Head.

Table 1. Range of shell height for one- and two-year-old scallops from Port Phillip Bay and eastern Bass Strait. Data for Port Phillip Bay from Sause et al. (1987)

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

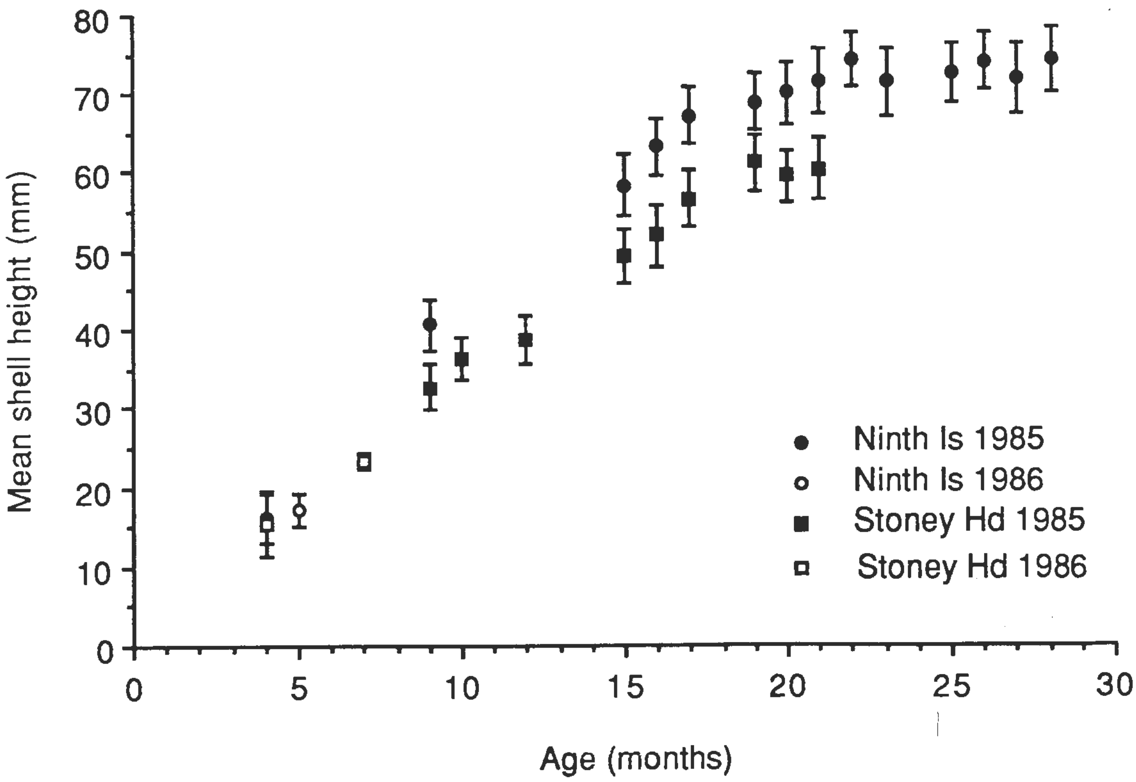

Figure 2. Shell height at age for scallops from Ninth Island and Stoney Head, 1986-7. Error bars indicate ± 1 standard deviation.

Condition

Estimated meat weights for scallops of 80 mm shell height from six populations in southern Bass Strait showed a similar spatial trend to that of growth rate: condition progressively declined towards the central north coast of Tasmania and to the north along the western side of the Furneaux Group (Table 2). This trend was also reflected in the allometric growth coefficients derived from the shell height/meat weight regressions; 'b' coefficients for Ninth Island and Stoney Head were 2.48 and 3.47 respectively.

Fecundity

Variations in fecundity of scallop populations in Bass Strait (Figure 4) closely followed spatial variations in growth rate and condition. The average fecundity of scallops at Ninth Island immediately prior to their first major spawning was three times that of scallops of the same age at Stoney Head.

Yield per Recruit

Estimates of the age at which scallops from Port Phillip Bay, Ninth Island and Stoney Head would have maximum meat weights are given in Table 3. Estimates for Port Phillip Bay are based on von Bertalanffy coefficients derived from tagging experiments carried out 20 years apart (Gwyther and McShane 1988). 'b' coefficients of three were applied to these data.

Table 2. Estimated individual meat weight and weight-per-bag for 'standard' 80 mm shell-height scallop from selected populations in southern Bass Strait. Weight per bag based on 500 scallops per bag. All data from samples collected in September 1987.

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

Table 3. Estimates of the age at which the yield-per-recruit is maximised for scallops in Port Phillip Bay and at two locations in southern Bass Strait. The instantaneous mortality rate (M = 0.52 year $^{-1}$) and data for Port Phillip Bay from Gwyther and McShane (1988).

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	20
Stoney Head	0.45	3.47	37

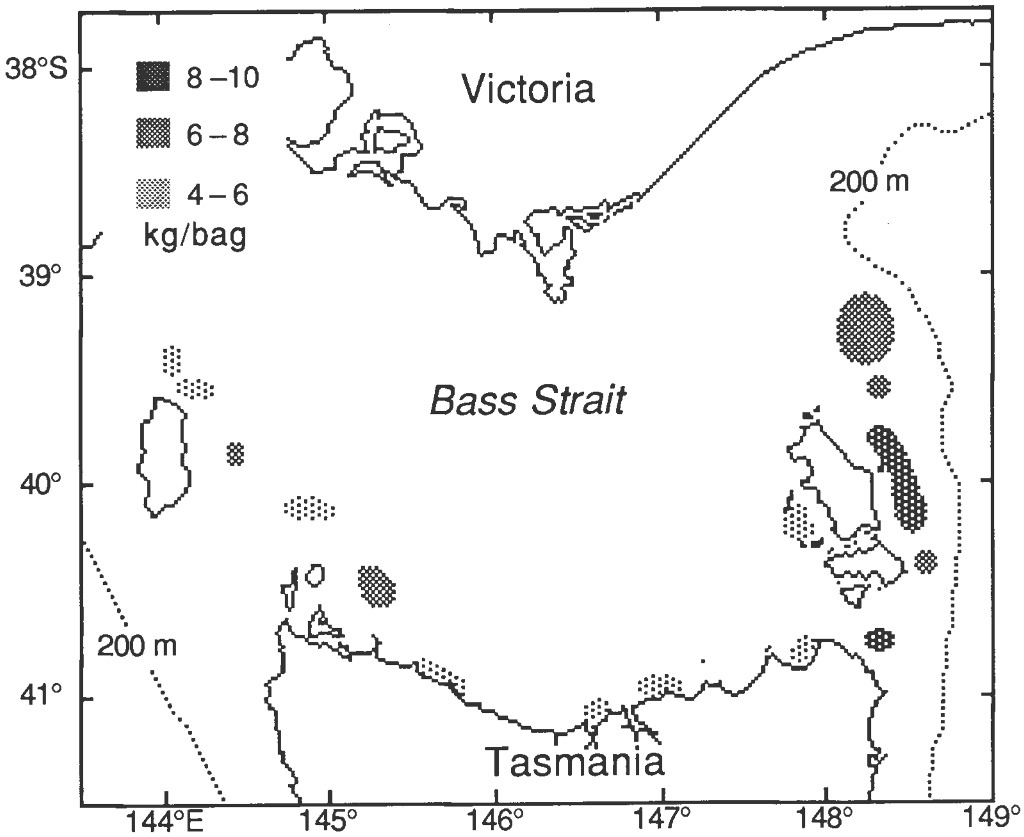

Figure 3. Meat returns (kg/bag), estimated from fishermen's logbook information, from scallop grounds in southern Bass Strait between 1970 and 1986.

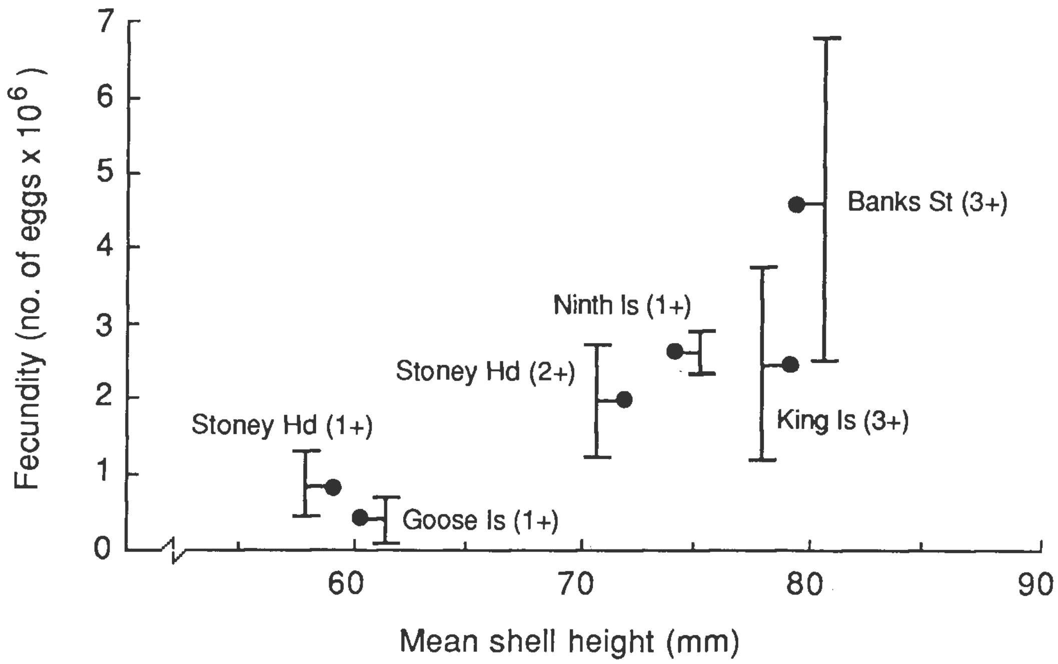

Figure 4. Mean fecundity (number of mature eggs per ovary) of scallops from selected populations in southern Bass Strait, September 1986. Numbers in parentheses are estimated cohort ages in years. Errors bars indicate ± 1 standard deviation.

Discussion

The results presented here are preliminary. They do indicate, however, that differences in growth rates and meat weight are marked, and suggest that there are discernible spatial patterns in the distribution of these differences. With the exception of the population in Port Phillip Bay, populations showing faster growth and highest meat weights (Banks Strait and King Island) were nearest to the the eastern and western margins of Bass Strait. Catch rate data for these beds, obtained during research cruises (Young *et al.* unpub. data), indicate that these differences are not the result of density dependent effects. Historical catch data for southern Bass Strait obtained from fishermen's logbooks confirm this observation and suggest that this pattern is persistent.

These observations are consistent with the hypothesis that areas of high productivity in Bass Strait are the result of nutrient enrichment from deeper waters at the shelf break along the eastern and, to a lesser extent, western margins followed by advection into the typically nutrient-poor central region (Gibbs *et al.*1986). The degree of penetration of such enrichment rate of depletion of nutrients by biological activity en route. Currents capable of producing significant advection in this region are predominantly wind-generated (Fandry 1983). A system with dynamics such as this would be expected to show not only marked spatial variations in productivity, but also temporal changes that would influence the relative condition of filter feeding animals, such as scallops, in different areas over time. Direct evidence for this comes from a reciprocal transplant experiment carried out with scallops from Banks Strait and King Island (Young *et al.* unpub. data). Over the six-month period of the experiment, both the experimental and control populations showed significant changes in relative condition. These changes were correlated with changes in chlorophyll *a* levels at the two sites.

What are the implications of this variability for the management of scallop stocks in Bass Strait? Clearly, it is unrealistic to impose a single, fixed, biologically based management regime on the region as a whole. The yield-per-recruit analyses for the Ninth Island and Stone Head populations show that optimal harvesting strategies could differ markedly for populations separated by as little as 30 km. Ideally, then, each population should be managed separately; however, the application of a yield-per-recruit approach at this scale requires a much more detailed knowledge of the dynamics of scallop populations in Bass Strait than currently exists.

In its most simple form, a yield-per-recruit analysis assumes a fixed growth curve that is unaffected by population density, and a mortality rate that is independent of age. Given the potential for local changes in productivity in Bass Strait, the assumption of a fixed growth curve is unlikely to hold over the lifespan of a cohort. Currently we have no reliable estimate of natural mortality for any scallop population in Bass Strait and no basis on which to assess possible age-dependent effects within populations. Results from cage experiments (Young *et al.* unpub. data) indicate that at the phytoplankton levels found in Bass Strait, there is a negative relationship between scallop density and condition. There is some additional evidence from the same experiments to suggest that scallops in good condition suffer lower mortality rates than those in relatively poor condition. Clearly, if a yield-per-recruit approach is to be used in the management of Bass Strait scallop stocks, then some indication of the range of natural mortality rates that populations can suffer is required so that the impact of different exploitation strategies on potential yields can be assessed.

The major difficulty in applying a yield-per-recruit approach to the management of scallop fisheries lies in the technique itself. When used to determine a minimum size for recruitment into a fishery, a yield-per-recruit analysis will predict an age at which the biomass of a cohort is at its maximum. This occurs when the conflicting rates of growth and mortality result in no net change in biomass. For those species in which growth rate declines once reproductive maturity is reached, this age will be at or near the age at which individuals spawn for the first time and well below the potential maximum age of the species. In the case of *P. fumatus*, both tagging experiments and modal analysis of size-frequency data indicate that growth rates decline significantly as scallops approach sexual maturity in their second year. Yield-per-recruit analyses for the fast-growing Port Phillip Bay and Ninth Island populations indicate that cohort biomass is maximised at 18 and 20 months respectively (Table 3). The first significant spawning takes place when individuals are between 20 and 25 months old and, while the maximum longevity of scallops in Bass Strait is unknown, it probably exceeds ten years in unfished populations (Fairbridge 1953). At both locations, a harvest strategy that attempts to maximise yield will result in a large proportion of maturing scallops being taken before they can spawn. Yield-per-recruit analysis for the slower-growing Stoney Head population indicates an optimum harvest age of 37 months, by which time cohorts would have completed their second annual spawning. In all three populations, however, harvesting to aximise yield would result in only a fraction of the reproductive potential of a cohort being realized. In the case of the Port Phillip Bay and Ninth Island populations, this could lead to recruitment overfishing, unless the fishery were closed before the size of the breeding stock fell below a critical minimum level. In theory, setting that critical level requires an understanding of the stock-recruitment relationships in each area, but in practice, purely arbitrary decisions have been made as to what constitutes an appropriate residual stock size.

In Port Phillip Bay, the fishery first exploits scallops when they are around 18 months old. In recent years, the spawning population has been protected by closing the fishery when the catch rates fell to less than six crates over six hours. Surveys indicate that this catch rate corresponds to a residual population in the bay of around 60 million scallops; these scallops constitute the breeding population for the remainder of the year (Gwyther this volume). No attempt has been made to apply similar management strategies to the Bass Strait grounds, where residual population size has been determined solely by the economics of fishing. The extremely low stock levels in Bass Strait indicate that this management strategy has not been successful. Some clue as to why comes from a CSIRO study of the Banks Strait grounds after the 1986 season (McLoughlin *et al.* unpub. data). This study showed that within 12 months of the cessation of fishing, high post-fishing mortality had eliminated almost all scallops not caught by dredging.

If high post-fishing mortality is typical of all fished scallop beds in Bass Strait, it would seem prudent to adopt a management strategy that increases the probability that individuals in a cohort have to spawn before they are fished, and to introduce harvesting techniques that reduce the impact of fishing on the residual population. Ways of reducing the impact of dredging are currently being assessed by both the Tasmanian Department of Sea Fisheries and the Victorian Department of Conservation, Forests and Lands. Both organisations have tested the Japanese "keta-ami" dredge as a possible replacement for the heavy mud dredges currently used throughout the southeastern fishery (Zacharin this volume).

Any proposal to increase the number of opportunities a cohort has to spawn before it is fished immediately raises the question: How many spawnings are necessary to ensure recruitment and maintain the viability of the fishery? At this stage we do not know what relation egg production bears to subsequent cohort strength, or whether the number of spawnings a cohort completes is more important in determining subsequent recruitment than the total number of eggs produced. A preliminary analysis of age-specific fecundity schedules for the Stoney Head and Ninth Island populations indicates that, on average a Stoney Head cohort would take around four years to produce the same number of eggs as a two-year-old cohort at Ninth Island (assuming a natural mortality rate of 0.5 year-1). However, at this age an unfished cohort at Ninth Island would have produced only 30% of the eggs it could produce in it life-time, compared with 60% for a similar cohort at Stoney Head.

It is clear that current management strategies and fishing practices in Bass Strait greatly limit the reproductive potential of scallop populations and have reduced stocks to unacceptably low levels. If recruitment failure is to be prevented, more flexible harvesting strategies that maximise the yield-per-recruit while maintaining an appropriate level of egg production must replace those that seek only to maximise yield. In the absence of any information as to the nature of the egg production-recruit curve, arbitrary levels that correspond to the egg production of scallops of known age would have to be used. As age shell height relationships vary throughout Bass Strait, appropriate minimum size limits that correspond to the desired age would need to be set for different zones within the fishery. Although the application of different size limits within a fishery would be difficult to administer, the alternative of a single minimum legal size would inevitably result in some slow growing populations never becoming available to the fishery.

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YIELD ASSESSMENTS IN PORT PHILLIP BAY SCALLOP FISHERY

D. Gwyther
Department of Conservation, Forests and Lands
Marine Science Laboratories
PO Box 114, Queenscliff
Victoria 3225

Abstract

Port Phillip Bay is a rare example of a fishery where the absolute size of the resource can be determined with some degree of accuracy. Levels of recruitment of 1+ year-old scallops and residual 2+ and older scallops are estimated from diver survey at the beginning of each season. From estimates of rates of growth, natural mortality and seasonal changes in condition, a model has been developed to determine monthly changes in biomass available to the fishery. Different fishing strategies can then be compared in terms of numbers of scallops removed, numbers remaining and yield obtained. Daily crate limits are set to obtain best yields available and to leave behind a residual spawning stock.

Introduction

Port Phillip Bay is a semi-enclosed bay of area approximately 2,000 sq. km and h supported a major scallop fishery since 1963. The fishery is worth up to $15 million during years of good recruitment but, in common with other scallop fisheries, fortunes fluctuate from year to year. This variable recruitment makes management based on principles of sustainable yield difficult or impossible to achieve. In order to gain some understanding of the yields available each year, the staff from Fisheries Division, Department of Conservation, Forests and Lands have conducted annual surveys of scallop abundance. These surveys have provided information necessary to set daily quotas, the main output control for management of the fishery.

The semi-enclosed nature of Port Phillip Bay allows estimates to be made of the absolute size of the resource by surveys conducted annually by divers. Knowledge of stock size, annual recruitment levels and amount of scallops taken out of the fishery each year has enabled us to estimate some of the parameters used in fishery assessments that are normally difficult to obtain. Combined with results from other studies of the biology of scallops in Port Phillip Bay (Gwyther 1986), it has been possible to model the yields available from a given stock each year and evaluate the effects on stocks of imposing different fishing strategies.

Annual Surveys of Abundance

Annual surveys of scallop populations in Port Phillip Bay have been conducted by the Fisheries Division since 1964. These were abandoned in favour of surveys by diver in 1982 (McShane 1982) when it was realised that catches by dredges did not adequately represent levels of pre-recruit one 1+ year-old scallops in the bay prior to the beginning of the season. Dive surveys follow a stratified random sampling strategy with the bay being divided into six trata according to historical distribution of effort and catch. Some 65-70 stations are sampled, most within the two main strata on the east and west sides of the bay where most of the scallops are located.

Population Structure

Over a number of fishing seasons from 1983, observations on board scallop vessels in Port Phillip Bay have shown the commercial population of scallops to be uni-modal, progressing in size from about 70 mm at the start of the season (April) to 80 mm by December. Also present among the catch each year were quantities of juveniles whose average shell size increased from around 20 mm in April to around 60 mm by December (Gwyther 1986). This pattern of recruitment in a 12-16 month period has been confirmed by tagging studies (Sause *et al.* 1987a; Gwyther and McShane *in press*). At the time of the annual pre-season survey in January, the population is bimodal in size structure and it has been possible to estimate the number of recruits as well as residual stock in the bay (McShane 1983; McShane and Gwyther 1984; Gwyther and McShane 1985; Gwyther and Burgess 1986, 1987; Coleman and Gwyther 1988).

Each survey has provided an estimate of the total number of scallops in the two main fishing grounds together with size composition and relative proportion of pre-recruit (1+ year olds) and residual (2+ and older) year classes. In Table 1, the numbers of recruits and residual scallops are compared. Since 1983, residual stock has been low and constant within the range 30-70 million each year. Appreciable numbers of residual scallops from the previous season were recorded only in 1982.

The fishery is now primarily dependent upon each recruit class of 1+ year-old scallops for commercial viability. In the event of poor recruitment in any year, operators in the Bay fishery face hardship as residual stock is insufficient to support commercial operations. This situation occurred in 1986, when the season only lasted six weeks and occurred again in 1988 when the season lasted only three weeks.

Quantitative information on stock structure obtained from the dive surveys has meant that aspects of fishery assessments such as stock/recruitment, natural mortality, fishing mortality and catchability can be determined.

Stock and Recruitment

The large fluctuations which characterise scallop fisheries cast doubt on whether an relationship exists between stock and recruitment which can be meaningful from a management point of view. Figures shown in Table 1 would tend to support the lack of any apparent relationship. However, studies of reproduction and settlement (Sause *et al* 1987a and b) have shown that while scallop spawning can take place over a prolonged period of time, settlement has been a discrete event, occurring in December to January in each of the years of study. Thus, the effective breeding stock is that remaining after each season, equivalent to the residual stock as estimated by survey each January and which has been fairly constant at 40-70 million for the past 6 years. Only in 1982 was the breeding stock significantly higher.

Table 1. Abundance and population structure of scallops in Port Phillip Bay (strata 3 and 5) sampled annually since 1982 (from Gwyther and Burgess 1987, Coleman and Gwyther 1988).

Age class	Length class	Millions of scallops present at the beginning of each season						
		1982	1983	1984	1985	1986	1987	1988
Recruit 1+ year old	40-70 mm	142	101	181	195	47	160	42
Residual 2+ and older	>70mm	250	43	44	74	69	39	39

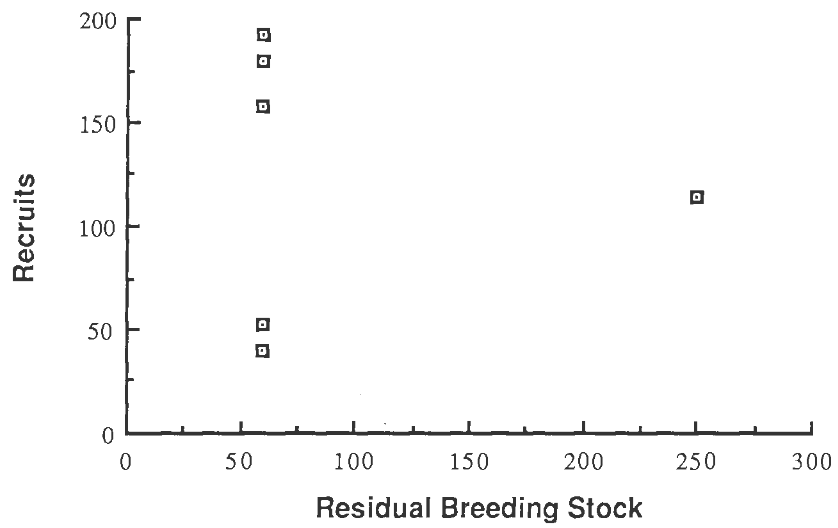

Figure 1. Recruitment arising from residual stock in Port Phillip Bay since 1982; numbers are millions of scallops.

Stock spawning in November/December would give rise to settlement in December /January and recruitment in the following year. Thus, residual stock may be compared to recruitment one year later and this is shown graphically in Figure 1.

The data are insufficient for any realistic interpretation of stock recruit relationships. For any given stock size, recruitment would be expected to vary according to other environmental conditions and this is certainly the case with scallops. It can only be concluded :t the residual stock levels remaining after fishing each year have been enough to give rise to high or low recruitment, probably dependent on other variables and that management measures designed to leave more than that level of breeding stock would not necessarily result in improved recruitment.

<u>Mortality of Scallops</u>

Estimates of fishing and natural mortality can be derived from estimates of population size, residual stock one year later and numbers removed by fishing (Table 2). Average rates of natural mortality are high, around 40% per year which is comparable with independently-derived estimates from experimental tagging studies (Gwyther and McShane *in press*). Fishing mortality is highest (63%) in years of high abundance when scallops are in surplus supply and lowest (17%) when stocks barely exceed residual levels.

Table 2. Estimates of annual fishing and natural mortality of scallops in Port Phillip Bay during 1982-87 (from Coleman and Gwyther 1988).

	1982	1983	1984	1985	1986	1987
Scallop abundance (millions)	390	143	219	270	116	268
Number of 2+ aged or older remaining one year later (millions)	43	43	74	68	39	39
Fishing mortality (millions)	150	37	61	170	20	135
Natural mortality (millions)	197	63	84	31	57	94
Fishing mortality (%)	38	26	28	63	17	50
Natural mortality (%)	51	44	38	11	49	35

Catchability Coefficient

From estimates of abundance, it is possible to predict mean annual catch rates if estimates of catchability (proportion of the total stock caught per unit of fishing effort) are known. Catchability and dredge efficiency values were calculated for 1984 and 1985 from density estimates made at the start of those years and mean catch rates subsequently achieved from that density during the year (McShane and Gwyther 1984; Gwyther and McShane 1985). By multiplying catchability coefficient by estimated abundance for each new season, mean catch rates were predicted. In practice, catch rates were high at the start of each season, and dropped markedly as the densest beds were fished out. Predicted mean catch rates were realised only for a short period of time during each season. Such predictions were therefore of limited value in setting appropriate daily catch limits and alternative methods of estimating yields available each year were applied (Gwyther and Burgess 1986, 1987; Coleman and Gwyther 1988).

Yield Assessments

Yields available from the scallop stocks in Port Phillip Bay each year are dependent upon numbers of scallops present, rates of growth and natural mortality, seasonal changes in condition and fishing strategy (crate limit and numbers of vessels fishing). A model has been developed to calculate yields available using the above input parameters (Gwyther and Burgess 1987). The number of scallops present at the beginning of the year declines through natural mortality until the season opens when fishing mortality is added. Numbers of scallops removed by fishing, expressed per crate, declines from around 2,700 at the beginning of the season to around 2,000 at the end as a result of shell growth. Yield per crate increases as scallops become mature and decreases again in the post-spawning period. Maximum yields are achieved during the winter period from June to September.

The output of the model gives the number of scallops removed, the yield obtained and the number of scallops remaining. Each season, quotas are set in order to obtain best yields from the fishery and to leave a residual stock of some 70 million scallops in the bay after fishing. For the 1987 season, when good recruitment gave rise to a total stock of some 268 million scallops, a number of different fishing strategies were compared (Gwyther and Burgess 1987) and are shown in Table 3.

In Table 3, examples 1-3 are variations of a basic strategy of six crates per day under which, each of the 85 vessels licensed to fish would remove 768 crates. By not fishing in April and May, (examples 2 and 3) and fishing more in the July-October period, it can be seen that fewer scallops are taken, more remain and yields are improved. Extending the season to December is not as advantageous as far as yield is concerned as is a strategy of increasing quotas during July to September (examples 4 and 5). Examples 6-8 show the results of maintaining a quota of six crates per day, omitting April and May. More scallops remain but yields are reduced. Example 9 explores the consequences of zero fishing during 1987 and fishing during 1988; this does not result in improved yields.

In the event, the daily limit remained at six throughout 1987. While the number of scallops caught and numbers remaining were fairly accurately predicted by the model, (the season closed at the end of November when catch rates fell below one crate per hour), scallops never attained their normal meat yield condition associated with spawning and yields per crate were low throughout the year.

Table 3. Estimates of yields (tonnes) under different strategies of daily quota, assuming 85 fishing boats during the 1987 season (from Gwyther and Burgess 1987).

Example	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Number of scallops remaining (millions)	Number of scallops removed (millions)	Yield (tonnes)	Total crates landed
1	6	6	6	6	6	6	6	6	0	68	125	1207	768
2	0	6	6	9	9	6	6	6	0	72	116	1240	768
3	0	0	6	9	9	9	9	6	0	76	108	1265	768
4	0	0	6	8	8	8	8	6	6	73	109	1257	800
5	0	0	6	10	10	10	8	6	0	73	111	1322	800
6	0	6	6	6	6	6	6	6	0	84	102	1077	672
7	0	0	6	6	6	6	6	6	0	98	82	938	576
8	0	0	6	6	6	6	6	6	6	88	92	1069	672
9(1987)	0	0	0	0	0	0	0	0	0	170	0	0	
(1988)	0	0	6	6	6	6	6	6	0	40	82	284	

Table 4. Estimate of yield (tonnes flesh weight) for a three month season with 85 boats taking six crates a day from June to August 1988 and an initial population of 92 scallops (from Coleman and Gwyther 1988).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Total
No. Scallops (M)	92	88.04	84.26	80.64	77.17	73.85	48.71	25.53	4.23	4.05	3.87	
No. Boats				85	85	85	85	85	85	85	85	
Crates/Boat				0	0	6	6	6	0	0	0	
Crates Removed				0	0	9180	9180	9180	0	0	0	27540
Scallops/Crate	2700	2700	2700	2700	2600	2500	2400	2300	2200	2100	2300	
Scallops Removed (M)				0	0	22.95	22.03	21.11	0	0	0	66.1
Scallops Remaining (M)	88.04	84.26	80.64	77.17	73.85	48.71	25.53	4.23	4.05	3.87	3.71	
Yield/Crate kg				17	18	18	19	20	19	18	17	
Total Yield Thousand kg				0	0	165.2	174.4	183.6	0	0	0	523.3
Yield Per Boat kg				0	0	1944	2052	2160	0	0	0	6156

In 1988, the number of recruits to the bay was so low that the total stock was only 92 million (Coleman and Gwyther 1988). This number did not allow a six crate limit to apply even for three months before reducing stocks below the 70 million residual level (Table 4). The season did however open in mid-July but because of extremely low catch rates, was closed again after only three weeks because of fears of depletion of residual stock.

Discussion

Quantitative estimates of abundances of stocks and recruitment in Port Phillip Bay have enabled an evaluation of population dynamics to be made at a detail unattainable for most wild fisheries. However, the level of fishing capacity within the bay is more than sufficient to reduce stocks to below a safe residual stock level and careful management is required. While he model has given a detailed insight into the effects on stock numbers of different fishing strategies, knowing how to manage the resource to leave behind a level of stock to ensure some recruitment for the future remains somewhat subjective.

Experiences and evidence from other scallop fisheries that have declined must challenge the notion that scallop stocks will always recover despite intensive fishing. Port Phillip Bay is particularly vulnerable in being dependent each season on recruitment of 1+ year-old scallops for commercial viability. The failure of recruitment in any year would mean little or no fishing as residual stocks are insufficient to support the industry. This happened in 1986 and 1988. However, yield per recruit analysis (Gwyther and McShane *in press*) suggests that yields are in fact greater by fishing the 1+ year-olds than would be the case by fishing 2+ year olds. Thus a strategy to optimise yields may not optimise reproductive output from the resource and a mechanism is therefore required which will protect the residual stocks. In practice, it has become apparent that a residual stock of 40-70 million remains in the bay when a daily limit of six crates becomes hard to achieve. Good recruitment has resulted from this stock but it is by no means certain that this is the most appropriate breeding stock level to leave behind.

A system of closure of the fishery when catch rates decline below one crate per hour has been applied in Port Phillip Bay in 1987 and 1988. Average catch rates of the fleet, or time required to take the daily limit can be easily determined from the time of return of vessels to port and implementation of this policy has received general support from the scallop industry. In open ocean situations however, where catch rates may be more variable, this policy may not be so easy to apply but is still a useful management mechanism available to protect breeding stock.

Any predictive model will have shortcomings when actual values of parameters vary beyond the extremes observed during the period of their estimation or experimentation. The very poor condition of scallops which occurred during 1987 meant that the model did overestimate yields available. Growth rate is another variable which has changed over time (Gwyther and McShane *in press*) with scallops reaching a recruited size of 70 mm shell length more than one year sooner now than 20 years ago. The present fishing strategy may therefore not have been appropriate earlier in the development of the fishery and no model can be expected to apply indefinitely. The value of the model for the Port Phillip Bay fishery is in its estimation of when residual stock levels will be reached under different strategies. If protection of residual stock is to be achieved by closures of the fishery when catch rates become too low, then this model does provide industry and management with some expectations of when this might occur.

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Summary of sessions on biology and fisheries of wild stocks.

Mike Walker
Executive Officer, FIRDC

We'll take this opportunity to look at the subjects we've covered to date. The history of scallop exploitation appears to have been a seek and destroy mission.

A range of management strategies have been tried with little success, except in the Port Phillip Bay fishery. Scallop fishermen seem to have been hunter-gatherers ; a group who have been unable to leave scallops alone even at low levels of abundance. This appears to have been the case for *Pecten* fisheries, but perhaps that's not so true for *Amusium.* There's some evidence of hope for *Amusium* stocks. Perhaps they're not as badly affected by fishing as *Pecten.* At leas this appears to be the case for Western Australia.

Let us now consider recruitment. Most of the papers on the topic took 20 minutes, but effectively they covered the component on recruitment in less than three minutes. There seems to be some circumstantial evidence for a stock recruitment relationship. Noel Coleman showed us there was a relationship between spat collection and pre-recruits to the fishery in Port Phillip Bay. Lindsay Joll believes there is a stock recruitment relationship, Mike Dredge is fearful that there is one and the Queensland *Amusium* fishery is about to collapse. Peter Young showed us some evidence that a relationship exists between the adult stock and spat settlement.

The disbeliever could well say the stock recruitment relationship is not identifiable and even if there is one, so what ? Are we going to manage our stocks any better if we understand stock/recruitment relationships ?

We have examined fishing pressure and its relationships to recruitment. Better dredge design may well cause less damage and enable us to catch more scallops. But as Lindsay Joll pointed out, more efficient gear may be more responsible for lower recruitment in the long term.

We have covered problems associated with taking scallops before they spawn and developments and strategies to leave a residual broodstock. Perhaps we are starting to get somewhere. Mike Bull has told us how he would like to develop a strip fishing strategy in order to leave some scallops for future recruitment enhancement .

I would like you to consider where I saw some of the gaps in knowledge of scallops in the wild.

It was interesting to note at a recent Seagrass Workshop the difference between seagrasses from the tropics and the temperate zone. The same differences have appeared at this workshop. *Amusium* and *Pecten* seem to be very different animals, and this appeared to polarise the meeting. We see *Amusium* people in one group and *Pecten* people in another.

A major problem with *Pecten* occurs when settlement takes place in spat bags and then you can't find them on the bottom. As Laurie Hammond and Noel Coleman explained to us, further work involving environmental factors seemed to be needed for predictive models.

No one seemed to speak much about settlement. The question I pose is To what extent does settlement in Port Phillip Bay charactise Pectinids ? Port Phillip Bay appears to be giving better stock recruitment data and better recovery than anywhere else except perhaps in the *musium* stocks. But no one seems to be worrying so much about sediment. I pose another question : How long does it take for dredge-disturbed sediment to return to its original stratification ? You turn up shells from a depth of 100 mm and they finish up on the top of the substrate. This may create an environment that is not suitable for scallop settlement.

I also pose the question: How much sediment can be put on a scallop before it dies ? Dredges must be stirring up a lot of sediment and covering scallops near them, next to the track of the dredge. No one has commented on the amount of sediment a scallop can dig itself from or withstand in its gills.

I also saw gaps in terms of larval work, in terms of what are the settlement cues. This gap is not just restricted to scallops. Demersal animals throughout Australia are poorly understood in this area. A major question to be answered is; What makes animals settle out from the water umn ?

We need to develop stock recruitment models. I am aware we are missing many parameters for these model, but perhaps we can make some guesses at some of the information required. Can we design experiments to obtain a better understanding of stock recruitment relationships ? We should look at *Pecten* and *Amusium* as two separate cases.

We obviously need to develop fishing strategies which leave scallops behind. It's pleasing to see that this objective is being considered in Victorian and Western Australia.

We have covered a wide range of fisheries topics in the first half of this workshop. I can only hope that it's not too late for the scallop fisheries.

SCALLOP CULTURE IN THE PACIFIC REGION

Derek A. Cropp
Department of Sea Fisheries
P.O. Box 619F, Hobart
Tasmania 7000
Present address: c/o Western Sea Farms
Carnarvon W.A 6701

Abstract

Scallop fisheries worldwide are characterised by fluctuating harvests. Consequently many countries have various schemes to improve and stabilise their scallop fisheries, either by artificial production of spat or by enhancing natural stocks. This report contains an assessment of the present state of research and development in China, Japan and Canada. The potential value and applicability of the various methods to conditions in Tasmania and mainland Australia are assessed.

Introduction

This paper is based on my observations during a study tour of selected scallop research instituitions in China, Japan, Canada and New Zealand. All four countries have adopted research strategies that have assisted the redevelopment of their scallop industries.

People's Republic of China

The Chinese Government has long promoted an intensive program for rearing scallops artificially. The program has been so successful that China's hatcheries now regularly produce more than 100 million spat each year. These spat are ongrown in hanging cages at sea until the scallops are of harvestable size. In 1986 the total scallop harvest (including that from culture) was 230,000 tonnes shell weight (Bainin 1988).

Hatcheries

Of the many multi-purpose hatcheries I visited in China, the most advanced was the scallop hatchery near Qingdao in Shandong Province. Another scallop hatchery at Gurei Bay near Xian in Fujian Province has features that merit description.

The Qingdao hatchery on the northern shores of Laoshan Bay (36° 30' N, 120° 46' E) is about 50 km northeast of Qingdao city in northern China. Laoshan Bay is the home port for a small fishing fleet. Seawater in Laoshan Bay has a salinity of 32 p.p.t. all year round and temperature ranges from 24-27°C in summer and 1-3°C in winter. Ambient water temperature during early April, before the breeding season, is 9°C.

The hatchery was built in 1983 at a cost of A$800,000. The concrete buildings stand on a rocky point in a semi-sheltered part of the bay (Figure 1). Seawater is pumped into settling ponds and then through sand filters either to storage tanks or to rooms where algae and larvae are cultured. The seawater is heated by steel pipes carrying hot, fresh water from a coal-fired boiler. Cooling water is not required. No water quality tests are performed at any stage although filtered seawater is examined under the microscope to check that micro-organism numbers are low. The main saltwater piping has never been cleaned during the three to four years of operation.

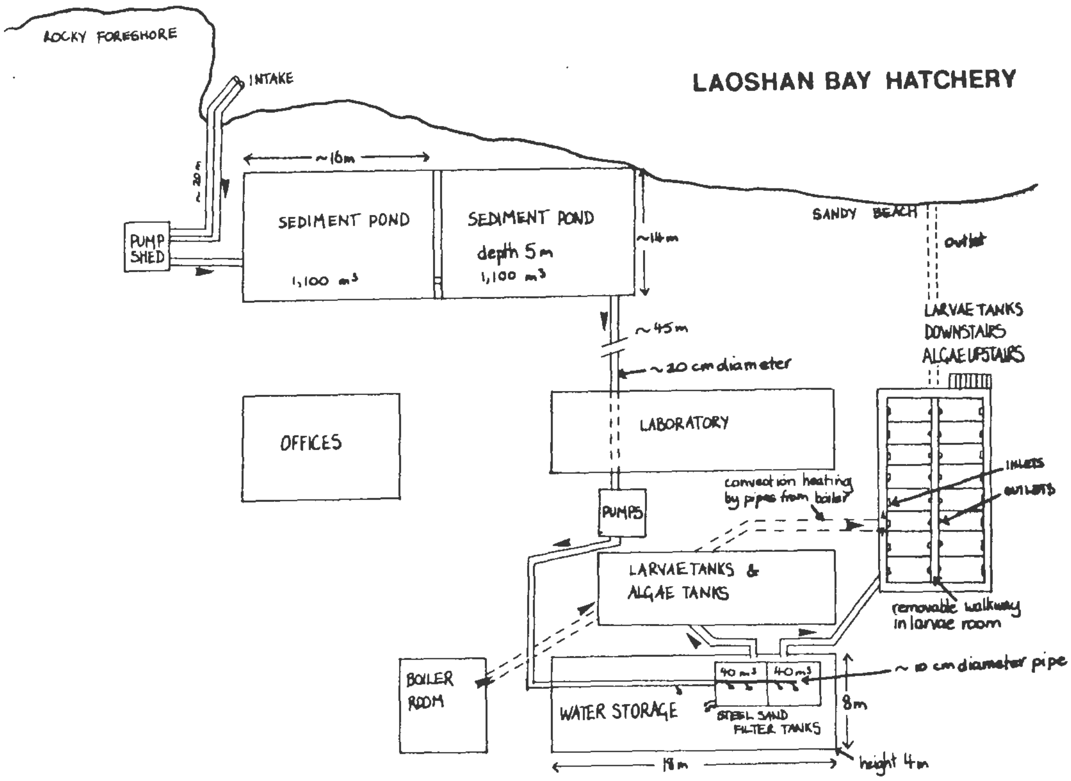

Figure 1. Laoshan Bay hatchery, Qingdao, China.

The larval rearing tanks are constructed of unlined concrete 2.5 m wide, 4.5 m long and 1.4 m deep (total volume 15,750 litres). The floor of each tank slopes towards the centre of the room and valve outlets are accessible below removable floorboards which form the central walkway. There are 14 tanks in one room.

Broodstock

At the Qingdao hatchery the species used most is the bay scallop *Aequipecten irradians*, a hermaphrodite species imported from Seattle, USA. Since the bay scallop was introduced, the smaller local species *C. farreri* is rarely utlised. *Aequipecten irradians* of 70-80 mm shell size produces 400,000 - 700, 000 eggs at one spawning. One-year-old cultured *A. irradians* that have been ongrown in hanging cages offshore are brought to the hatchery for gonad conditioning about two weeks before the intended spawning. The scallops are held in layered lantern cages suspended in the larval-rearing tanks at a density of 70-100 scallops per 1,000 litres. The water temperature in the tanks is raised from ambient (9°C) to 23°C at a rate of about 2° C per day during the first seven days and then kept at 23°C until the scallops begin to spawn in a further seven days. During these 14 days the scallops are fed three times a day (daily total 150 litres) on an algal culture containing 20 million cells per litre. The tank water is changed every two days; incoming water is heated by convection from hot water pipes at one end of each room.

The scallops, held at a density of 100 adults per 1,000 litres, yield the required quantity of eggs (20-35/mL ; maximum of 100-300/mL) during two hours of spawning. The adults are removed after the two hours. At this stage the sperm/egg ratio is 7-30 sperm/egg, although the recommended optimum is 3-4 sperm/egg. If the average is less than two sperm/egg then the adults are returned to the tanks for further spawning. No measures are taken to stop self- or over-fertilization of the eggs. By the time the eggs have developed into swimming larvae (day 2-3), natural mortality has reduced the number of larvae to 7-8 per mL.

Gurei Bay is about 450 km southwest of Fuzhou near the town of Xiaan. Seawater in the bay has a mean surface temperature between 12-13°C during winter and 30-32°C during summer. Salinity ranges between 30 and 35 p.p.t. The optimum salinity for the local scallop species *Chlamys nobilis* is 32 p.p.t. The marine farm and hatchery were established in 1979 to culture the Chinese scallop *C. nobilis* (Reeve) and the Guangdong Province scallop *Chlamys farreri.*

At the Gurei Bay hatchery the local *C. nobilis* and the imported *A. irradians* are also cultured. Broodstock of *C. nobilis* (70-80 mm shell size) are collected from cages in the sea during late April and placed in indoor concrete tanks where, under subdued lighting, they are fed on cultured algae for two to three days to improve their gonad condition. The scallops' shells are then cleaned, and the scallops are kept out of water for one to one and a half hours, while the sexes are separated.

Initially, 60-70 males are placed in glass spawning tanks 120 cm long, 50 cm wide and 40 cm deep. The water temperature is raised by solar heating 2°C above ambient and the water-level is adjusted so it just covers the scallops. Spawning usually begins about five minutes after the broodstock have been immersed in the warm water. After the males have been spawning for ten minutes, they are removed from the tank and replaced by females. The males are placed in another tank to continue spawning. The ratio of females to males is 5:1. One female of 60-70 mm shell size can produce one to one and a half million eggs, a 80-90 mm female can produce one and a half to three million eggs, and a 100 mm female up to eight million eggs.

Larvae

Larvae are cultured in concrete tanks which have been cleaned manually with a solution of potassium permanganate or calcium chlorate (20 p.p.m.) Larval *A. irradians* are placed into a cleaned tank 33-48 hours (varies for *C. farreri*) after the adults had started to spawn. Filters on the inlet of each tank are a simple sock type with a mesh size of 15 μm. The filters can be washed and re-used with minimal cost. Faecal matter and other detritus is removed twice a day through the outlet at the bottom of each tank. Every two days, water in the tanks is replaced. Replacement water is heated by convection from hotwater pipes before it reaches the larvae tanks. The hatchery phase of scallop culture takes a total of 20 days per batch. Of this, 12 days at 19-20°C, nine days at 23°C or seven days at 28°C, is the actual larval life.

From day two until day six, when larvae are 140 μm in size, the larvae are fed on diatoms (40,000 cells/ml/day). *Isochrysis* is the preferred diatom but the seawater temperature is too low; consequently, the diatom *N. closterium* is used until *Isochrysis* can be used (during the warmer part of the year). From day 6 to day 15 the larvae (170-240 μm) are fed on a mixture of diatoms (30,000-40,000 cells/ml/day) and *Platymonas* (3,000 cells/ml/day).

Algae

Algae are grown from starter cultures obtained from the Yellow Sea Fisheries Research Institute and the Oceanography Institute. Both Institutes produce starter cultures from specific algal cells isolated from seawater. The cultures are intended to be axenic. This seems to be unlikely considering the quality of equipment used in producing the cultures. The species used are the brown diatom *Nitzschia closterium* (cultured at 20°C), green *Chlorella sp.* (cultured at 25°C) and *Phaeodactylum tricornutum* (cultured at 20°C). At Gurei Bay *Platymonas sp.* and *Chaetoceros sp.* are preferred. Even if the starter cultures were axenic, bacteria would be present in subsequent cultures due to the lack of hygiene at both hatcheries. Individual algal species are cultured indoors either in unlined concrete tanks or in concrete tanks lined with ceramic tiles. Water in the tanks is heated by convection from steel hotwater pipes. The tanks' dimensions are the same as those of larval-rearing tanks but the water is only 400 mm deep. The cultures are not aerated, but are occasionally stirred by hand.

Water for algal culture is piped directly to each tank from the sand filter and does not pass through sock filters. The algal-rearing tanks are cleaned with solutions of potassium permanganate or calcium chlorate (20 p.p.m.) before being filled with saltwater.

Larval Settlement

The larval culture tanks are also used for spat settlement. Two types of substrate are commonly used in the Qingdao hatchery; small pieces of natural palm fibre rope (6 mm diameter) woven into panels and artificial thread of 2 mm diameter woven into netting/knotted mesh of 15 mm squares, in panels about 1.5 m long and 0.3 m wide. Before being used, both mesh substrates are kept in seawater for several days and then dipped into an antibiotic to kill most micro-organisms and bacteria on the mesh. Immediately after this treatment, all pieces of the substrate are weighted at one end and immersed in the settlement tanks. The upper end of each panel of substrate is attached to PVC pipes (10 mm diameter) spanning the width of the tank (ie. 3-4 m long).

An alternative substrate used in some areas, for example, Gurei Bay, consists of polyethylene mesh bags, 20-25 cm wide and 50 cm long, loosely filled with polyethylene material or palm fibre rope. The mesh size of the exterior bag is 0.5-1.0 mm and each bag has a circular weighted floor (with drainage holes). The numbers of eyed larvae are assessed and a suitable number of collectors are then placed in the tanks. The settlement rate varies from 20,000 to 100,000 spat per collector.

No inducement is used to settle the larvae, but aeration is continued. Previous work at the Qingdao hatchery has indicated that an increase of temperaure at the metamorphosis stage may improve settlement. The larvae settle when their shell size is 160-220 μm (temperature dependent). Overall survival from trochophore to post-metamorphosis is usually 70%, but occasionally is as low as 30%.

In Gurei Bay, spat collectors are left in the larvae tanks for three to four weeks during which one-third of the tank water is changed daily. Before settlement there are 100,00 to 200,000 larvae per 1,000 litres of water. The number of collectors used is 10-15 per 1, 000 litres, while the number of spat that settles ranges from 1,000-25,000 per collector.

By the end of the three-to-four week settlement period the spat are 1-2 mm in height. At that age they are transferred into mesh bags which are attached to a surface longline for ongrowing through to the lantern cage phase and then harvest. Seaweed is cultured between the scallop longlines.

Ongrowing

Qingdao

When spat are at least 160-170 μm in size, substrate estimated to contain about 100, 000 spat is put into a rigid black PVC tube (60 cm long, 30 cm diameter), fitted with two external eyelets at one end and a piece of 300 μm mesh over each end of the tube. Spat in these tubes are fed on a mixture of *Platymonas* and either an *Isochrysis* species or a diatom (usually *Nitzschia sp.*), until about 400 μm in size.

The Chinese scallop *C. farreri* attaches itself to the substrate by a strong byssal thread but *A. irradians* has only a weak attachment. A strong attachment generally helps to improve survival especially during transport because the scallops do not fall to the bottom and smother each other.

When the spat are about 400 μm, the tubes are suspended on longlines in the sea. After the tubes have been on the longlines for one to two weeks the mesh on the tubes is changed to one mm and densities are reduced to 3,000 spat per tube. When the scallops are five mm in size the tubes and their contents are transported, dry, by boat (300-500 tubes/vessel/trip), or occasionally by truck (300/truck/trip), to another ongrowing site operated by local people employed by the Government.

Transport by sea takes several hours but causes only low mortalities (1-2%). Transport by truck usually takes about one hour but due to an air temperature of 15°C (late April-early May) mortalities are low (3-4%). When the tubes arrive at their destination they are immediately hung in the sea below an offshore longline (Figure 2). The longlines have a surface mainline because sea conditions are calm. The scallops are then gradually transferred to seven-level lantern cages and stocked at densities such that they initially occupy 30-70% of the available area on each level. These cages are 300 mm in diameter and have two mm mesh. The scallops are removed from these cages when the scallops occupy nearly all the available area. Thus, at harvest size there are about 15 scallops per level.

Because of fouling by algae and ascidians the cages are cleaned occasionally; at the same time predators are also removed. Predators include a Portunid crab and a species of gastropod.

Growth rate of scallops in the cages is up to 70-80 mm in one year, provided the original spat were produced from the hatchery in April, when water temperatures were increasing. Growth is slower when water temperatures are decreasing. The seven-level cages are hung individually on longlines in ten metres of water.

Production is 45,000-75,000 kg of scallops, shell weight, for each hectare. The wet weight of meat (the gonad is not eaten) obtained from the scallops is approximately 10% of live weight. Dry weight of the meat is 29% of wet weight. Prices are A$1/kg live weight, A$12/kg wet meat weight and at least A$40/kg for dried meat. A 70-80 mm scallop produces 2.3 g (wet weight) of meat.

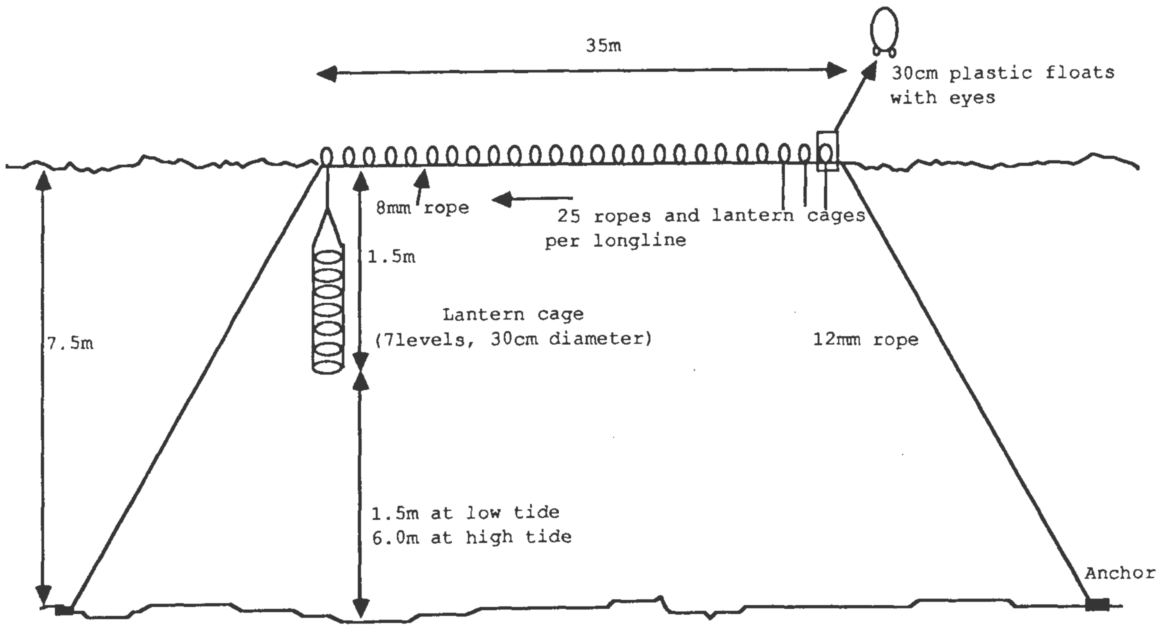

Figure 2. Arrangement of lantern cages and longlines used in Gurei Bay, China.

JAPAN

Japan is the world leader in enhancing wild scallop fisheries and its scallop production is more than 200,000 tonnes shell weight per annum (Bartrom 1987). The fishery relies exclusively on wild spat collected at sea and has no hatchery-based scallop aquaculture. Scallop stocks are now sufficiently managed and developed to ensure a reliable annual catch. Most of Japan's scallops are produced near Hokkaido where the fishery is based on the collection of wild spat which are then sown onto the seabed under controlled conditions.

The techniques that the various fishing co-operatives use to catch scallop spat at sea in northern Japan are basically similar. However, the types of equipment they use vary considerably, and depend primarily on sea and weather conditions in each area and on the level of spatfall.

The spat collection systems I describe are those used in Mutsu Bay (northern Honshu) and Shibetsu/Nemuro Strait (eastern Hokkaido). The two main areas studied exhibit different organisation and environmental situations. These differences have resulted in markedly different methods being employed.

Mutsu Bay

Mutsu Bay (Figure 3) is the largest scallop-producing area in the world and has produced as much as 60,000 tonnes shell weight in one year (Ventilla 1982). The fishing co-operatives in the bay utilise a total area of up to 52,000 h for hanging culture and 23,000 h for sowing (reseeding) culture out of a possible 166,000 h. Hanging culture is used in the inshore area (10-15 m depth), while sowing culture is used in water 15-30 m deep. Although Mutsu Bay is large, scallop culture in the bay is now so intensive that concern has been expressed that the maximum annual production level (50,000-60,000 tonnes shell weight) has been reached within 30 years of enhancement programs commencing.

Samples of adult scallops are collected regularly in Mutsu Bay for analysis of the gonad index (GI= wet gonad weight /wet weight of all tissue). Two to three times a month, during December-April, scallops are obtained from hanging cage (lantern) culture and by dredging the seabed at several sites around the bay. The major spawning usually occurs in March when the GI is greater than 25%. However in 1983 when water temperatures in winter were unusually high, most spawning occurred when the GI was only about 22%.

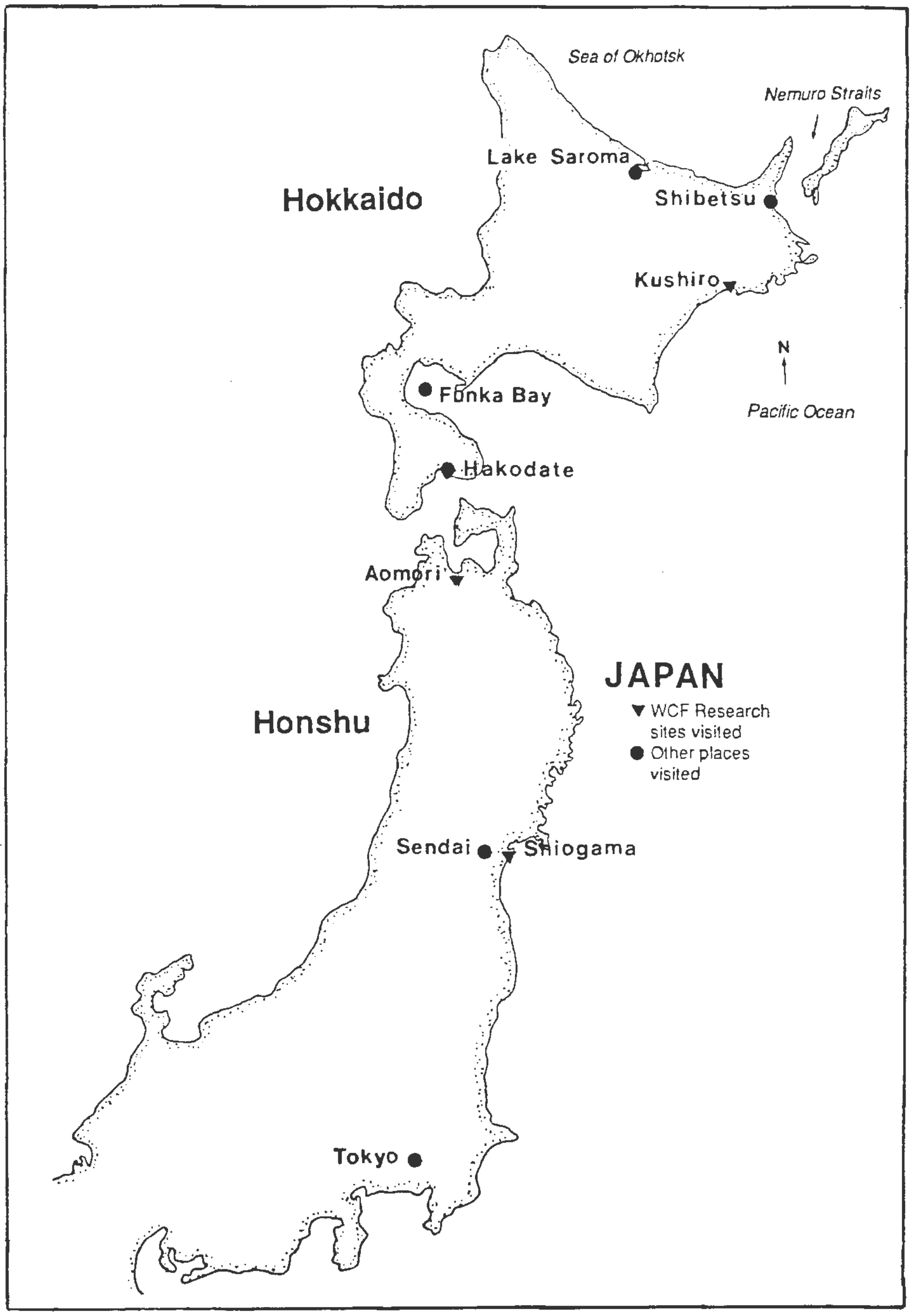

Figure 3. Research sites visited (▼) in Honshu and Hokkaido.

Shibetsu

Shibetsu is a small east-coast town of about 8,000 people and fronts on to the Nemuro Strait which separates Hokkaido from Russia (Figure 3).

The operations of the Shibetsu Fisheries Co-operative (SFC) form the basis for scallop production in this area. SFC has 34 scallop members who own (individually or jointly) 14 fibreglass scallop boats of about 9.9 tonnes gross weight. The boats are 10-14 m long, can carry 13 tonnes and are powered by diesel engines of up to 500h.p. The fishermen work a minimum of 120 days per year and earn A$150,000-200,000. At busy times during the year casual labour is employed.

The SFC owns and operates its own research boat. During May, June and July, SFC staff on the boat weekly monitor the increasing GI of adult scallops. Close liaison with other northern Hokkaido Co-operatives is maintained during these months, as biologists believe that larvae settling off Shibetsu originates from spawning scallops in the Okhotsk Sea. The other co-operatives also conduct their own gonad and larval monitoring program and the results are sent to the controlling Prefectural Fisheries Organization.

As GI increases, research staff begin a weekly larval monitoring program. Samples of plankton are collected in dual-layer plankton nets (Figure 4) pulled vertically to the surface from a depth of 20 m. The two layers of mesh, 300 μm and 90 μm, allow rapid sorting and analysis of plankton samples which are automatically separated from the large crab and other larvae and rubbish. When plankton samples contain a high proportion of scallop larvae larger than 180 μm longlines and spat collectors are deployed nearby.

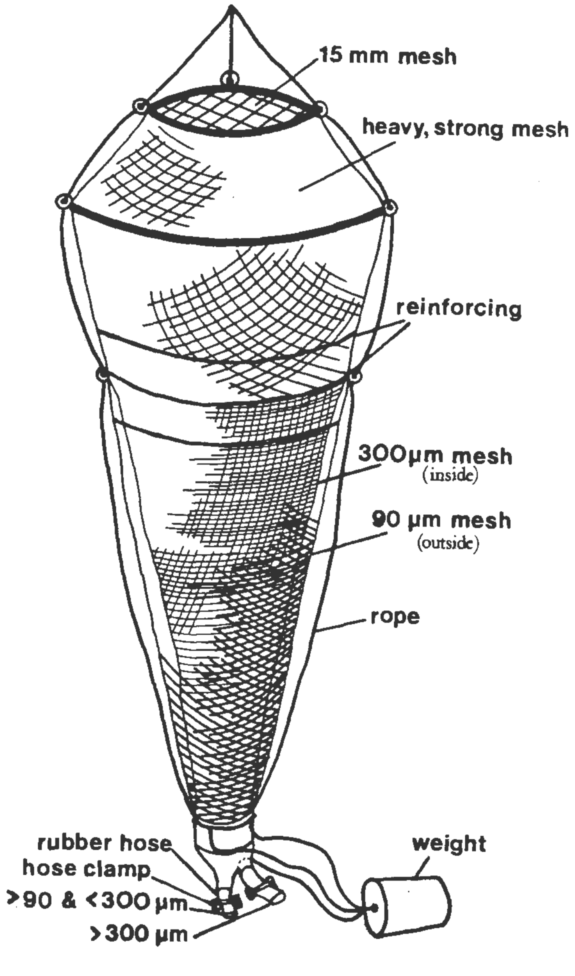

Figure 4. Duel-layer plankton net used for larval sampling in Shibetsu, Japan.

SFC deploys 250,000 spat collectors each year and aims to catch about 500 spat per collector. The collectors are tied (bottom first) on vertical rope droppers at 25 bags per dropper with 67 droppers per 100 m longline (ie. 1,675 collectors per longline (Figure 5). A total of 150 longlines (occupying an area of 4.5 x 10^6 m^2) is used to support the 250,000 collectors.

Samples are taken several times from the spat collectors to assess the extent of spatfall, survival and growth, and the most suitable time to remove scallops from the collectors. At sorting time the droppers are hauled aboard the scallop boats and taken ashore for sorting. At the start of the sorting period, which lasts about one month, spat ≥ 10 mm (30-40% of total catch) are kept. By the end of the sorting period the spat have grown and spat ≥ 20 mm only are kept; all the rest are dumped as waste.

Scallops retained after sorting are immediately put into intermediate culture cages (or pearl nets in some areas) which are taken back to sea and strung on a deepwater longline. Lantern cages are hung vertically in the water column but are attached from the bottom up (Figure 6). Sand bags (25 kg) are attached to the bottom of the longlines and floatation buoys to the top.

After several months in intermediate culture, the scallops, averaging 45 mm in size, are again taken ashore, removed from the cages and sorted. Some organisations use mechanical sorters for this operation. The scallops are then placed into self-draining fish bins and taken back to a designated release area from which all the starfish and scallops have been removed, as part of the rotational harvesting system, by Keta-ami dredges. The scallops are released by simply tipping them over the side of a scallop boat travelling at about eight knots to give a density of 7-13 scallops per square metre. In years when spat catches are low, SFC buys five centimetre spat from other co-operatives in Hokkaido, transports them dry in refrigerated trucks and releases them.

The growth and survival of scallops is monitored for three years by either a sledge-mounted video camera or by Keta-ami dredging. The scallops are harvested by up to 14 SFC boats dredging almost one behind the other so that as many scallops (and starfish) as possible are caught. The catch of each boat inormally consist of approximately two tonnes of scallops for every ton of starfish. This ratio varies from area to area but all starfish caught are taken ashore. The harvest area is methodically dredged until the catch of scallops and starfish per drag is virtually nil. All the catches are landed at SFC.

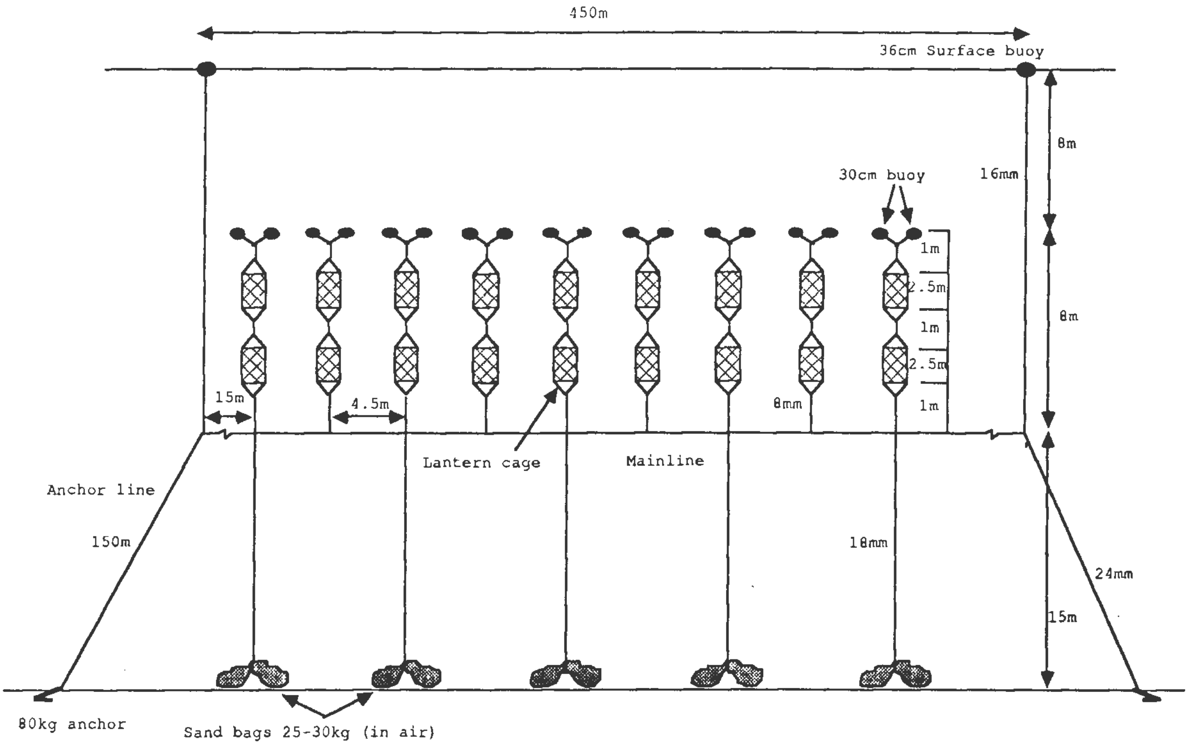

Figure 5. Arrangement of spat collectors and longlines used off Shibetsu, Japan.

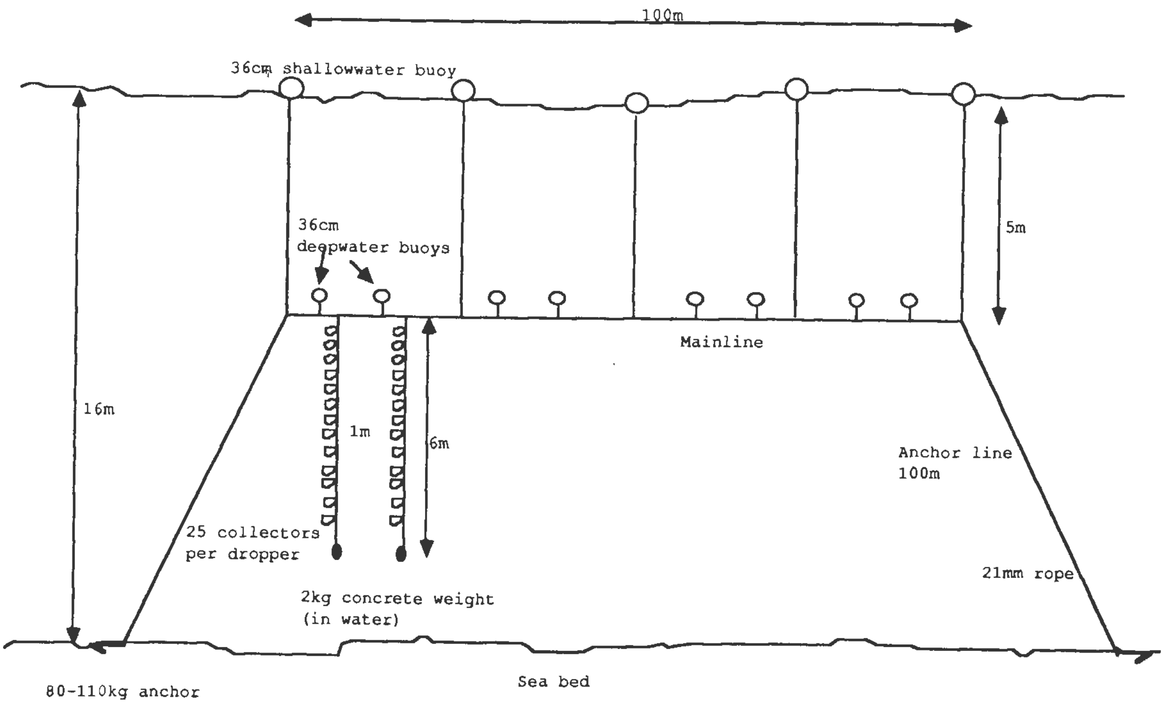

Figure 6. Arrangement of cages and longlines used off Shibetsu, Japan.

The scallops are trucked a short distance to be weighed and processed. The plant is owned by SFC so that pricing, supply and demand are carefully controlled to accommodate changing circumstances. The starfish are taken away in trucks and used as a fertiliser. The total annual catch of live scallops in shell was about 3,700 tonnes in 1985/86 and 5,000 tonnes in 1986/87. About 2,000 tonnes of starfish were caught each year.

In one reseeding area of about 2 km^2, 650 tonnes of scallops and 450 tonnes of starfish were caught during 1986-87. This equates to about two starfish weighing 0.5 kg each per 20 m^2.

CANADA

Thirteen species of scallops have been recorded in British Columbia, Canada (Bernard 1983) but only four species are large enough or present in sufficient numbers to warrant investigation as a potential resource for a scallop fishery (Bourne 1969). Scallop stocks have been too low to support a viable fishery; therefore, researchers have been investigating intensive hatchery-rearing as a means of producing large numbers of scallop spat. Bottom seeding in the cold deep waters near British Columbia is impractical and so a hanging cage culture industry is being considered.

British Columbia has conducted several years of research into artificial rearing of the imported Japanese scallop *Patinopecten yessoensis* and the local rock scallop *Chlamys gigantea.* This work has followed unsuccessful attempts to catch large quantities of naturally-occurring spat at sea. Larvae of both species have been successfully reared to settlement but because the rock scallop characteristically attaches to a firm substrate, its suitability as a culture species is restricted. The ongrowing of *P. yessoensis* in cages appears to have the best economic potential.

Hatchery

The large imported Japanese scallop *Patinopecten yessoensis* has been used for most of the culture work at the Pacific Biological Research Station, Nanaimo, British Columbia.

The hatchery at Nanaimo has been constructed within the confines of the established research station. Intake water for the hatchery ranges in temperature from 7° to 10°C, while the maximum surface-water temperature is 14°C. Incoming water is filtered (to 1 µm) through cartridge filters although 5 µm filtered water is considered to be adequate (C. Hodgson, Pacific Biological Research Station, British Columbia, pers. comm.).

Broodstock

Adult *P. yessoensis* (which are dioecious) kept in indoor tanks under subdued light are acclimatised to a water temperature of 6-8°C (ambient is 10°C) while being fed on algae to enhance their gonad condition. After being acclimatised, the scallops are air-dried for one to one and a half hours and replaced in water at 14°C. The temperature shock stimulates spawning soon thereafter.

Larvae

Fertilised eggs obtained from the broodstock are washed to remove excess sperm and then tipped into fibreglass tanks (1,000-5,000 litre) soon after the spawning. The largest tanks are 1.5 m high, 3.0 m in diameter and hold about 5,400 litres of water. The water is changed twice each week and its temperature is kept at 14.5-15°C by mixing heated and cooled water in pipes. This temperature is maintained throughout the larval life of the scallop. The density of larvae is initially 1.3 per mL but falls at each water change to about 1 per mL.

No aeration or food is provided while the eggs are developing to the trochophore phase (0-3 days); survival during this period is 22%. Aeration caused the eggs to accumulate around the edge of the tank.

Larvae are removed by sucking water from 15 mm above the bottom of each tank by means of an inverted J-shaped PVC pipe hooked over the edge of the larval-rearing tank. Larvae in the water are caught on a screen or sieve immersed in a tray of water to minimise damage to the larvae. The mesh size of the screens vary from 35-236 µm depending on the expected size of the larvae. The final 15 mm of water in the bottom of the tank is drained through an outlet into a different screen and the larvae are then washed into a beaker for examination. Any swimming larvae are separated of and added to the healthy larvae; the rest are discarded. Every time a tank is emptied, larval size is measured as the width or distance across the scallop, parallel to the hinge line. Larvae are measured so that any slow-growing larvae can be separated from the healthy larvae and washed away with the waste water.

Various antibiotics have been used in the larval-rearing tanks and have resulted in marginally higher survival and growth rates. However, the antibiotics are so expensive to use on a large scale that they are no longer used at Nanaimo.

Algae

From day three to settlement, cultured algae are fed to the larvae as shown in Table 1. Naturally occurring algal cells in the water are counted using a Coulter Counter and cultured algae are added to increase the cell density to the level required. Algae are cultured in five-litre carboys under clean conditions. Algae fed to the larvae must be at the growing phase because the protein value (and lipid-energy level) of algae, especially *Thallassiora pseudonana (3H)*, in the growing phase is much higher than when in the stationary phase. Algal food for settled spat and adult scallops is cultured in 350 litre tanks containing medium inoculated with algal cells from a carboy. The culture does not have to be axenic.

Table 1. Feeding shedule for scallop larvae at Nanaimo.

Age of larvae (days)	Food conc. ($x10^3$/ml)	Algal food
3-5	5	*Chaetoceros calcitrans* (or *Isochrysis* aff. *galbans*)
6-10	7-10	*C. calcitrans* and *I.* aff. *galbans.*
11-15	10-12	*C. calcitrans* and *I.* aff. *galbans*
16-30	12-15	*C. calcitrans, I.* aff. *galbans* and *Thallassiosira pseudonana*

Larval Settlement

The larvae of *P. yessoensis* are ready to metamorphose and settle at day 21-25 when at a size of 240-260 µm. Larvae are removed from the screen during changing of the tanks to be checked for metamorphosis. A sample of larvae caught on the screen is placed in a beake of water and if they clump together, they are ready to settle.

The settlement substrate, called 'Kinran' rope, is a 6 mm diameter, multistrand synthetic rope, with multiple strands of nylon, about 90 mm long, teased out either side. The rope is soaked in filtered seawater for two weeks before being placed into a clean larval-rearing tank when the larvae are ready to settle. The lengths of rope (each one metre long) are hung vertically in a static 2,500 litre tank. Water in the tank is changed twice each week for three weeks, after which the tank becomes part of an aerated flow-through system in which one-half of the water is exchanged each day. A settlement rate of 1,200 spat per one metre section of rope is the highest recorded. No settling inducement is used although various chemicals have been tested with unsatisfactory results.

Other research work at Nanaimo has centred around energy levels in the larvae and in the algal food. Studies have shown that energy levels in larvae generally decrease up to the pre-metamorphosis stage, even during constant feeding. Lipids are the main dietary requirement for metamorphosis (Whyte, Pacific Biological Research Station, British Columbia, pers.comm. 1987). Before metamorphosis the larvae begin to store reserves of energy as lipids which are depleted rapidly during development from a swimming larvae to a settled spat. Other research has shown that when the neurotransmitter serotonin has been used to induce spawning, the eggs have contained less energy reserves than normal.

Results from the study on energy levels show that larvae required algae of high nutritional value as well as a combination of algae that provides the different nutritional requirements.

Ongrowing

Following the three-week settlement period, the 'Kinran' ropes are placed in mesh bags (two per bag) and moved into tanks on a barge floating in the bay. Filtered seawater (50 μm) is pumped into the tanks which are set up as an aerated flow-through system. In the system scallop spat can be cultured for a short time but as they grow they are transferred from the bags into hanging cage culture in imported Japanese lantern cages. Results from initial trials have been encouraging but show that growth is highly site-dependent.

Sowing Culture

Reseeding of scallop spat on to the seabed off western Canada is possible only in a very small area. The deep, cold waters of the region are not good for culture and make collection of large amounts of natural spat impractical. The most prolific species of local scallop grow attached to the bottom substrate and have to be harvested by divers. At present hatcheries are the only possible source of large numbers of spat.

Management

Because development of any sizeable scallop fishery in western Canadian waters depends at present on artificial culture, suitable methods of growing spat to harvestable scallops must be evaluated. An economically and logistically feasible method of harvesting the scallops needs to be considerered also.

The production of large numbers of spat at the Nanaimo hatchery appears imminent and continuation of the hatcheries work by a private commercial company also seems likely. Various marine farms for ongrowing of scallops will need to be established in addition to the oyster farms which are already scattered around British Columbia. Unfortunately, some of the best sites for marine farms are on waterways on which the timber industry in British Columbia relies heavily to transport logs.

Relevance to southern Australia

At present, fisheries managers in Tasmania have two main options for the future: to continue to develop hatchery technology as a means of helping large-scale commercial spat production, which could be used to enhance natural scallop stocks; or to develop a long-term program of collecting wild spat to enhance natural stocks. Either method of obtaining spat juvenile scallops or could help a new aquaculture industry to develop in Tasmania and/or mainland Australia.

Tasmanian scallop fisheries could benefit by using overseas technology and perhaps developing other unmarketed local species. Although *Chlamys asperrimus* (doughboy scallop) and *C. bifrons* (queen scallop) have previously been regarded as having low market value, their potential must be fully evaluated. Large numbers of doughboy scallops already exist in Bass Strait and although meat yield is small, the species could easily support an alternative fishery as does the *Amusium pleuronectes* fishery in Queensland and the *C. farreri* and *C. nobilis* industry in China. These three species are all harvested at 60-70 mm in width and yield a very small amount of meat.

Doughboy and queen scallops have been successfully reared in a hatchery (Dix 1976 and Rose and Dix 1984) and appear to have more potential than *P. fumatus*. These two species could form the basis of a new scallop industry.

Enhancement of natural scallop stocks by means of a unified community approach, as in Japan, is logical in re-establishing a scallop fishery in Tasmania. Necessary grouping or co-operation between the various sectors of the industry is the only situation which would allow a sustainable fishery to be developed again, either naturally or with the help of aquaculture techniques. A concurrent change in fishing methodology for the wild fishery is required to improve the catching efficiency and decrease the fishing mortality. Results in Japan and New Zealand have shown there need not be a senseless waste of scallops during fishing operations.

A combination of various features from local and overseas longlines has resulted in the design of the longline being used for research at Maria Island in Tasmania (Figure 7). In addition, a sub-surface longline design for hanging cage culture has been proposed (Figure 8).

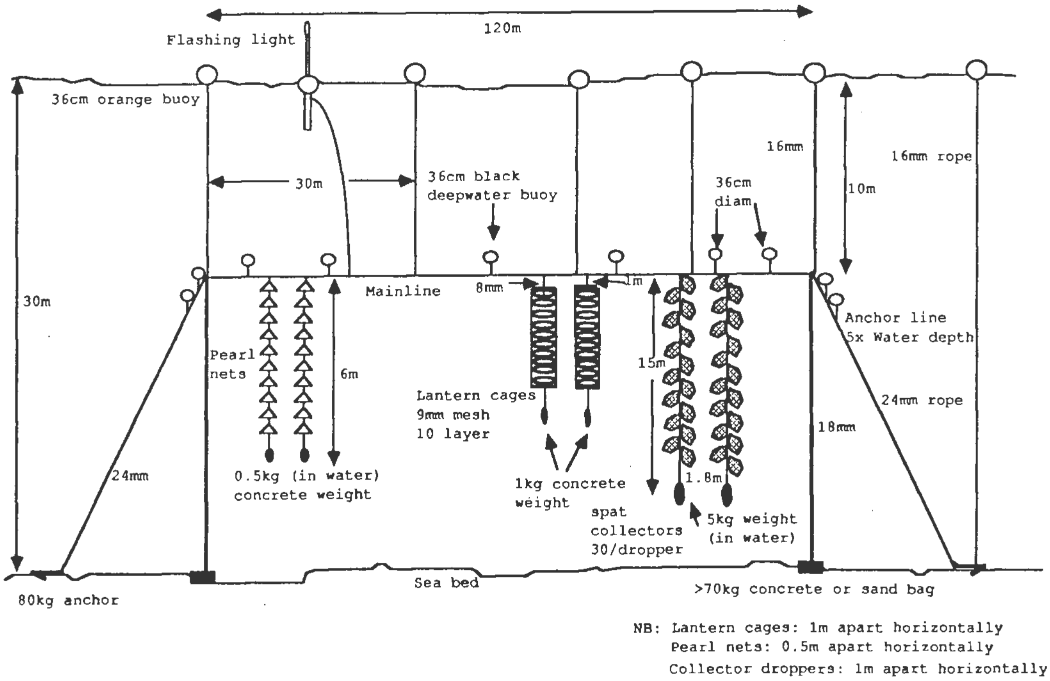

Figure 7. Arrangement of pearl nets, lantern cages, spat collectors and longlines used in Tasmania.

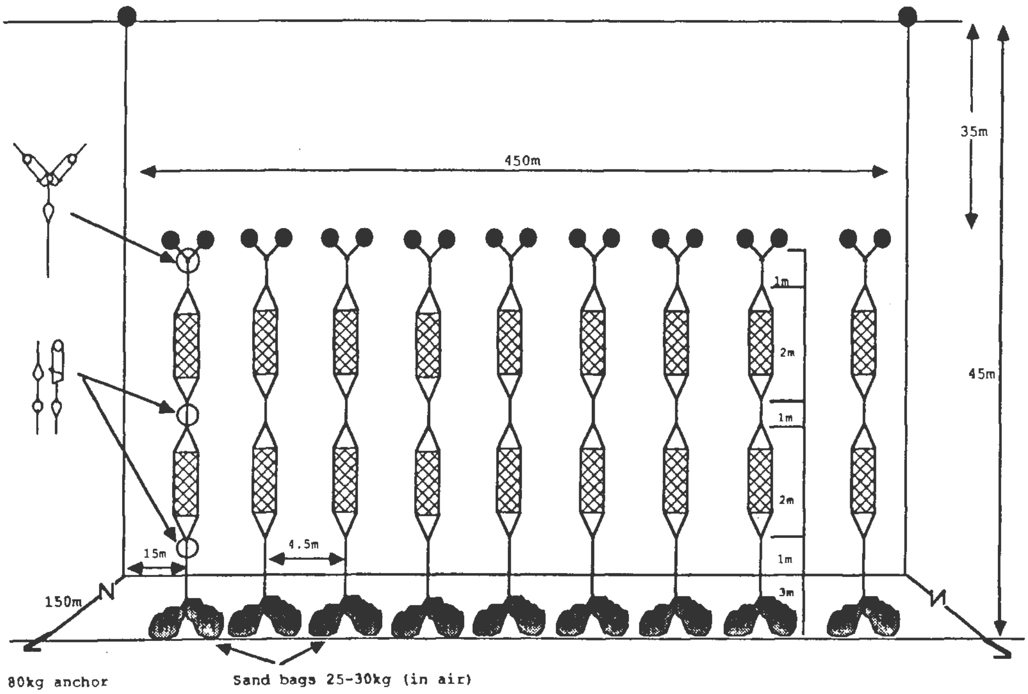

Figure 8. Arrangement for hanging cage culture of scallops in Tasmanian waters.

This design is adapted from the system used at Shibetsu Fisheries Co-operative where weather conditions are similar to those encountered at Maria Isand. The sub-surface longline incorporates a deep mainline that allows mooring of lantern cages from the bottom up so that movement of scallops is minimised during rough seas. The design also allows the cages to be hauled to the surface and to be worked on by a vessel equipped with teboyoke rollers rather than to be collected by divers, as has been the case in Tasmania for this type of longline.

Summary

The present state of Australia's scallop fisheries poses some difficult management and biological problems that have been clearly illustrated in the collapse of Tasmania's scallop fishery (Zacharin this volume). A combination of poor recruitment (McLoughlin *et al.* 1988), heavy overfishing and an inefficient and destructive dredge (P. C. Young pers. comm.) has le to the cessation of the Tasmanian scallop fishery. The recovery of the fishery is expected to be a protracted process unless strict management control is imposed and a program of enhancing the scallop stocks with wild-caught or hatchery-produced spat is successfully implemented.

Tasmania has extensive coastal and offshore zones that have either supported scallop fisheries in the past or appear suitable for scallop beds. The technology available worldwide is now sufficiently developed to allow researchers to take advantage of the developments and to re-establish scallop fisheries in fished-out or suitable areas. A unified approach by government and the private sector is essential to success such as that exemplified by the secure financial state of scallop fishing co-operatives in Japan. In China a similarly successful (although a smaller scale) scallop cultivation program has been established under government control.

Acknowledgements

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NEW ZEALAND SCALLOP ENHANCEMENT PROJECT-COST AND BENEFITS

M F Bull
Ministry of Agriculture and Fisheries
Private Bag, Nelson
New Zealand

Abstract

Three different methods for the bottom culture of scallops, tested during a three year pilot program in Golden Bay, New Zealand are described. The methods are 'direct release' (release of spat on to the seabed direct from collector bags), intermediate culture (release after a further period in pearl nets), and 'natural release' (enhancement of post-larval settlement success by the provision of simple artificial settlement materials). Predictions on costs, the likely levels of seed production, and the survival rate to harvest are made for a commercial operation in the Golden Bay area. It is concluded that both the direct release and the natural release methods should give excellent returns to capital but the intermediate culture method would be uneconomic.

Introduction

In the 1970s trials on scallop spat catching and ongrowing were carried out in New Zealand by the Ministry of Agriculture and Fisheries (MAF) and a number of private organisations (Bull *et al.* 1985). The results of these trials indicated that while hanging culture of the New Zealand scallop was technically feasible it was unlikely to be economic under New Zealand conditions at that time (Cameron 1983). It was concluded that bottom seeding was likely to be a more viable option.

In 1982 Talley's Fisheries Ltd and the MAF carried out some modest scale seeding trials in Golden Bay and the Marlborough Sounds. This was followed up in 1983 by MAF and the Overseas Fishery Co-operation Foundation of Japan embarking on a joint pilot scale seeding operation in the Golden Bay area. The main objectives of this project were to adapt Japanese seeding methods to local conditions and test the commercial viability of the system. The joint project had an initial aim of seeding ten million spat per year for three years and continued project had an initial aim of seeding ten million spat per year for three years and continued until December 1986. Since that date further trials have been carried out by MAF with the operation becoming more commercially oriented and the seeding area being extended to include nearby Tasman Bay (Figure 1).

In this report three alternative spat catching and seeding methods developed during the trials are described. Estimates of associated costs and likely productivity for commercially orientated operations using these methods in the Golden Bay area have been based on data obtained during these trials.

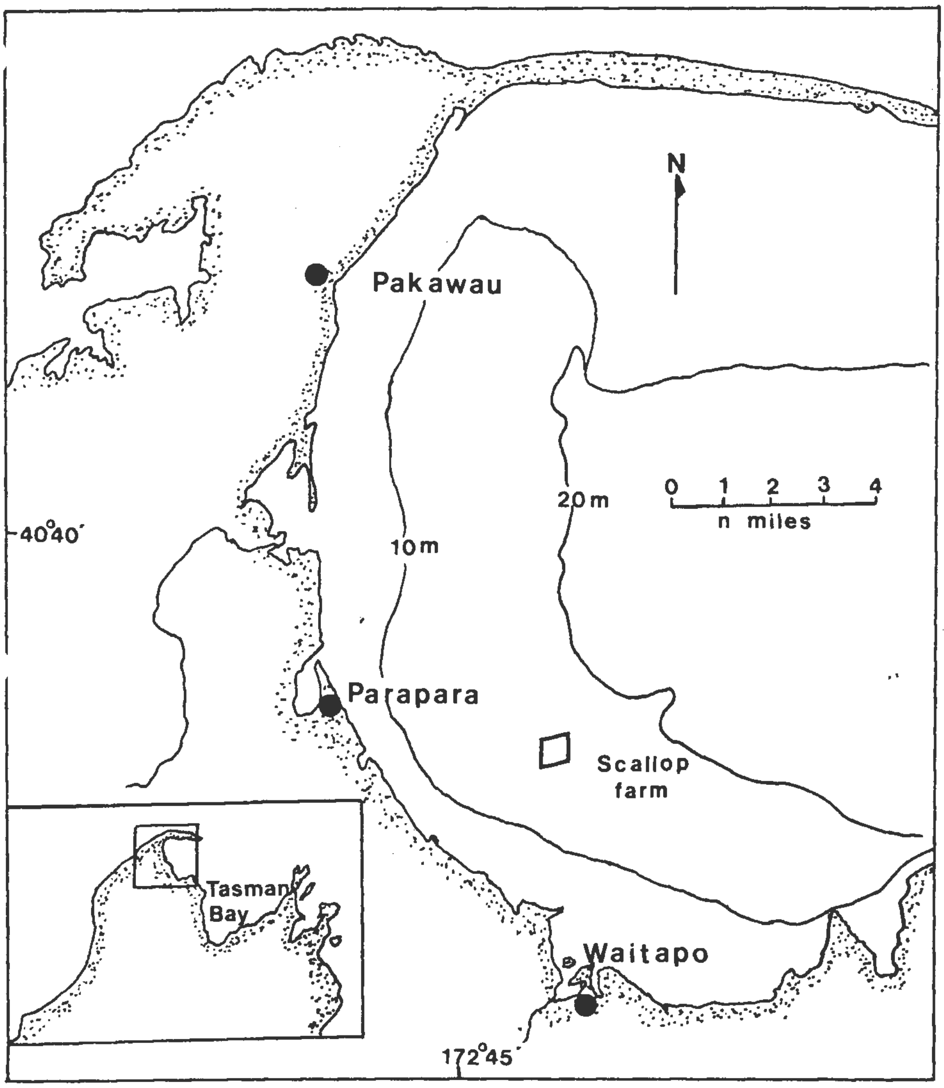

Figure 1. Trial site in Golden Bay, New Zealand.

Methods

Direct Release

Scallop spat were caught in Japanese-type spat bags suspended from sub-surface longlines, held for three months in the bags and then released directly on to the seabed at the chosen on-growing site. The basic unit of gear was a modified Japanese sub-surface longline of 200 m backbone length which carried 100 droppers of 20 spat bags/dropper (Figure 2). Spat bags were made from 0.4 m^2 of 5 mm aperture outer mesh and 0.6 m^2 of 9 mm inner mesh.

The lines and spat bags were set in early December using local fishing vessels of 12 - 15 m length and a 15 m gear carrying-barge. In late January and mid-February it was necessary to add additional floats to the backbone to maintain buoyancy. The gear was removed from the water in mid-March by which time the majority of spat had reached a shell height of at least 10 mm.

On recovery from the water the spat bags were immediately transported to the chosen seeding site, opened and the spat were shaken over the side as the vessel meandered over the release area. All equipment was then taken ashore where outer meshes were discarded and inner mesh and other gear cleaned.

During the winter, backbones and other gear were repaired and new spat bag droppers constructed.

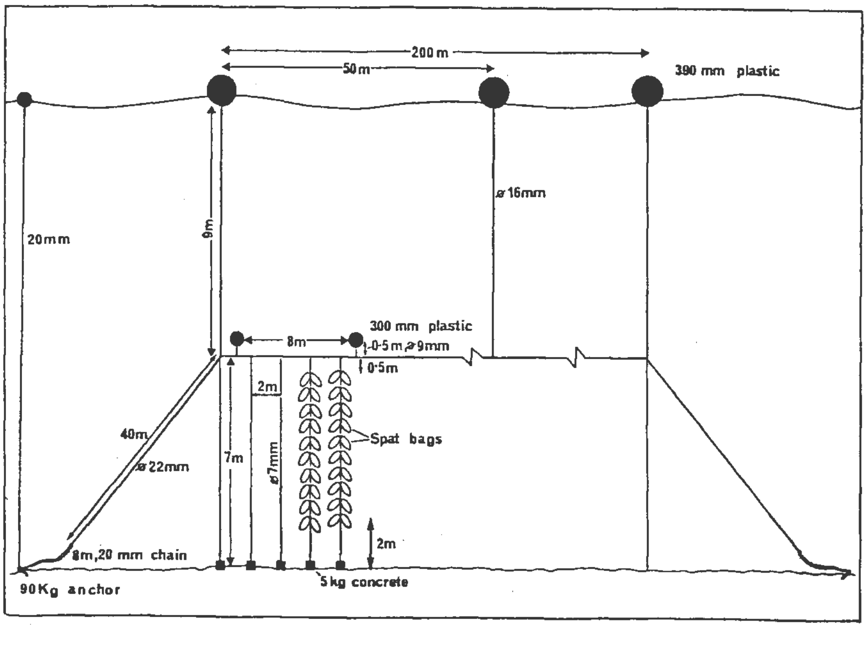

Figure 2. Spat collector and longline design for Golden Bay, New Zealand.

Intermediate Culture

Exactly the same system was used for the intermediate culture method as for the direct release method except that spat were transferred to pearl nets and held in strings of seven on longlines of exactly the same structure as for the spat bags rather than being released from the bags. With 100 strings per line and 75 spat per net each line carried approximately 52,500 spat. Spat were released in June at a density of approximately three per m^2.

Natural Release

Longlines carrying material that attracted settlement of scallop larvae and held the developing spat above the seabed during their byssal phase were set out prior to spawning. 'hen the spat detached they fell to the seabed below, where they remained until recovered by dredging six to eight months later. They were then transplanted to the grow-out areas.

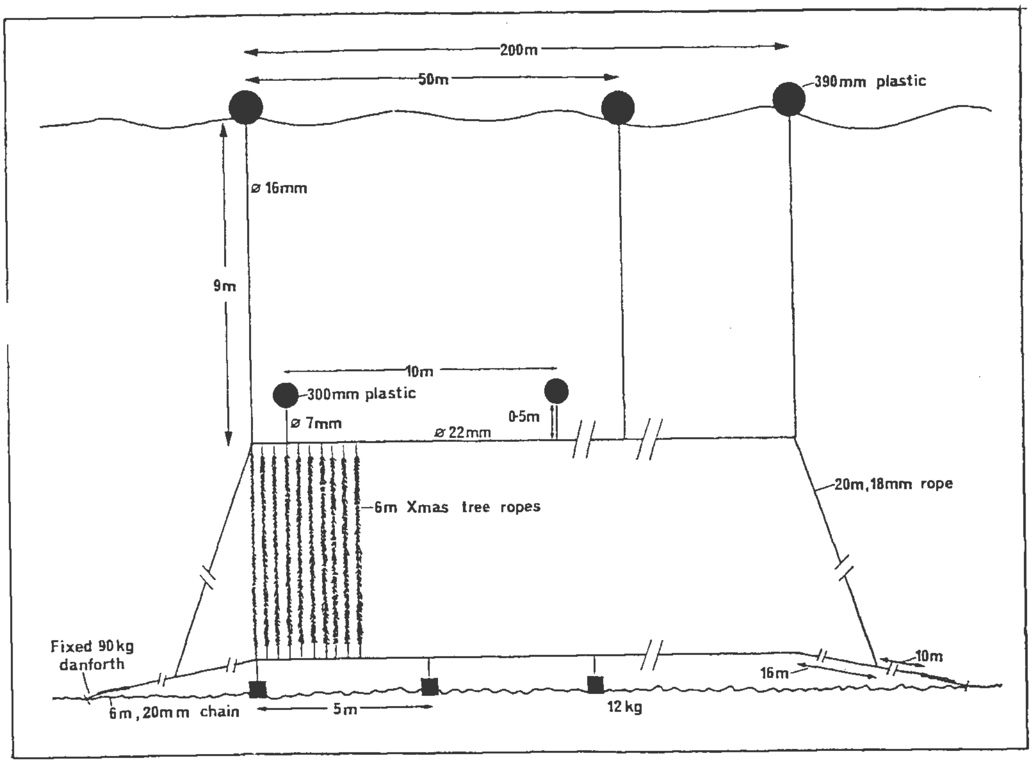

Figure 3. Longline design for the natural release method in Golden Bay, New Zealand.

Initially strips of the 9 mm mesh used in spatbag construction were employed as the settlement material. Later, 12 mm hairy polypropylene rope (Kinran) developed for the local mussel industry and known as 'christmas tree rope' was used. This proved to be a good settlement material for scallops and had the advantage of sometimes attracting a bycatch of mussel spat that could be sold.

The longlines used in this system were again 200 m in backbone length and carried 600 x 6 m lengths of mussel rope (Figure 3) or 100 droppers carrying mesh strips. These lines were set in early December and removed in early March as were the spat bag lines. Juvenile scallops of 35 - 45 mm shell height were recovered using fine mesh dredges in August.

Results

Relative Productivity of the Different Methods

Seed Production

The average number of spat in collectors sampled at the time of release varies between 1,000 and 2,000 per bag for bulk lots of collector bags set in Golden Bay during December in 1981 and 1983 to 1987(Figure 4).

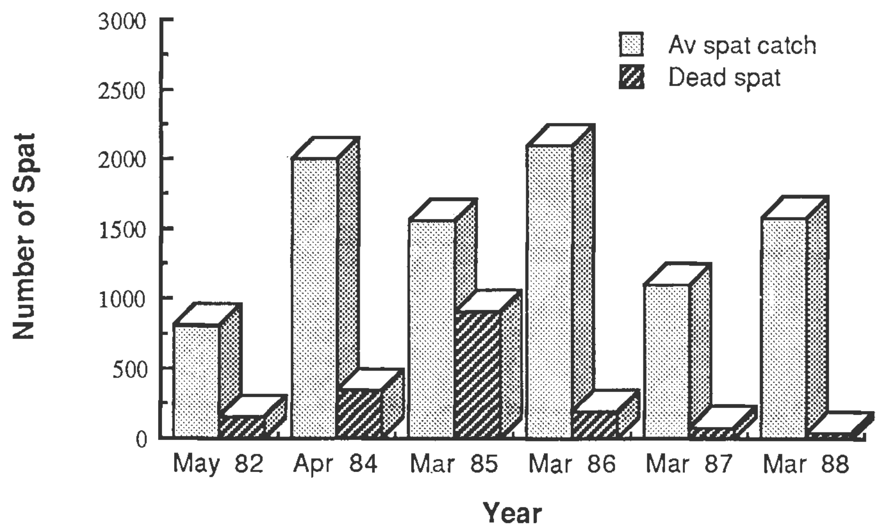

Figure 4. Average numbers and survival of scallop spat taken in bulk lots of collectors placed in Golden Bay during December 1981 and 1983-1987 inclusive.

In some years spat suffered relatively high levels of mortality in the bags. Mortality appears to have been related to the degree of fouling in bags by mussels and should be minimised in future by ensuring that scallops are released from the bags before the mussels become a problem.

An average release of at least 1,000 live spat per bag or 2,000,000 per spatbag longline should be achievable in Golden Bay in most years. While this total quantity would be available under the direct release system, Japanese management practice for the 'intermediate culture' system is to discard the smaller spat (perhaps 30%). A further minor loss of spat (up to about 5%) can be expected as a result of mortality during the intermediate culture period. However, a much greater constraint on the productivity of the intermediate culture system is the low carrying capacity of the pearl net longlines only 52,500 spat per line.

Seed production from the natural release method is difficult to assess as there have only been two years in which juvenile scallops originating from the natural release method have been utilised for transplanting. In 1986 an average of 2,500,000 eight-to-ten-month-old scallops were transplanted for each of the 14 longlines of settlement material placed in the water the previous summer. This figure dropped to 500,000 per line in 1987, and in 1988, there was no evidence of significant settlement below lines placed in Tasman Bay and almost total mortality of spat which settled below lines in Golden Bay (Table 1). Clearly this method has potential for high seed productivity but has considerable risk of failure. A figure of 660,000 spat per longline has been used for the cost benefit analysis.

Survival of Seeded Stock

During the trials, survival estimates for the different release groups have been estimated by means of dive surveys, recapture of tagged scallops and production from commercially fished seeded plots. Results have been extremely variable but most cases of low survival rates are attributable to poor management practices and should now be avoidable in light of present knowledge.

For the purposes of the cost benefit analysis in this paper, 'average' survival rate figures have been set at 15% for direct release, 30% for intermediate culture and 40% for scallops transplanted from a natural release. These assumed rates are based on some of the better results achieved in the trials including:

(a) the commercial harvest in December 1986 of approximately 1,450,000 scallops from a one km^2 plot seeded with 9,700,000 spat by the direct release method in May 1984. Estimated harvesting efficiency was 68% giving a total survival rate of 22% (Bull 1987).

(b) a dive survey estimate of 44% survival for intermediate culture scallops released in June 1984 and surveyed 14 months later (Bull 1986).

(c) recapture of 135 live tagged scallops during commercial harvesting of the seeded plot in December 1986 from a batch of 426 which had been tagged and released after being dredged from below the spat catching lines in October 1984. With an estimated harvesting efficiency of 68%, this gives a total survival rate of 47% (Bull 1987).

Table 1. Deployment of spat catching equipment and trial results.

December 1984 - April 1988

Area		Golden Bay			Tasman Bay
	1984/85	1985/86	1986/87	1987/88	1987/88
No. xmas tree longlines x length	2 x 80 m	2 x 80 m	0	6 x 200 m	6 x 200 m
No. mesh type longlines x length	3 x 80 m	12 x 200 m	12 x 200 m	6 x 200 m	6 x 200 m
Observed spat density on sea bed (month observed)	>1000/m^2 (Feb) 40 - 200 m^2 (April)	20-2000/m^2 (March)	25 - 65/m^2 (April)	>500/m^2 (Feb) 0.01/m^2 (April)	1.3/m^2 (April)
Survival to August	Poor	Good	Good	Very Poor	?
Approximate number transplanted	Nil	32.5 million	5.9 million	Nil	Nil

Estimated Seeding Cost by Method

The estimated costs of running a commercial system under each of the alternative methods have been assessed. The costs projected are related to the running of a 48-longline system which is the present scale of the MAF operation in the Golden Bay/Tasman Bay area. In the case of the intermediate culture system this would initially involve the setting of two longlines of spat bags and later switching to 48 longlines of pearl nets. It is assumed that the spat catching activity is confined within a single plot. Although this plot may be moved from year to year it will always be within one hour's steaming time of port. Likewise, seeding areas are assumed to be within one hour's steaming of both the home port and the spat catching site. It is further assumed that no rental is required for either spat catching or ongrowing sites, and that it is only necessary to have marker beacons at the spat catching site.

Gear prices quoted are approximate and are based on May 1988 prices for equipment available in the local area.

The system is assumed to be run by a manager whose salary is NZ$35,000 per year with extra labour being hired when required at NZ$10 per hour. All work at sea is assumed to be done by local scallop vessels at a rate of NZ$70 per hour for vessel and skipper. A 200 m^2 shed and one hectare of bare land are required for gear maintenance and storage.

The estimated costs of the different sections of each operation are summarised in Table 2.

Estimated Profitability by Method

The following figures for seed production per longline and percentage survival to harvest in the third year would seem appropriate in assessing likely profitability of the three methods:

(a) direct release of 2,000,000 spat per longline, with 15% survival;
(b) intermediate culture of 52,500 juveniles per longline, with 30% survival;
(c) natural release 660,000 transplanted juveniles per longline, with 40% survival.

Based on these estimates, expected production from a 48-longline system would be 14,400,000 , 756,000 and 12,800,000 scallops respectively. These would be on the seabed at the time of harvest. Only a proportion of these could be landed because of indirect fishing mortality and the inability of fishermen to work when scallop densities are low. In the trial harvesting of a seeded plot in 1986, an estimated 68% of the crop was harvested (Bull 1987). Eighty percent of the stock on a seeded plot should be economically recoverable if harvested without a size limit.

Table 2. Cost yield estimates for 48 longline operations based on each of the three methods described.

Method	**Direct release**	**Intermediate Culture**	**Natural Release**
Costs			
Size of Operation	48 longlines	48 longlines	48 longlines
Equipment			
Year 1	$335,000	$262,000	$301,000
Year 2+	92,000	54,000	64,000
Labour			
Year 1	126,000	110,000	88,000
Year 2+	110,000	106,000	85,000
Hire land and shed	3,000	3,000	3,000
Running costs vehicle	6,000	6,000	6,000
Managers Salary	35,000	35,000	35,000
Total cost year 1	$525,000	$416,000	$433,000
Total cost year 2	$225,000	$204,000	$193,000
Yield			
Number release	96 million	2.52 million	32 million
Expected survival	15%	30%	40%
Number of survivors	14.4 million	756,000	12.8 million
Expected recapture (80%)	11.52 million	604,800	10.24 million
Meat yield (12g/scallop)	138,240 kg	7,258 kg	122,880 kg
Price per kg	$15.25	$15.25	$15.25
Harvest cost per kg	$5	$5	$5
Gross Income	$1,416,960	$74,390	$1,259,520

In the 1986 trial harvest the average meat yield per scallop was 9.7 g, but scallops in the whole of Golden Bay were in particularly poor condition that year and a yield of at least 12 g per scallop could normally be expected.

Taking these figures into account, a 48-longline operation could be expected to yield respectively about 138 tonnes, seven tonnes and 123 tonnes for the direct, intermediate and natural release methods.

At the 1987 price to fishermen of NZ$15.25 per kg meat this gives an annual gross income of NZ$2.1 million, NZ$0.1 million and NZ$1.9 million.

Catching costs have to be considered. At a rate of NZ$1000 per day (present charter st) and a daily catch of 200 kg meat weight, unit catch cost is NZ$5 per kg.

The direct release method should give an extremely profitable operation. Given the assumptions made, the natural release method should also be profitable and may be preferred if a significant bycatch of mussel spat can be obtained. The intermediate culture method appears to be uneconomic (Table 2).

Discussion

The profitability of the direct release and natural release methods described in this paper are, to a large extent, reliant on a cheap and abundant supply of spat and relatively high survival rates. Operation of the direct release method would become uneconomic if the catch was to drop below 300 spat per bag, or if survival was to drop below 5%. There are a number of management and indirect costs that have not been taken into account, but which could have a significant impact on the viability of a large-scale commercial operation. In the Golden Bay/Tasman Bay area, for example, there are other user groups who would be affected if a large scale scallop enhancement operation were developed in the area. These include both amateur and commercial scallop fishermen who would demand continued access to wild scallop production in the area or compensation for exclusion. Trawl fishermen who could face a temporary ban to trawling activity on newly seeded grounds would also be disadvantaged. Such conflicts are likely to be a common feature of commercial enhancement operations throughout the world but their impact will obviously vary depending on their scale and the degree of political support enjoyed by the various user groups.

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GENERAL DISCUSSION

Bell: At what size should scallops from both direct release and intermediate culture be released? Do you have better survival at a given size?

Bull: When scallops are released from bags they have a range of sizes because of variable growth rates. In 1988 they have been averaging 5 mm but in 1987 they were 5 to 20 mm, averaging 11 mm. On the basis of our samples of surviving stock, there is little difference between the survival rates of the small and larger released scallops.

Evans: Have you given consideration to handing over operations to industry?

Bull: We have given this question a great deal of consideration, but the whole area is very difficult. Both Golden Bay and Tasman Bay are open and unsuited for subdivision into small private cropping areas. Marlborough Sounds is much better suited for this type of operation. In New Zealand, there are some areas suited for reseeding and many that are not. At this stage we are looking more at the possibility of running a commercial enhancement operation for the fishery rather than a privately owned operation.

Gwyther: What is the value of the trawl fishing operation that shares the area you have considered enhancing?

Bull: I can't give a specific answer. There are more fisheries in these areas anyway, gill netting and the like. Seasonal bans in recently seeded areas may be needed.

Gwyther: Have you enough information to rule out intermediate culture?

Bull: We ruled it out after the second year of trials. Initially we had a gut feeling that the technique was uneconomic, but our more recent analyses support this feeling.

Gwyther: So you've finished with intermediate culture altogether?

Bull: We are not doing any more intermediate culture at Golden Bay. There is another program to be developed in the Auckland area, and circumstances may be different there.

Bell: Any idea on what is causing mortality?

Bull: Virtually no idea at this stage. In the first year of our work, dive surveys indicated that 70% were lost between May and August. We monitored them again in the following February and losses weren't nearly so bad. We've examined fish taken from the release site and scallops rarely appeared in their guts. Our attempts to film young scallops over an extended period have been unsuccessful.

THE HISTORY OF SCALLOP CULTURE TECHNIQUES IN JAPAN

Susumu Ito and Atsuko Byakuno
Overseas Fishery Cooperation Foundation
c/o- Department of Sea Fisheries
G.P.O. Box 619F, Hobart
Tasmania 7001.

Abstract

We have introduced the history of development of scallop culture techniques in Japan. Technical methods utilised during the development of scallop culture have been reported, using Mutsu Bay, which has the longest history of scallop culture, as an example. Detailed descriptions of forecasting natural spat collection, reseeding techniques and mass mortality are given. The importance of remembering that the scallop is a living creature is stressed.

Introduction

The beginning of research into the development of scallop culture techniques in Japan goes back to about 1935. By 1965 a variety of basic techniques had been established. Since then commercialised scallop production has progressed to reach as much as 2,500,000 tonnes shell weight per annum.

In this report we trace the process of development in scallop culture techniques and the solutions for problems that were associated with this development.

Scallop enhancement in Japan

The current situation of scallop enhancement in Japan is as follows.

Figures 1 shows the Japanese scallop (*Patinopecten yessoensis* Jay) which is used in enhancement projects. Both shells are slightly curved. It can reach sexual maturity at a minimum size of 9 to 10 cm shell length (S.L.) and has a maximum size of 15 to 16 cm. The species is dioecious and spawns once a year in early spring. A live scallop can stretch many

Figure 1. *Patinopecten yessoensis,* used in Japanese scallop culture.

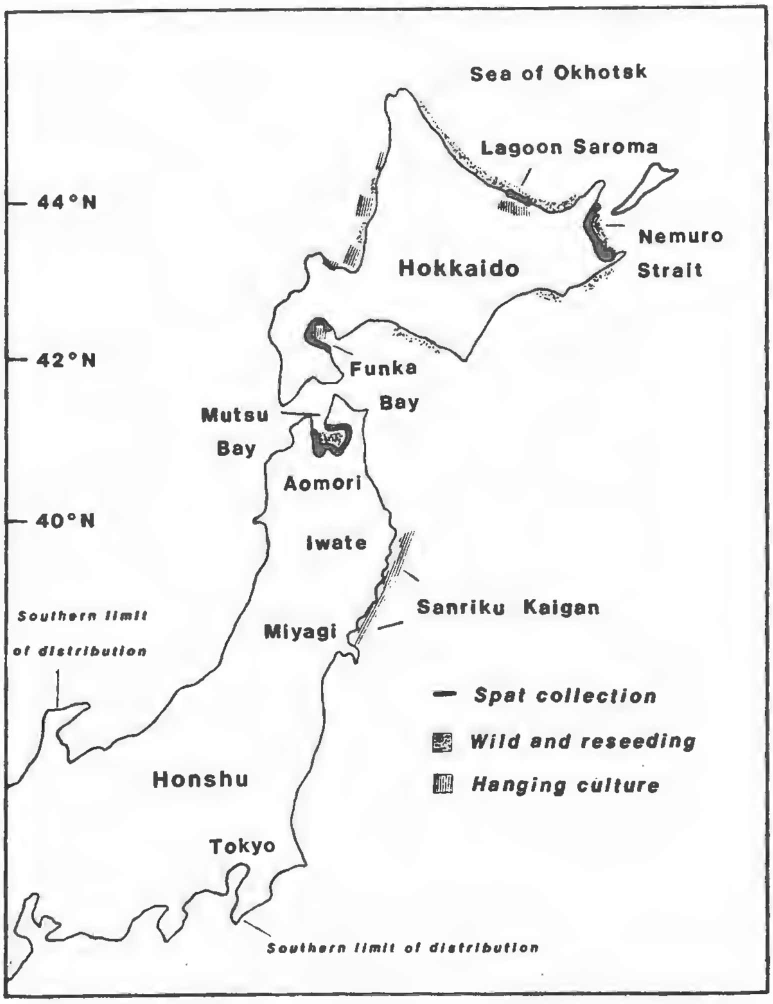

Figure 2. Scallop production in Japan.

sensory tentacles from its shell. When these contact a strange substance, the scallop may swim away from it in response. Understanding this behavioural aspect of the scallop is very important for scallop culture operations.

Figure 2 shows the distribution and production areas for *P. yessoensis* in Japan. They are harvested mainly between 40° N and 45° N. Fishermen have applied natural spat collection, reseeding and hanging culture in Mutsu Bay over a long period. Funka Bay on the south coast of Hokkaido, is a major area for natural spat collection and hanging culture, and Lagoon Saroma on the northeast coast of Hokkaido, is another area where natural spat collection, reseeding and hanging is widely applied. In the Sea of Okhotsk and Nemuro Strait reseeding is the main technique used for scallop enhancement.

Regional production of scallops in Japan is illustrated in Figure 3. Generally, hangi. culture is more common than reseeding in bays, whereas reseeding is predominant on the open sea.

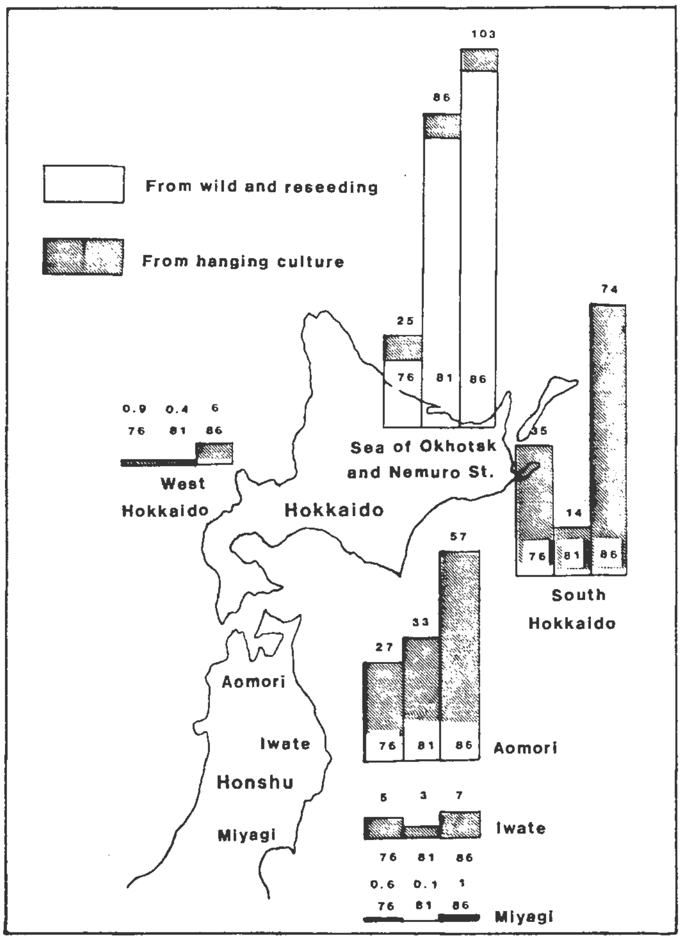

Figure 3. Regional production of scallop (shell weight x 10,000 tonnes) in Japan.

Variation in the annual production of scallops in Japan is shown in Figure 4. Twenty years ago the yield was around 10,000 tonnes but by 1987 it had reached approximately 250,000 tonnes. Hanging culture flourished first and reseeding of artificially reared and wild spat followed. The yield ratio from each method is presently one to one.

The life history of *P. yessoensis* and the corresponding work schedule for scallop enhancement is illustrated by Figure 5.

Longlines are used extensively in all phases of culture operations. A main line is suspended 8 to 15 m below the sea surface so any possible deleterious effects of wave movement will be diminished (Cropp this volume).

Culture equipment used for the main culture techniques is illustrated in Figure 6. Spat collection bags are used to trap post-larval scallops from the water column. Pearl nets are used for intermediate culture and lantern nets are used for hanging culture. Ear hanging is used as a culture technique in some areas.

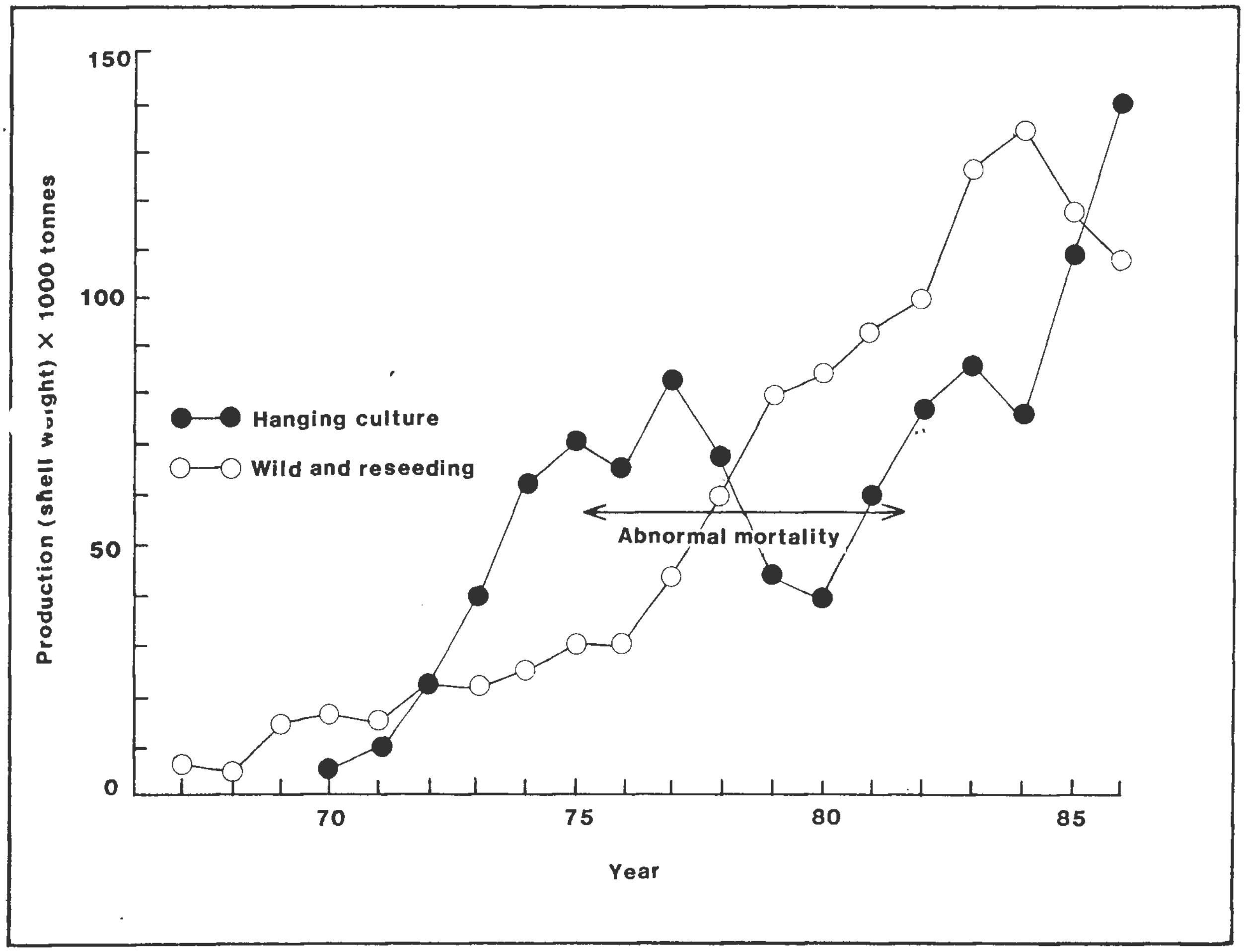

Figure 4. Annual production of scallop from Japan.

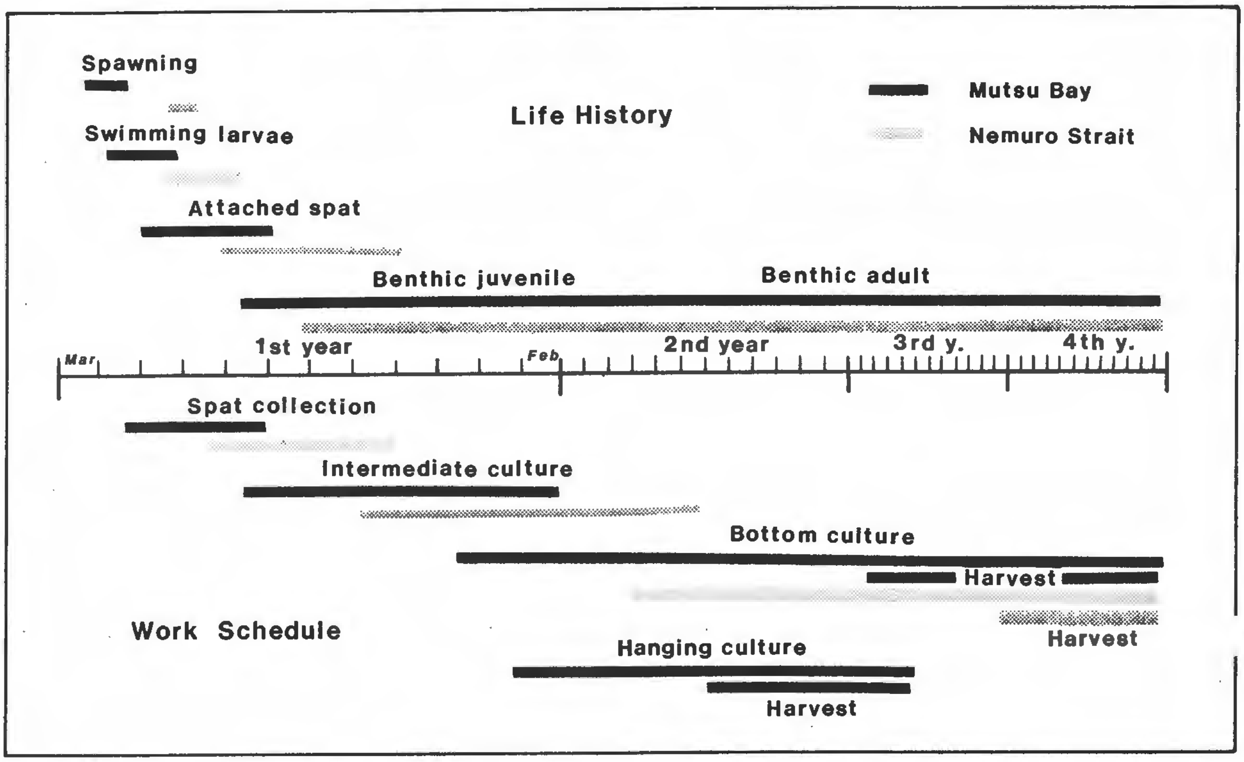

Figure 5. Life history and working schedule for scallop enhancement in Japan.

Keta-ami dredges are used to harvest scallops in wild and enhanced fisheries (Zacharin this volume). As scallops are partly buried in bottom sediments, they have to be scooped up using a mesh bag with chains attached to the front teeth. The teeth are attached to the front of the dredge and knock the scallops from the bottom into the mesh bag. The dredge catches between 15% and 70% of scallops in its path, depending on bottom conditions. The proportion of scallops which suffer broken shells is less than 5%.

The development of scallop culture techniques and the process of overcoming problems

The technical development of scallop culture was first practiced in Mutsu Bay. This is the oldest, indeed the pioneer area for scallop culture in Japan and the world. Lessons learnt from early problems in this area are very important.

As shown in Figure 7, there was a dramatic fluctuation in scallop production at the primary stage of wild fishing and for the next 30 years between 1935 and 1965. Various enhancement techniques were used in attempts to overcome these fluctuations in catch. Nine aspects of enhancement techniques are shown in Figure 7 as arrows which indicate the time in which these aspects were investigated, and are briefly documented in Appendix 1.

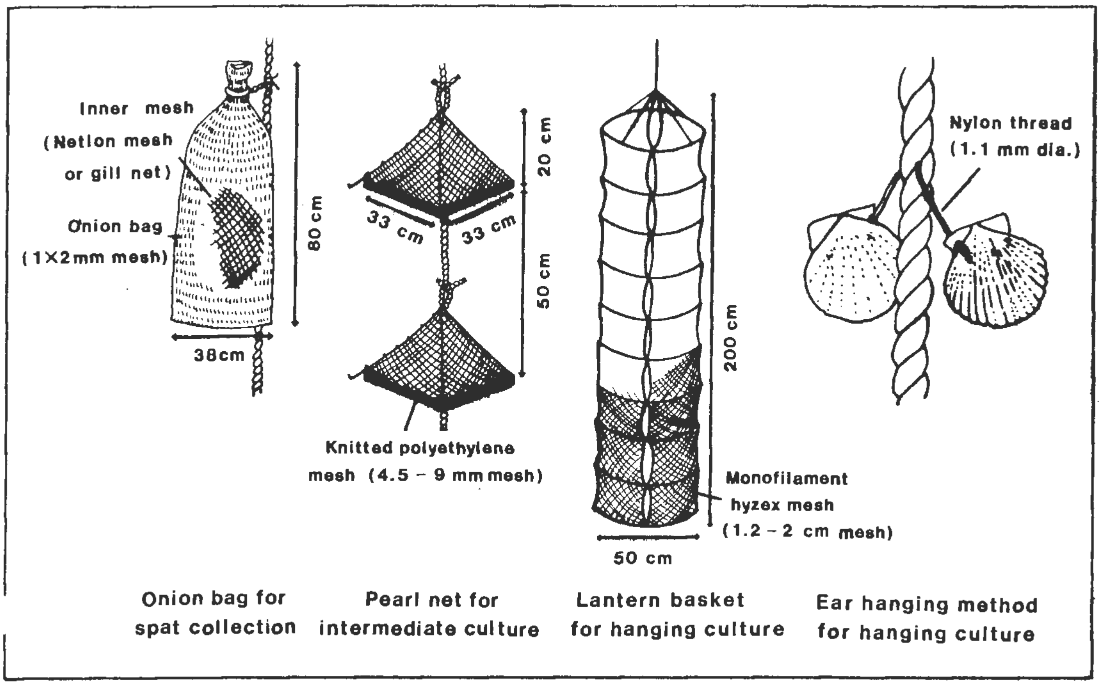

Figure 6. Equipment used for hanging culture of scallops.

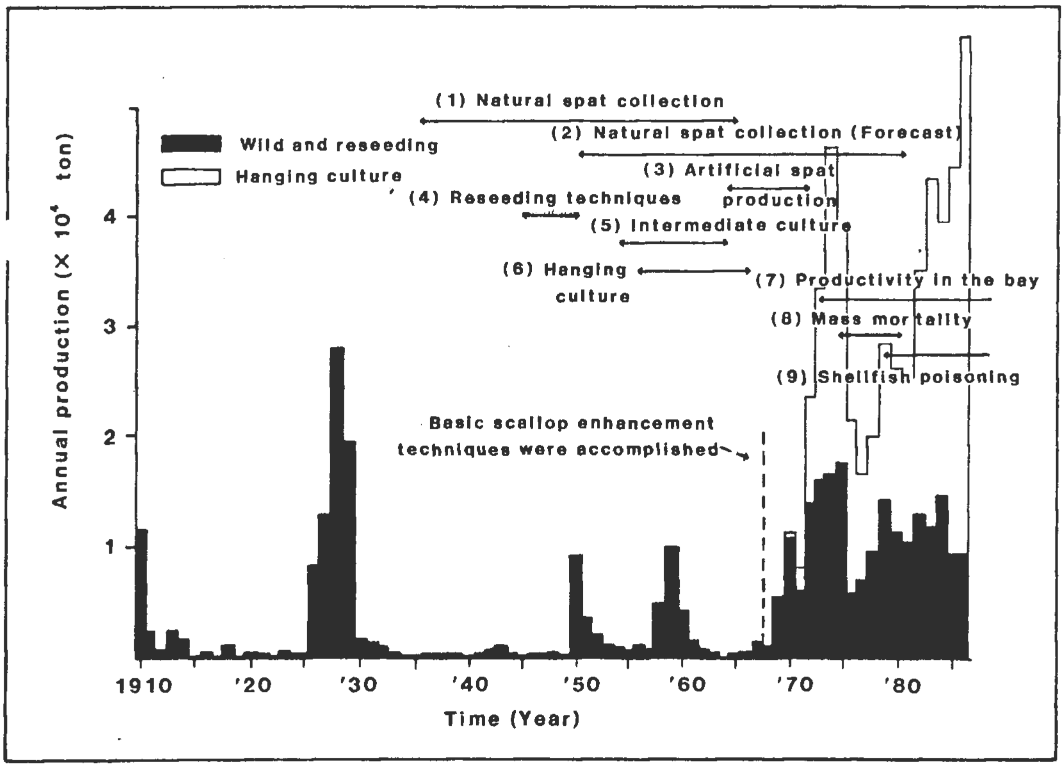

Figure 7. Annual scallop production and the history of technical development in Mutsu Bay.

In 1965 the basic techniques for scallop culture were known. During the following ten years production increased rapidly. In 1975, mass mortality and other problems arose. Research into these problems was intensified for several years, difficulties were gradually resolved and production recovered .

In the remainder of this paper, attention will be focused on:

1) Forecasting natural spat collection;
2) Reseeding techniques; and
3) Mass mortality.

The forecasting of natural spat collection

Figure 8 shows the seasonal changes in gonad index (G.I.) for adult scallops between 1980 and 1984. The period when G.I. drops is indicative of the spawning season. Therefore it is useful to survey G.I. in order to find the spawning period and an approximate measure of the magnitude of spawning from the relative change in G.I. Figure 8 also illustrates the spawning period and the scale of fluctuation in spawning magnitude between years.

The relationship between average water temperature for the three months from September to December (which is the period during which *P. yessoensis* gonads mature) and the number of days required for the G.I. to reach 20% in the following year is shown in Figure 9.

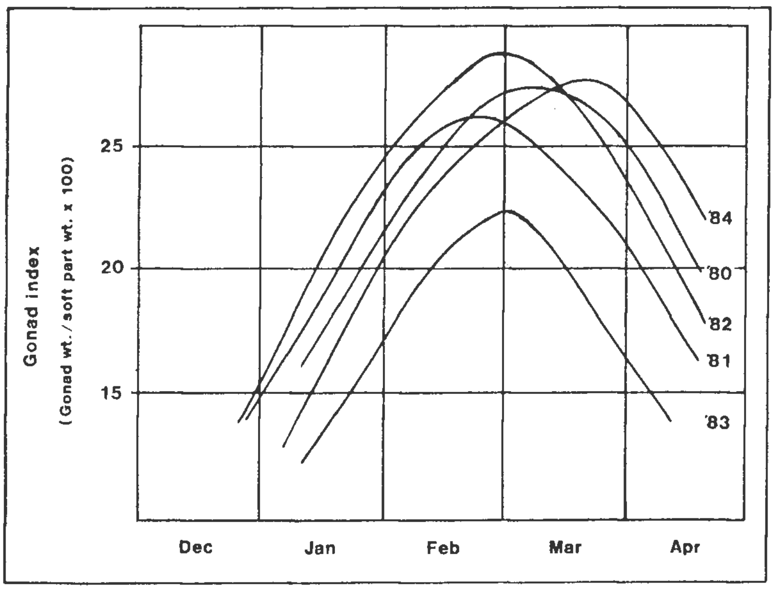

Figure 8. Seasonal changes in the gonad index of scallops in Mutsu Bay.

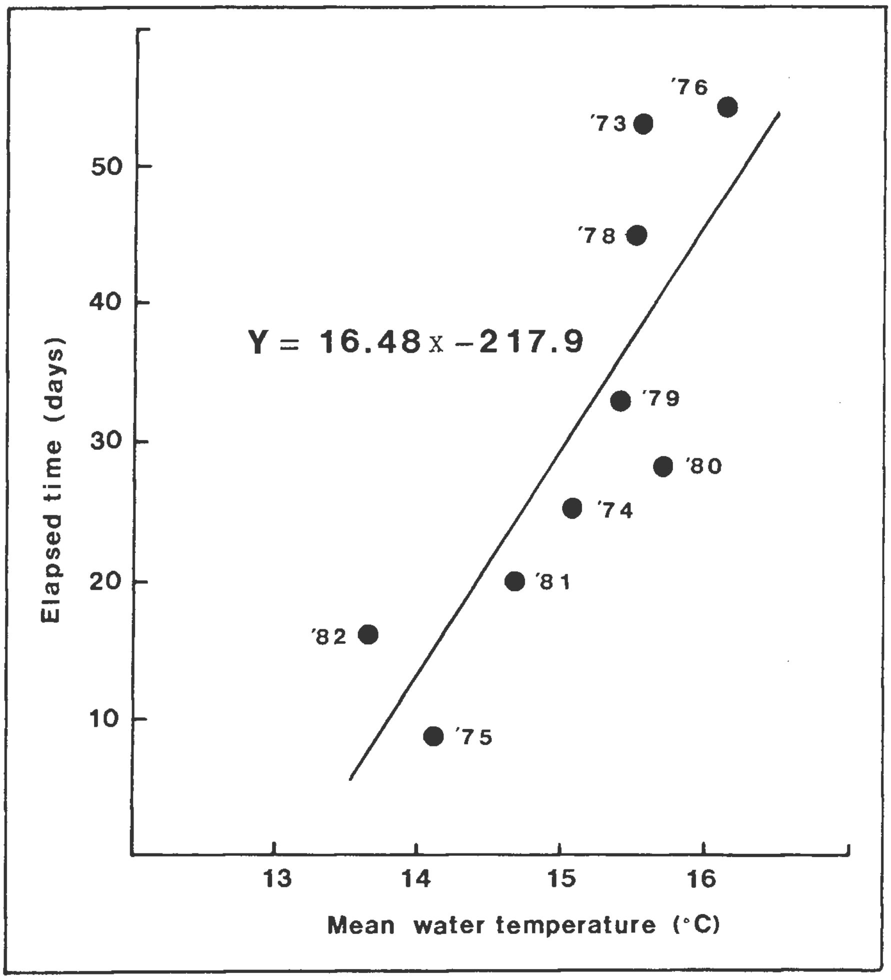

Figure 9. Relationship between mean water temperature and time taken for gonad index to reach 20 %.

Gonad development was faster in those years when the water temperature was lower during September to December. *P. yessoensis* spawns when the water temperature increases from between 4^{o} and 5^{o} C to 6^{o} and 7^{o} C. This phenomenon is called the critical temperature for spawning and usually occurs soon after the occurrence of the winter minimum water temperature in Mutsu Bay.

Figure 10 shows the change in scallop production and the number of spat per collector in Mutsu Bay since 1965. The maximum number of spat per collector increased when the scallop broodstock increased in number. There were years of poor spat catch despite the augmentation of the scallop brood stock. Other studies concluded that the water temperature in those particular years was not suitable for gonad maturation, spawning or the development of larvae.

In 1968 larval size and abundance was monitored at five day intervals in Mutsu Bay. The number of attached spat during this period was also monitored (Figure 11). According to the observations, maximum spat catch was obtained when 50% of the larvae reach 200 um (S.L.) or more (Kanno 1970). In Mutsu Bay, the final decision of when to deploy the collectors is made on the basis of larval size. In Nemuro Strait, surveys on the movement of a mass of water in which larvae are located is carried out. This method has been also been used successfully to decide where to deploy the collectors.

The Aquaculture Centre of Aomori Prefecture has deployed a Buoy-telemetering system to monitor water temperature, salinity, dissolved oxygen and water current from four different depths at three different locations in Mutsu Bay on an hourly basis. Spat settlement can be reliably forecast one month prior to its occurrence, using water temperature data received from this system and information on G.I. of spawning stock.

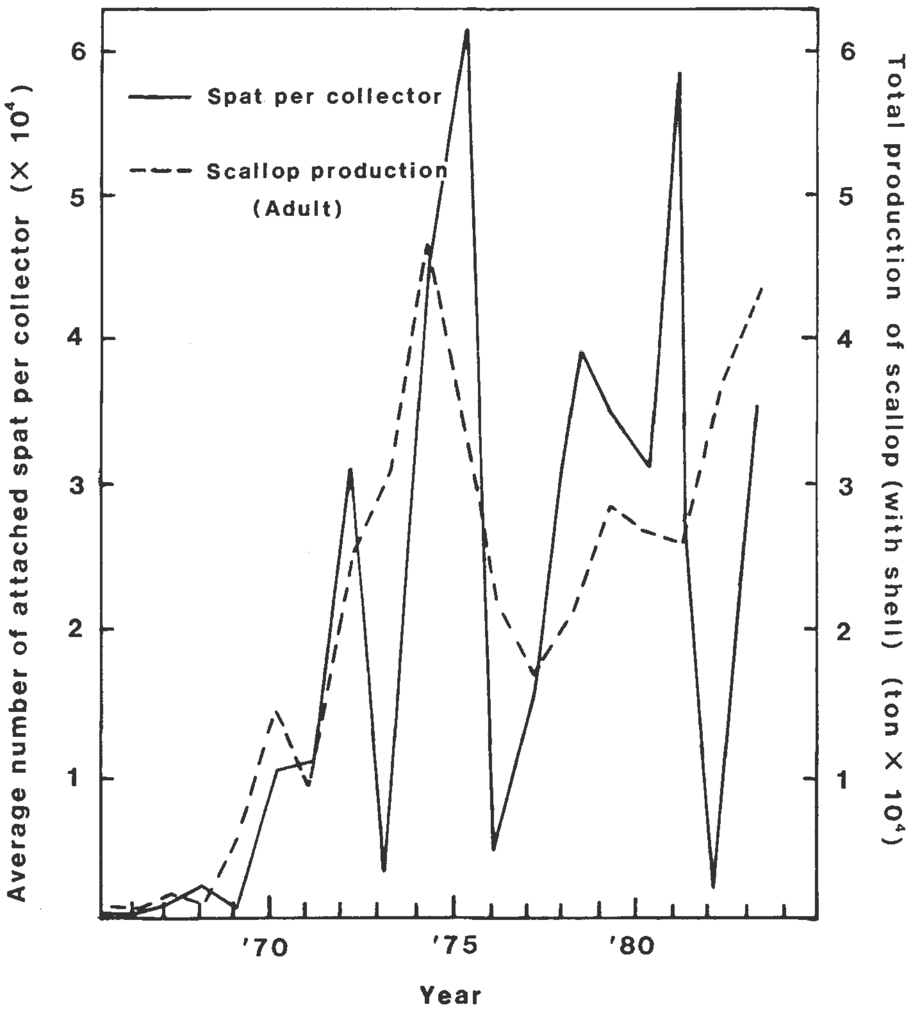

Figure 10. Average spatfall and total scallop production in Mutsu Bay.

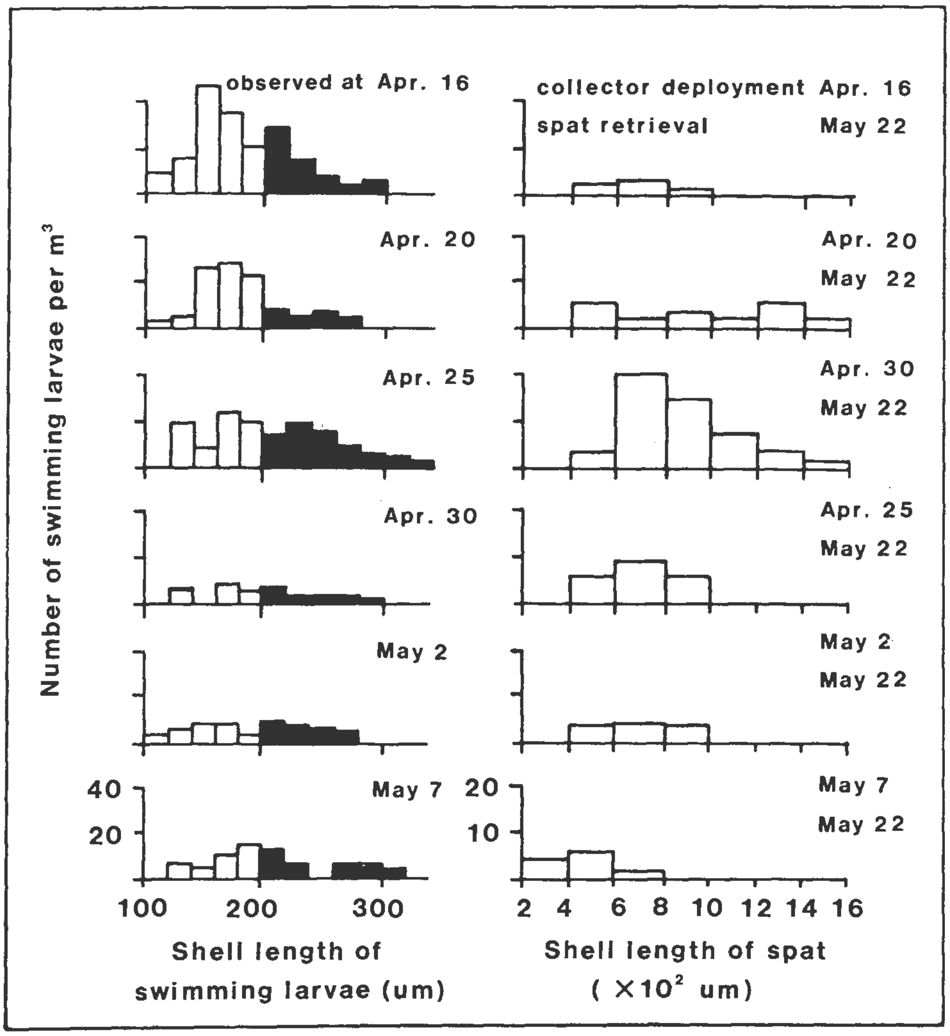

Figure 11. Number of swimming larvae found every five days and the number of spat attached to collectors.

The number of spat collection bags, the number of settled spat and the proportion of collected spat that were utilised in the period from 1967 to 1972 are shown in Table 1. The total number of spat taken using natural spat collection has exceeded 1,000 million since 1969. The rate of utilisation is consistently around 10%. There is no shortage of spat even in exceptionally poor spat collection years. The maximum number of scallops required for annual enhancement does not exceed ten million.

Larger spat are selected from the total spat collection for use in intermediate culture. Strict selection criteria are used for cultured scallops. Scallops are required to grow to a harvesting size (10 to 11 cm S.L.) in one and a half years after settlement, although in the past scallops took two to two and a half years to grow to this size. The repeated selection of large spat may have resulted in a genetic improvement of the scallop's growth potential but there is no conclusive evidence of this.

Table 1. Outlook of natural spat collection and utilisation in Mutsu Bay (1967-1972).

	1967	1968	1969	1970	1971	1972
No. of longlines for spat collection	228	683	1000	2049	2067	2144
No. of collectors x 10,000	10	30	58	151	249	206
Mean no. of attached spat per collector	1012	2039	405	10124	10782	31023
Total no. of spat collectors x 1,000,000	176	893	229	15725	38283	58024
No. of spat for reseeding x 1,000,000	52	324	150	1197	1531	469
No. of spat for hanging culture x 1,000,000	2	23	27	78	132	288
Total no. spat used x 1,000,000	54	347	177	1275	1,663	757
Rate of utilisation (%)	30.6	38.9	77.6	8.1	4.3	1.3
Scallop yield (tonnes)	1781	1125	5936	11770	8621	24003

Reseeding techniques

In the early days of scallop culture, spat ranging from six to eight mm S.L. were released directly onto the bottom from collectors. Survival rates from these releases were consistently low. To achieve a better survival rate, intermediate culture was introduced. Using this method, scallops are grown to about three cm (S.L.) and released onto the sea bed. The survival rate is between 30 and 40%. The appropriate reseeding density is less than five to six scallops m^2.

In the past, released three cm scallops never survived. This phenomena largely occurred as a result of mis-selection of suitable reseeding grounds. Yanamoto (1950) conducted benthic surveys in search of information to solve this problem. He divided Mutsu Bay into four faunal community areas on the basis of benthic animal distribution, and found *P. yessoensis* was a member of the faunal community in area IV (Figure 12).

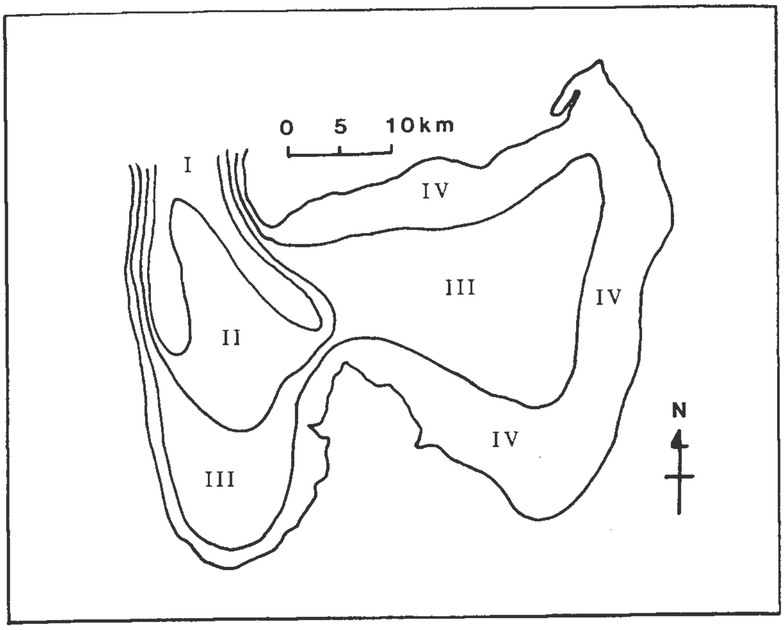

Figure 12. The benthic communities of Mutsu Bay. Area IV is suitable for scallop reseeding.

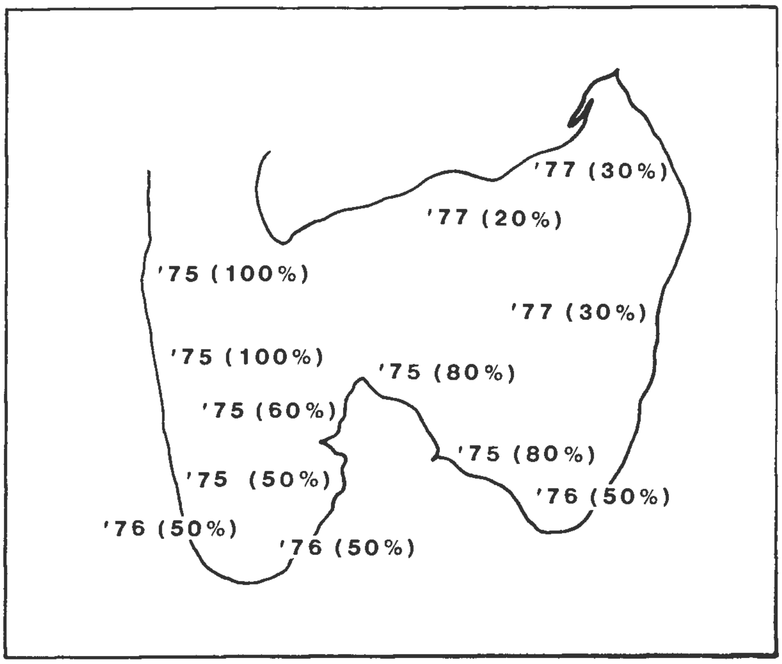

Figure 13. Peak year and maximum percentage mortality of scallops in Mutsu Bay.

Yanomoto recommended that future reseeding only take place in area IV. As a consequence of these studies there were less problems in attaining some scallop survival.

The scale of reseeding in any area is a major factor affecting the harvest. Reseeding becomes successful only on a large enough scale to diminish predation rates. In Mutsu Bay starfish are the major predators of three cm scallops. Scallops are not reseeded before starfish are removed by dredging. In the Sea of Okhotsk, the survival rate increased substantially when the quantity of reseeded scallops was increased to about 60 million from preliminary small-scale reseeding attempts. Small scale reseeding gave unsatisfactory survival rates.

Mass mortality

In Mutsu Bay, scallops grown in hanging culture from early summer to autumn in 1975 displayed the following symptoms:

1) Deformation of the shell;
2) Changes in the colour of the shell's inner surface; and
3) Abnormal growth of gonads.

This lead to the death of 80% of scallops and caused panic among the fishermen.

Mass mortality first took place at the mouth of the Bay and gradually spread to the inner area (Figure 13). It then occurred in different places one after another over the next fiv years (Figure 14). Mass mortality was believed to have been caused by either a virus an inflow of an abnormal water mass.

After careful research into the phenomenon it was discovered that scallops "bit" each other when placed in pearl nets at high density during intermediate culture. As a result the mantle edge of the scallop was damaged and its secreting gland (for shell making) was partly destroyed. Scallops became deformed because of their inability to secrete shell materials around the entire margin of the shell. The constant leakage of secretory fluid from the lesions results in a significant wastage of energy, scallop having open blood systems. Scallops in this condition invariably died. Rough treatment of scallops and wave oscillation also caused the biting problem.

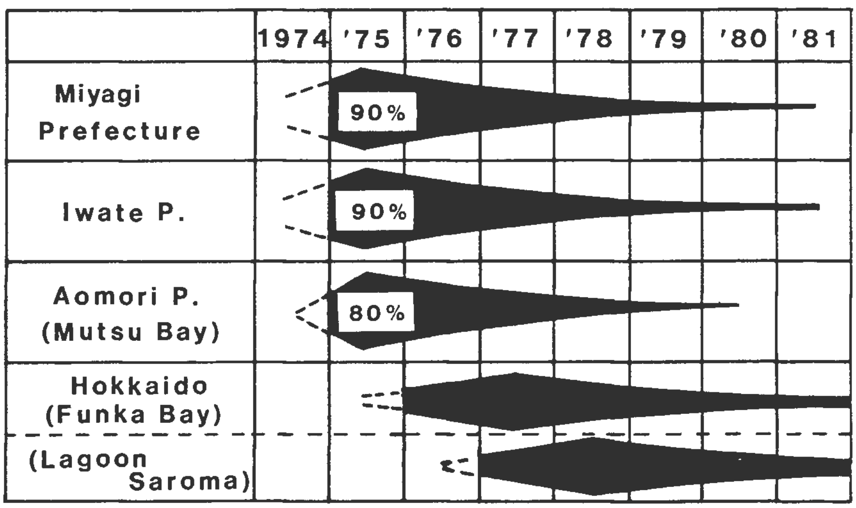

Figure 14. Period and rate of mass mortality in Japan.

Table 2. Required density of spat for hanging culture, intermediate culture and reseeding in Mutsu Bay.

	Intermediate rearing	Hanging culture
100 spat/pearl net year 1 July/Aug	20 spat/pearl net year 1 Sept/Oct	10 seed/level lantern cage year 2 Mar/Apr
	Intermediate rearing	Reseeding
100 spat/pearl net year 1 July/Aug	50 spat/pearl net year 1 Sept/Oct	6 seed/m^2 year 1 Dec

The Aquaculture Centre of Aomori Prefecture recommends intermediate culture and hanging culture using the densities shown in Table 2. This has prevented mass mortality.

We have sought to understand why the unusual mass deaths of scallops took place sequentially in different growing areas, in the manner of an epidemic. The answer appears to be associated with social and psychological factors. When scallop culture developed in a region, the number of fishermen engaged in the business increased and a competitive attitude emerged. As a result scallop culture tended to become too dense as the fishermen strove for higher production. When the competition became fierce, people tended to forget that scallops were animals and instead treated them as a commodity. In other words, they were seen as being merely a means for making money. This problem first occurred in the areas where scallops were first produced and gradually spread to other areas.

When we engage in scallop culture, we should not forget that a scallop is an animal.

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APPENDIX I

Stages of development in the Japanese scallop culture industry.

1. Natural spat collection gear.

   Between 1935 and 1965 there was continuous improvement of equipment used for the collection of natural spat. Initially, Japanese cedar (*Cryptomeria*) leaves were used for spat collection. The leaves were originally hung from a fence net but later, surface longlines and then sub-surface longlines were used.

2. Forecasting natural spat production.

3. Artificial spat production.

   From 1964 to 1972 the Aquaculture Centre of Aomori Prefecture pursued a feasibility study on artificial breeding of *P. yessoensis* in tanks. The results demonstrated that artificial breeding in tanks was less efficient than natural spat collection. Therefore this method was abandoned.

4. Reseeding techniques.

5. Intermediate culture.

   The first trial of intermediate culture, i.e. the grow-out of spat 6 - 8 mm S.L. to about 30 mm S.L., in a protected environment was done in 1955 using a wooden box with plastic mesh. Many improvements in cage design and the hanging method continued until about 1965 when the pearl net was introduced from pearl oyster growers. Still later, the multi-level intermediate culture cage was developed in Hokkaido.

6. Hanging culture.

   In about 1965 two types of hanging culture methods were designed for grow-out of scallops from 30 mm S.L. to market size. One technique was the lantern cage and the second, the ear hanging method. Other types of hanging culture cages were designed after this time but they were not successful.

7. Productivity in Mutsu Bay.

Since about 1970 farsighted people were apprehensive about the number of scallops produced in Mutsu Bay. Scallop growth rates had been observed to decrease as scallop numbers increased.

The Aquaculture Centre of Aomori Prefecture research chlorophyll production in the Bay during 1972-5. The results demonstrated that Mutsu Bay could only sustain about 90 million scallops per year in the enhancement project. They therefore insisted that an excessive increase in scallop culture must be prevented. The majority of scallop growers did not accept this ruling and thus mass mortality has occurred since 1975.

Mass mortality.

9. Shellfish poisoning.

In 1979 shellfish poisoning resulting in diarrhoea was attributed to scallops produced in Tohoku Region, including Mutsu Bay. The cause was found to be an accumulation of poison from scallops consuming a planktonic dinoflagellate *Dinophysis forti*. The Aquaculture Centre has continued to monitor toxin levels in scallops and the plankton.

ONGROWING SCALLOP CULTURE IN TASMANIA

Derek A. Cropp
Department of Sea Fisheries
G.P.O. Box 619F, Hobart
Tasmania 7001.
Present address: Western Sea Farms
Carnarvon W.A 6701.

Abstract

A wide array of methods for culturing scallops (Pecten fumatus) from settled spat up to harvest is presently available. Some suffer from high equipment and operating costs and others from high mortality and low growth rates for the scallops. This paper examines some methods of growing scallops from settled spat to marketable size.

Introduction

After several years of research by Department of Sea Fisheries (DSF) staff, methods for successful collection of naturally occurring scallop spat (using mesh-filled bags) have been developed. Concurrently, research into hatchery techniques for rearing scallop spat resulted in small numbers of scallops being produced. There was a subsequent requirement to develop efficient and economically viable methods of culturing juvenile scallops up to a marketable size.

The type of ongrowing equipment and/or handling methods is largely influenced by the size at which scallop spat are available. This tends to determine when and at what size spat are transferred to the next step in ongrowing culture. Scallop spat are seasonally available in Tasmania from either natural spawnings at sea or hatchery production. It is hoped that hatchery production will eventually be extended to supply spat throughout the year, through conditioning broodstock. Growth of scallop spat obtained in mesh collectors and subsequent ongrowing is examined.

Spat collectors

Spat have been successfully obtained in recent years using large mesh collecting bags. The bags, woven black plastic sacks (60 x 90 mm) with a mesh size of 4-5 mm, were stuffed with about six metres of old (hardened) monofilament shark mesh netting and tied at the mouth with two to three metres of tarred twine. They were then termed collectors (Cropp 1985a). This style bag has been deployed on sub-surface longlines at various sites in Tasmania since 1982. A site in Mercury Passage, near Maria Island (Figure 1) was sampled consistantly.

Once larvae from a hatchery or wild source settle in these collectors they usually remain attached by byssal thread until they are six to ten mm in size (Hortle and Cropp 1987).

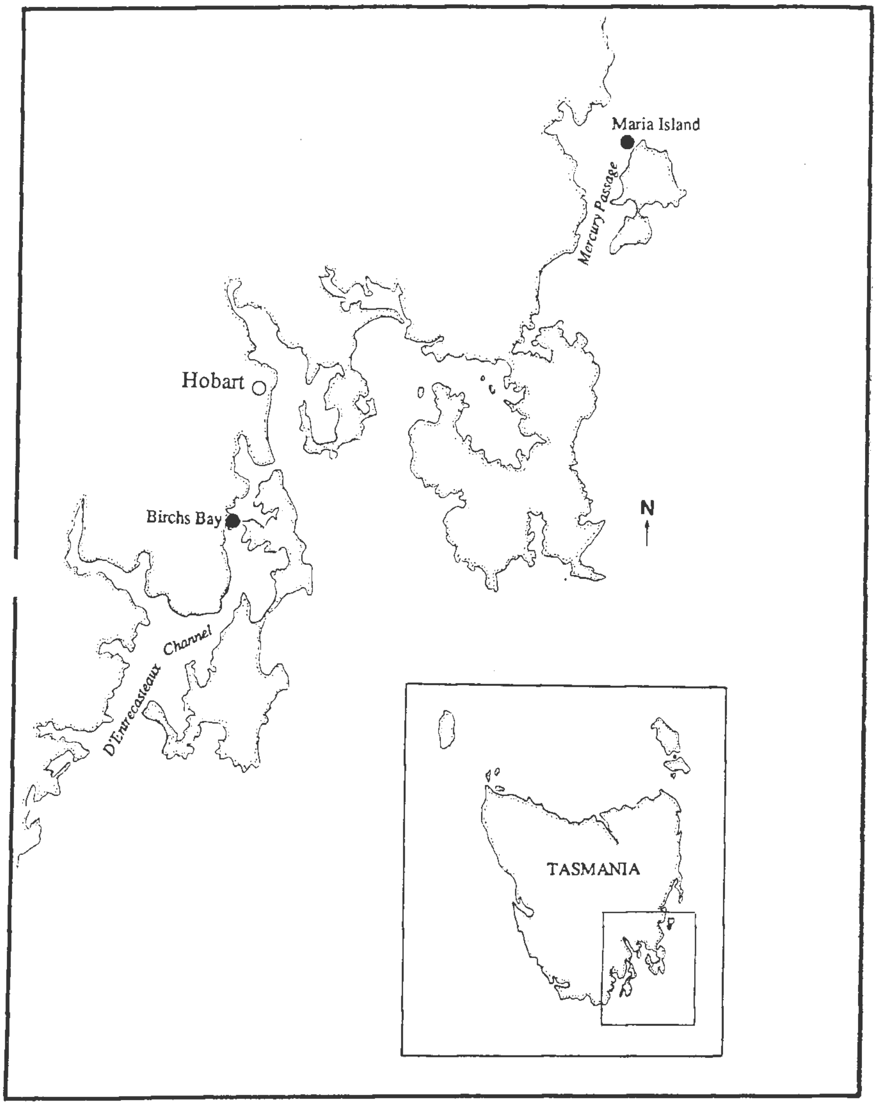

Figure 1. Location of ongrowing sites on the east coast of Tasmania.

A number of factors need to be considered when determining how long spat can be left in collectors before being removed.

(1) Growth of spat may be limited if numbers in each collector are high. After three months, scallops in a collector containing 2,000 spat were at least two mm smaller than scallops in a collector with 500 spat.

(2) Previous research showed that larger spat had a higher survival after reseeding than smaller ones.

(3) The level of ascidian settlement in collectors is an important factor and requires monitoring. In collectors deployed at offshore sites ascidians have usually settled in collectors at the same time as scallops settled. As the ascidians grow on the mesh substrate they restrict the water flow in collectors and can deform or crush juvenile scallops. Spat must be removed from the collectors before this situation occurs.

(4) Fouling by algae and encrusting organisms also reduces the water flow through collectors. As fouling increases, growth of scallops slows.

Several years of experience in growing spat has demonstrated that ascidians are the major factor affecting when spat should be removed from collectors. During one year when ascidian settlement was limited, spat were left in collectors for up to eight months and a size of 35-40 mm was attained. Over this period, water temperatures were reasonably high and growth was up to 1.5 mm/week. In most years however, fouling was sufficiently heavy that spat had to be removed from collectors after five months in the sea. Spat were then 15-30 mm in size with a mean of 22 mm. At this size, spat were easily sorted, graded for size if necessary, and placed into the next stage of culture.

Spat collection trials began in 1982 using small netlon collectors. As larger numbers of spat were required, larger spat bags were used. The mean annual spat catch per collector assessed in late March-early April has shown a dramatic decline in recent years. During the 1987/88 season, as in 1982/83, a distinct second settlement of spat was observed (Figure 2). In 1987/88, the second settlement was more numerous than the first. Collectors deployed in September 1987 produced seven spat per bag, while those deployed in November and December yielded 72 and 178 spat per bag respectively. This illustrates the necessity to deploy collectors as close to the time of major settlement as possible. Accumulated fouling restricts settlement and survival of spat.

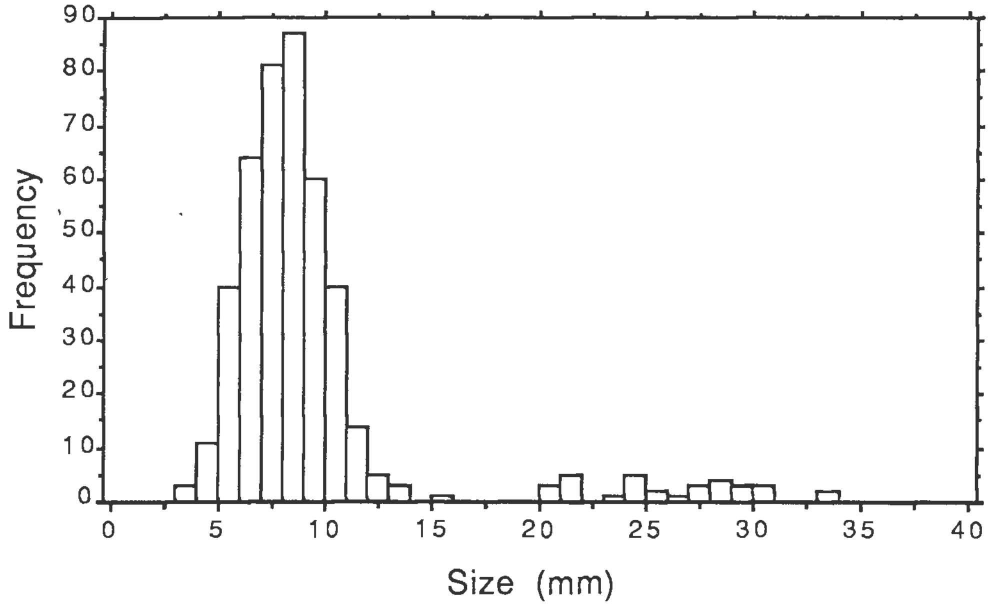

Figure 2. Length frequency of spat from three Mercury Passage droppers deployed in September 1987.

Hanging Cage Culture

Scallops can be reared in mid-water cages after being removed from collectors. In Tasmania, scallops have been grown through to a size of 90 mm shell-width using Japanese pearl nets and lantern cages. These cages were suspended at a depth greater than six metres on sub-surface longlines. Trials were conducted in Mercury Passage in depths of 30 m and in Birchs Bay in a depth of 10 m (Figure 1).

Better growth rates were obtained at the offshore site at Maria Island than at the ıeltered inshore site at Birchs Bay. The cages and scallops at Birchs Bay were heavily fouled. Algal fouling of the lantern cages at Birchs Bay impeded the flow of water, shown by the accumulation of faecal material and silt. This has previously reduced growth rates of bivalve species (Walne 1972; Leighton 1979).

Scallops at Maria Island showed no significant difference in either size, whole weight, meat weight or percentage recovery at different depths (Hortle and Cropp 1987). Greater variance in growth rates and meat weights may have been observed if trials had been conducted over a wider range of depths (Hortle and Cropp 1987).

Temperature variation between the two sites may also have affected growth rates. Previous studies (Walne 1972; Kirby-Smith and Barber 1974; Leighton 1979) have shown that the growth rate of scallops is positively correlated to temperature. Higher summer and lower winter temperatures have been recorded at Birchs Bay than those at Maria Island. Such temperature differences may have led to reduced metabolic rate of the scallops at Birchs Bay and therefore the reduced growth rate (Cropp 1983).

The mortalities observed at the two sites were much lower than recorded by Dix (1981). Dix attributed high mortalities to heavy fouling, but may instead have been due to the high densities used in his experiments.

Duggan (1973) showed that increased density in this type of culturing severely impaired growth and survival rates. Survival generally decreased with time (Table 1) but survival remained above 90% at both sites. Although the cages at Birchs Bay were fouled, scallop survival was approximately equal to that at Maria Island, indicating that densities were below a critical level.

Table 1. Survival figures over various time periods for scallops grown in midwater cage culture at two sites.

Location	Dates		Days	No. Scallops		Survival
	Start	Finish		Start	Finish	
Maria Is.	19.05.83	12.07.83	241-295	518	518(351*)	100(67.8)
	24.10.83	23.11.83	399-428	210	209	99.5
	12.07.83	19.01.84	295-486	70	65	92.9
	31.08.83	21.02.84	345-519	206	202	98.1
Birchs Bay	27.01.83	10.03.83	128-170	432	411	95.1
	27.01.83	26.05.83	128-247	432	397	91.9
	24.02.83	25.03.83	156-185	140	140	100
	24.02.83	26.04.83	156-217	1707	1648	96.5
	26.05.83	25.08.83	247-339	257	252	98.1
	27.07.83	16.09.83	300-361	78	77	98.7
	26.04.83	27.07.83	217-310	430	412	95.8
	25.08.83	11.01.84	339-478	206	199	96.6
	11.01.84	06.04.84	478-563	71	68	95.8

Zacharin (1985) found wild scallops with meat weights of 13 to 18 grams per scallop in a survey of waters north-east of Tasmania. He described those scallops as having ripe gonads and flesh in excellent condition. The scallops ongrown at Maria Island had a mean meat weight of 13.7 g (range 11-18 g), suggesting that midwater cage culture can produce scallops of similar quality to those produced in the wild fishery.

The growth rates observed in this study are comparable to those recorded by Dix (1981). He found that scallops would reach harvestable size within 18 to 20 months but suggested that mortality was too high for the culture of scallops to be economically viable. From results obtained in this study it appears that hanging cages could be used to successfully culture the Tasmanian commercial scallop *Pecten fumatus*. This method of culturing scallops has not been economically feasible due to the high cost of imported materials and labour (Cropp 1985b; Cropp 1987). However, if the value of landed scallops remains at the prevailing prices, this may change. In addition, alternative cage designs and cheaper construction methods could be used; these might improve economic viability.

Tape Culture

Another form of hanging culture that may prove to be viable here is tape culture. The tapes hold scallops glued back to back on polypropylene packing tape. Early investigations did not find a suitable glue that set rapidly on wet surfaces. Initial experiments showed growth rates of taped scallops were similar to scallops in cage culture (Table 2).

The tape system is similar to the ear hanging method employed in Japan - a successful but very labour intensive method.

Reseeding

In Tasmania scallops have been grown through to 90 mm in shell width on the seabed, in an enclosed trial area of 21.2 m^2 at a final scallop density of 10 per m^2 (DSF unpublished data). Scallops attained a shell width of 80 mm at an age of approximately 550 days, 250 days after release. These scallop attained an ultimate mean width of 93 mm and meat weight recovery was 19% of total weight, or 18.8 g/scallop (Figure 3).

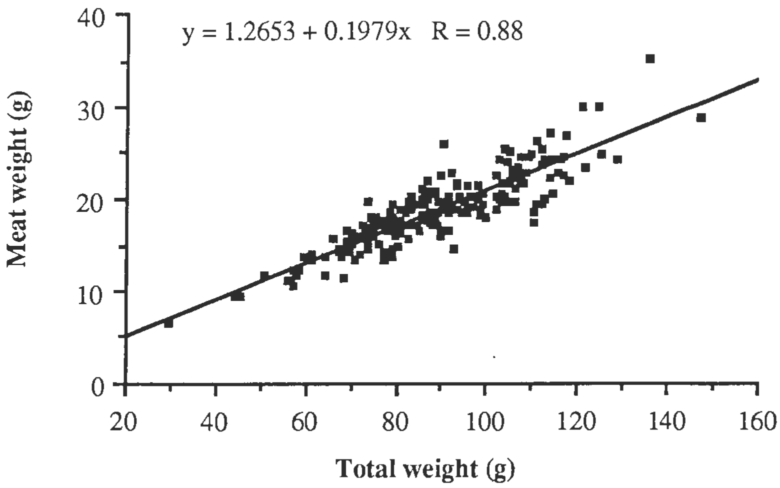

Figure 3. Relationship between total weight and meat weight

These results were obtained in an area where the scallops could not escape and where predatory starfish (*Coscinasterias calamaria*) were removed on a regular basis. In excess of 20% of the scallops released were recovered alive.

The movement of starfish into reseeded areas has been examined over a three-year period (Figure 4). Starfish were collected by divers at regular intervals. The presence of scallops appears to have attracted starfish to the reseeded area as starfish density increased on reseeded patches.

Floating Upweller System (FLUPSY) Culture

FLUPSY is the acronym for a Floating Upweller System, a barge-like platform usually constructed of aluminium. Water is pumped through holding bays via a central channel using propellers. The propellers are driven by hydraulics powered by an electric motor. The FLUPSY used for these trials had 14 compartments measuring 90 x 90 cm. Water passing through the FLUPSY was pumped from 0.5 metres below the surface.

Juvenile scallops used in intermediate culture trials were obtained from spat collectors in Mercury Passage during September 1984. Spat were sorted from collectors at the end of March 1985 and transferred, in water, to the FLUPSY situated at Dunalley on Tasmania's south-east coast.

Scallops were distributed through the 14 bays at high densities. The FLUPSY flow rate was maintained at 600 litres per minute. Three size-groups of scallops were sorted prior to their placement in the FLUPSY:

Group A : Mean size	16.38 mm;	standard deviation	2.55
Group B : Mean size	22.54 mm;	standard deviation	2.54
Group C : Mean size	33.94 mm;	standard deviation	4.10

Group A animals were stocked at densities ranging between 6,800 and 11,500 per bay. Group B animals were stocked at densities ranging between 3,700 to 6,600 per bay, and Group C scallops at 1,500 (one bay only). Growth and survival rates during a 16 week period from March to July are shown in Table 3.

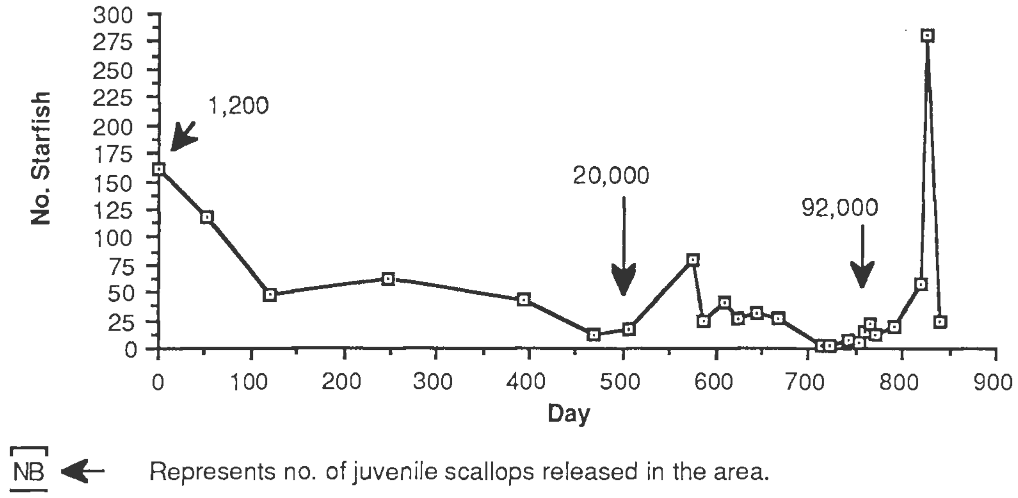

Figure 4. Number of starfish removed from 50 x 50 m area seeded with scallops

The initial stocking density in the FLUPSY clearly influenced the scallop growth rate (Figures 5, 6 and Table 3). Survival for the small Group A animals was not affected by these . ɜh densities. However, when similar densities were used for the larger Group B animals, a reduction in growth rate and survival occurred (Figures 6 and 7).

Compared with the growth of similar-sized scallops at sea, growth in the FLUPSY was poor (Cropp 1985b; Hortle and Cropp 1987). Water temperature has an effect on growth rate for scallops at sea (Leighton 1979), growth being correlated with increasing temperature. The temperature range inside the FLUPSY would probably have adversely affected growth rates (Figure 8).

Table 2. Growth of 0+ scallops in various forms of culture

Culture Method	Depth (m)	Site	Growth (mm/wk)
Glued to tapes	10	Mercury Passage	1.73
Glued to tapes inside cages	10	Mercury Passage	1.53
Pearl Nets	10	Bicheno	1.37
Collectors	10	Mercury Passage	1.36
Upwellers	-	Bicheno	0.69

Table 3. Growth and survival of scallops at varying densities in the FLUPSY

Bay	No. Scallops	%Occ.	Growth(mm/wk)	Survival	Final % Occ.
Group A					
01	11,500	361.4	0.045	97.83%	315.4
04	7,400	232.6	0.142	97.16%	279.0
09	6,800	213.7	0.235	97.79%	312.2
Group B					
03	4,600	257.1	0.101	96.96%	261.8
10	4,100	229.1	0.150	95.73%	234.2
11	3,700	206.7	0.173	98.78%	221.6
12	4,000	223.5	0.153	96.68%	230.7
13	4,000	223.5	0.157	97.83%	233.5
14	6,600	368.8	0.041	90.91%	340.9
Group C					
08	1,500	188.6	0.216	98.67%	229.7

(% Occ. = Percentage of surface area available, 8,100 cm^2 that was occupied by scallops)

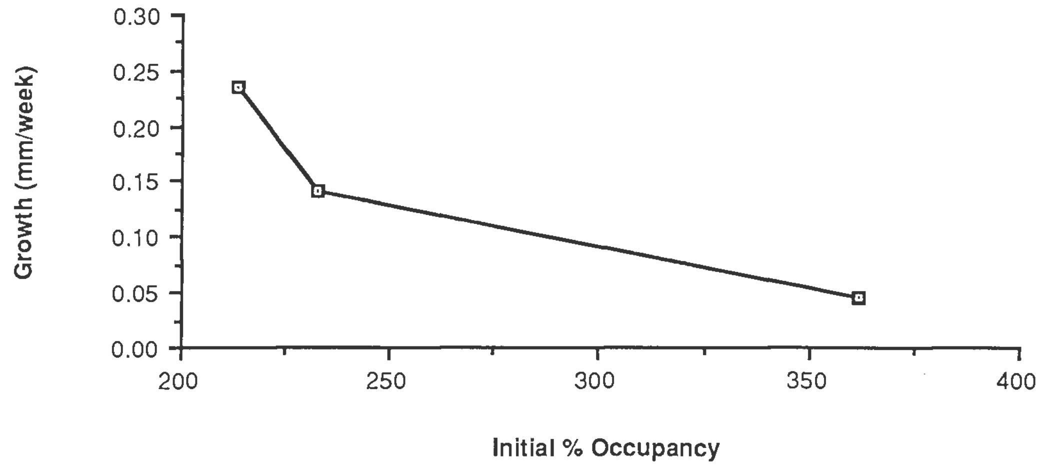

Figure 5. Growth of Group A scallops at varying densities

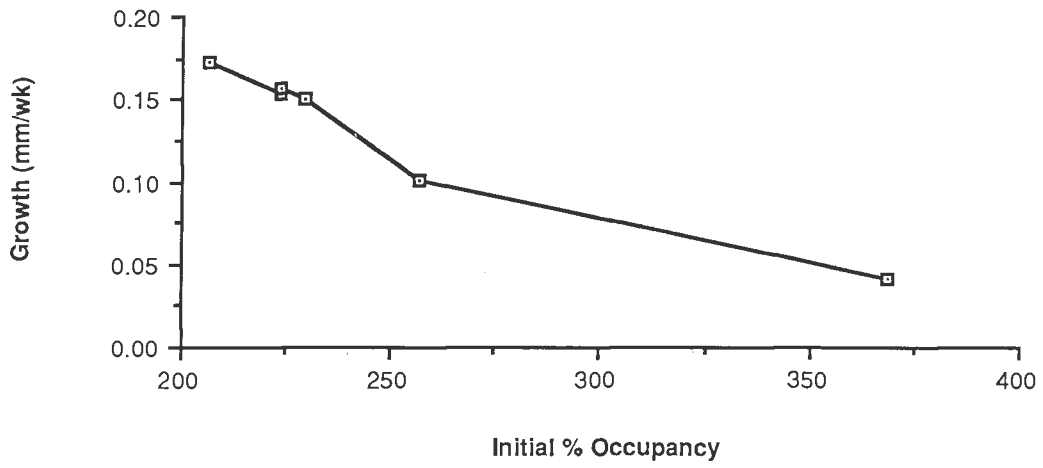

Figure 6. Growth of Group B scallops at varying densities

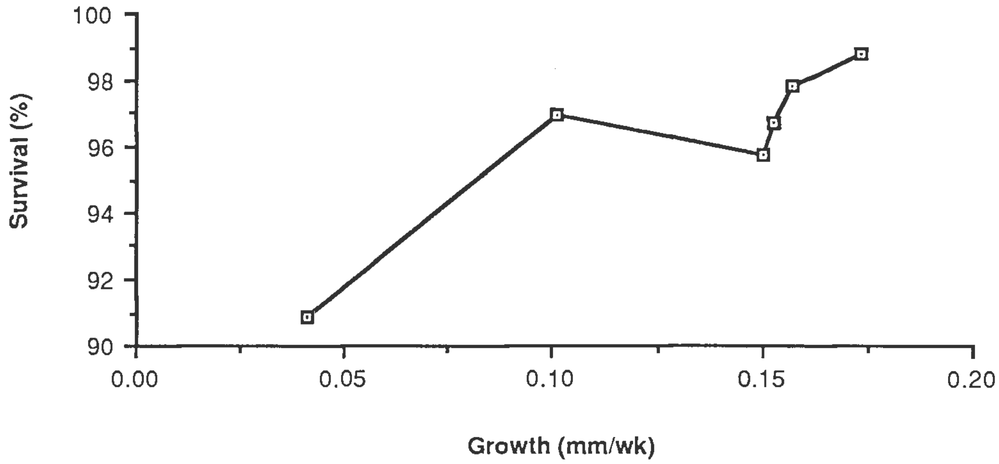

Figure 7. Growth and survival for Group B scallops

Note that the large Group C scallops recorded the second highest growth and survival rate while percentage occupancy was the lowest in the trial.

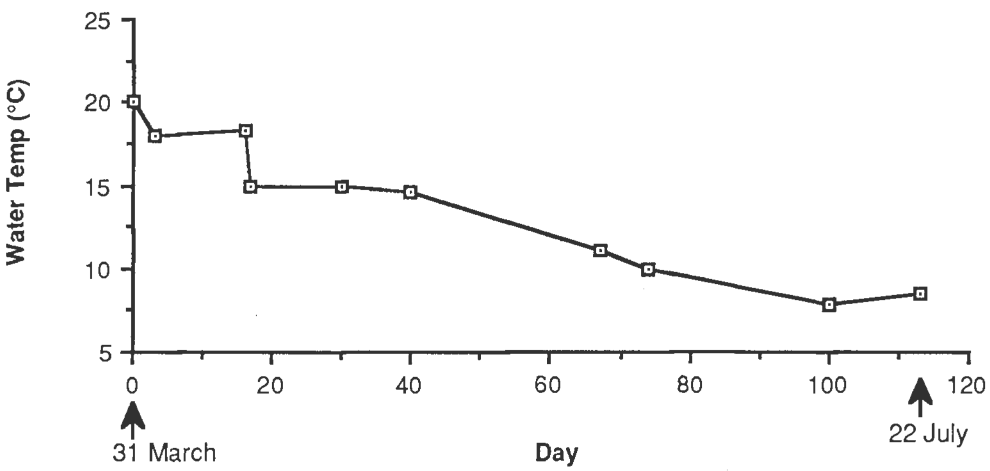

Figure 8. Surface water temperature inside the FLUPSY

High stocking rates were employed during FLUPSY trials as the maximum carrying capacity of the system was to be assessed. The FLUPSY cost approximately A$0.20 per hour to run at a flow rate of 600 litres per minute. A high survival rate was recorded but the growth rates were poor compared to scallops in hanging culture.

An improvement in growth rate may be possible if natural algae is supplemented or bloomed artificially (Pratt 1949).

A smaller upwelling system can also be used but density effects are still restrictive. This form of culture requires a high water flow or increased food levels to produce satisfactory results. If the price of scallops continues to increase then it may useful on a large scale as an intermediate form of culture; it is not a long-term culture method.

Conclusion

Scallop culture research in Tasmania has been aimed at establishing an economically ɹble methodology. Information gained from some of the work mentioned in this paper has shown us that for intermediate or ongrowing culture scallops prefer good water movement, protection from starfish, low densities of individuals and minimal fouling.

Culture of scallops in a mid-water situation tends to produce better results than sea-bed culture although different problems and costs must be considered.

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GENERAL DISCUSSION

Gwyther: Would you care to speculate on how many longlines can be put into a body of water before they become too dense and there is insufficient food in the water to support scallops on them ?

Cropp: We don't have the number of scallops to consider that aspect yet. In the open sea we've had scallops in collectors at very high density and in close proximity and as yet I've seen no effects which I could relate to overstocking in that body of water.

I can imagine that the effects of excessive density might occur in enclosed waterways such as the D'Entrecasteaux Channel where water flow is not so good. Oceanic areas like Maria Island should be able to take a lot before crowding occurs. The natural phytoplankton levels are high, the water deep and by spacing longlines 50 m apart, I don't anticipate any problems.

Bell: Do you have any growth rate data for caged scallops ?

Cropp: Growth to an extent is density-dependant. In trials where densities were 250% of cage surface area, or where scallops were stacked two and a half deep, growth was slower than when densities were lower.

Bell: What densities were in the cages when you conducted growth studies ?

Cropp: For lantern cages, scallops initially covered 33% of cage surface area and were taken out once percentage cover reached 75%.

Bell: Was that the density in the trials at Maria Island and Birchs Bay ?

Cropp: Yes. By the end of the experiment the density cover was as high as 100%.

COST COMPARISON OF HATCHERY AND NATURALLY PRODUCED SPAT FOR THE SCALLOP *Pecten fumatus* REEVE

*Derek A Cropp and #Ken R Frankish

*Department of Sea Fisheries
G.P.O. Box 619F, Hobart
Tasmania 7001
Present address : c/o Western Sea Farms
Carnarvon W.A 6701

#Tasmanian Shellfish Co.
Dunalley, Tasmania 7177

Abstract

Recent advances in hatchery technology have resulted in the production of small quantities of commercial scallops. An assessment of the costs involved in this work has been used to produce an economic analysis for the projected production of 15 million eyed scallop larvae which could be settled onto spat collectors and then ongrown. Scallop spat obtained from collectors placed at sea is shown to be more expensive. Wild spat collection in close proximity to an established scallop population may well be economically viable in future. If the high market value of scallops is maintained, then hatchery produced spat could enable a new aquaculture industry to develop.

Introduction

The dramatic decline in Tasmanian catches of commercial scallops (*Pecten fumatus*) has resulted in rapid price rises and the present high market value of scallops. As a result, the potential for scallop culture to become economically viable has increased markedly. Catching naturally occurring scallop spat in Tasmanian coastal waters is currently difficult due to low broodstock numbers and an alternative method of obtaining spat for ongrowing is necessary.

This paper examines the cost of producing spat of the commercial scallop *Pecten fumatus* either in a hatchery or by collection of naturally occurring animals. Hatchery work summarised in this paper was conducted at several commercial oyster facilities in south-east Tasmania.

After implementing new technology and personal overseas experience gained over several years, five batches of larvae (to date) have been successfully reared through the crucial period of metamorphosis to settlement. The most recent and largest of the five batches was reared in February 1988 and produced 400,000-500,000 spat at settlement. Research at the Tasmanian Shellfish Company (TSC) resulted in significant improvements in the survival of larvae, reduction in the duration of the larval phase and an increase in the percentage of eyed larvae setting. These are all important factors in reducing the end cost of scallop spat.

The potential of collecting naturally occurring scallop spat in Tasmanian waters was investigated in the 1970s by Dix (1981) using technology adapted from Japan and Europe (Paul *et al.* 1981). Although only a low level of success was recorded, his work was still encouraging as the site chosen was not in close proximity to a bed of scallops. Subsequent work from 1982-86 (Hortle and Cropp 1987) proved to be highly successful considering the low numbers of breeding adults (indicated by dredging trials) in the collection area. A maximum catch of 1,120 scallops was obtained in one collector with an average (assessed in March/April), for all collectors deployed, of approximately 400 in 1984, 1985 and 1986. The catch averaged 159 scallops per collector in 1987 and initially appeared to be 7 for 1987/88. However, a late second spatfall in January 1988 produced a mean of 178 scallops per collector (Cropp 1988). If scallop enhancement proceeds without interference then it is expected that the spat catch will improve in future years as the local scallop population increases, much as it did in Mutsu Bay, Japan (Ito *et al.* 1975) where catches rose from 200 per collector to 44,000 per collector in six years.

Longline designs used during research have improved each year. Gear and techniques now employed are described briefly, both for hatchery reared and natural spat. The collectors used for settlement of spat are the same in both situations. They consist of a mesh onion bag or gunny sack packed loosely with old (hardened) shark netting and tied with twine at the top (Cropp 1985). Investigations are already underway to develop and produce (in Australia) a new type of mesh collector based upon those used in Japan (Ito *et al.* 1975).

In this paper, the methodology and costs necessary to produce 15 million larvae up to the setting or eyed stage are examined. Growth, mortality and settlement rates are all predictions based upon previous culture of small numbers of larvae and spat. An equivalent cost model for production of spat from natural stock using spat collectors is also given, and the two have been compared. Application of the figures to future developments should be done with caution as there is considerable potential for variation in costs.

Hatchery Culture

Introduction

Techniques and equipment detailed in this report have all been trialed during hatchery research. The largest artificial spawning of scallops in Tasmania produced 125 million eggs but no hatchery in Australia has yet produced more than 500,000 settled spat from one batch of larvae. This report details the methodology and costs necessary to produce 15 million larvae, up to the setting or eyed stage. It is anticipated that 100 million fertilized eggs would need to be produced per spawning (day 0), from a minimum of 30 broodstock (greater than 70 mm in height), conditioned and spawned on-site, to have 15 million eyed larvae remaining at day 19 (assuming a mortality of 85%). This number of eyed larvae would be required to produce the target of one million spat of 10-15 mm shell height.

Algae would be cultured in carboys to feed the larvae and in bags for the broodstock. Algae from carboys would also be used for settled spat in the larvae tanks. It is intended that the polyethylene mesh bags for spat collecting (Cropp 1985) would be placed in the larvae tanks as a settlement substrate for the scallops. After a settlement period of up to 7 days the collectors would be transferred to a longline for ongrowing.

All labour in the hatchery has been evaluated using a wage of A$12 per hour. The contract labour used for construction of collectors and longline is costed at A$10 per hour. Labour on both operations involves a normal working day of nine hours.

Costs of the Proposed Hatchery

An established and operational hatchery similar to that shown in Figure 1 is available for lease to carry out scallop spat production. The lease cost of the facility is assumed to be $2,000 per month or $65.75 per day. Capital costs for such a facility are shown in Appendix 1. All costings are relevant to the year 1988.

Algae Culture

Algae start-up

Axenic starter cultures are necessary for initiating the growth of algae. These were available free from the CSIRO Division of Fisheries in Hobart, but now cost approximately $30 per 250 mL inoculum.

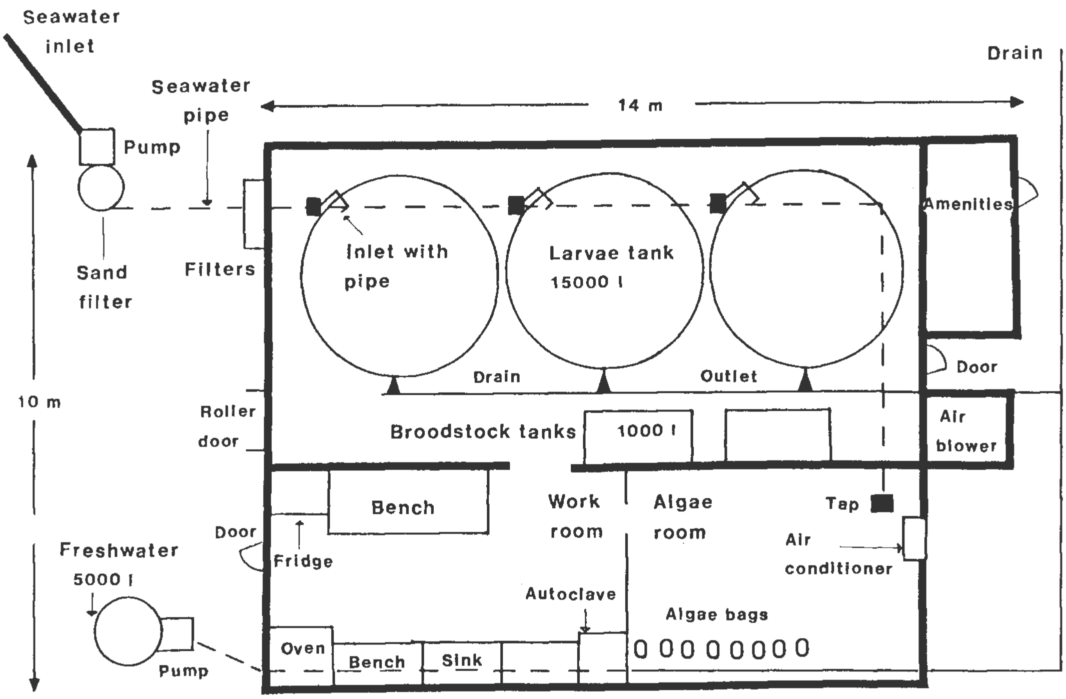

Figure 1. Proposed scallop hatchery layout

The costs shown in Table 1 include the purchase of four algae cultures plus postage. The diatom algal species that would preferably be used are *Chaetoceros calcitrans* (*C.c.*) and *Thalassiosira pseudonana* (*3H*). Two other preferred species are the golden brown flagellate Tahitian *Isochrysis* aff. *galbana* (*T. iso.*), and the green unicellular *Nannochloris atomus* (*Nanno.*). Several of these cultures should be held in reserve in case they are required at a ter date.

Four species of algae are cultured in stages in 250 mL, 500 mL and 5 L flasks, of which only three of the species are selected to be grown through to the 23 L carboys. The selection will depend on the relative condition and growth rates of the cultures. Satisfactory cell counts in carboys (autoclavable transparent polycarbonate flasks with a small mouth) are: *T. iso.*, 8,000 cells/µL; *Nanno.*, 25,000 cells/µL ; *C.c.*, 20,000 cells/µL ; *3H* , 15,000 cells/µL. When the algae have attained their respective densities they can be fed to the larvae (or broodstock if necessary). As single species diets do not provide all nutritional requirements a selection is used. When bag culture of algae is initiated it is necessary to use a 5 litre flask to inoculate each bag.

Table 1. Algae preparation costs

Item	Cost ($)
Labour (2.5 hrs/day for 18 days at $12/hr)	540
Electricity for pumps, aeration, lights, air conditioning and autoclave	88
Starter cultures (4)	150
Nutrients	8
Plastic bags	21
Filters	30
Carbon dioxide (CO_2)	32
Miscellaneous	20
Total	889

Large scale algae culture should only be commenced when the broodstock are approaching spawning condition, about two weeks prior to the projected spawning date. All aspects of algae culture are relatively expensive hence wastage of algae needs to be minimized. The nutritional value of the algae is dependant on age and varies between species (Whyte 1987; Helm and Laing 1987) and is an important factor affecting the growth and survival of the larvae (Laing 1987). Maximum benefit is obtained if algae is fed to the larvae when it has a high nutritional value (high lipids and polyunsaturated fatty acids) - as well, this often corresponds to a low level of bacteria. Older algae can be fed to juvenile or adult scallops as they are able to cope with poorer quality food than larvae.

Algae preparation (start-up) costs are detailed in Table 1 with all labour (not only algae culture) in the hatchery evaluated using a wage of $12 per hr for a normal working day of nine hours. Regular backflushing and maintenance of the sand filter is essential but is included as a labour cost at other stages. The algae room of the proposed hatchery has a capacity of 8 x 420 L bags. One bag of usable algae can be produced each day provided all operations proceed as planned; this is sufficient for scallop culture as detailed. Provision has been made for an electric blower to provide an air supply.

Algae culture prior to broodstock conditioning (day 0-18)

For conditioning of broodstock, two algal species (one flagellate and one diatom in bag culture) should be sufficient. The labour time required to prepare the algae system is 18 days (after the cultures are received) at two and a half hours per day. It is necessary to start preparations for algae culture approximately 80 days before the first anticipated spawning day (day 0 for larvae). This allows enough time for the algae system to be set up and for the cultures to attain satisfactory feeding densities.

The time line (Figure 2) shows that the first two five L flasks are inoculated on day 5 and thereafter at a rate of two per day, with the first bag being inoculated on day 12. This procedure allows a choice of algae for inoculation into bags and also as a back up in case of algal failures. Normal procedure (for this size hatchery) is that three new carboys containing Guillard's "f/2" solution (Appendix 2), trace metals and vitamins are innoculated each day after all mediums have been autoclaved. Each algae requires five to seven days of growth in the bag before it is usable as a high density culture.

To initiate bag culture, heavy duty plastic bags are inserted into holding frames and filled with filtered air and then filtered seawater. Overnight sterilization of each bag is accomplished by adding a 12% sodium hypochlorite solution to the bag. This is neutralized the following day with a solution of sodium thiosulphate before nutrients are added. The bag is subsequently inoculated with a 5 L flask of healthy algae. Daily checks of algae quality and cell counts are all that is then required before the algae is fed out. The bags can be refilled repeatedly (for up to several weeks) with sterilised and filtered seawater after each food volume has been removed (0.25 to 0.5 of the bag per day), provided the algae remains healthy and continues to grow. This procedure of semi-continuous bag culture also serves to reduce costs. Food hygiene is not crucial for the adults but the plastic bags are not re-used once the cell counts have been stable for more than a few days and the algae appears to be in poor condition.

The conditioning of the first batch of broodstock begins on day 19 (in tank A, 1,000 L) and ends on day 79 when they are induced to spawn. The spawning day may occur sooner but this reduces costs in accordance with reduced conditioning time. The costs shown in Table 1 are for the 18 days of culture, up to the start of broodstock conditioning, when feeding commences.

Algal culture during broodstock conditioning (day 19-64)

It is expected that by day 19 bag cultured algae would be ready for feeding to the adult scallops and the conditioning period would begin. Daily costs are shown in Table 2.

Satisfactory algal densities in bags would be as follows: *T. iso.*, 2,000 -4,000 cells/µL; *Nanno.*, 4,000 -8,000 cells/µL; *C.c.*, 4,000 -8,000 cells/µL; *3H.*, 3,500 -6,000 cells/µL.

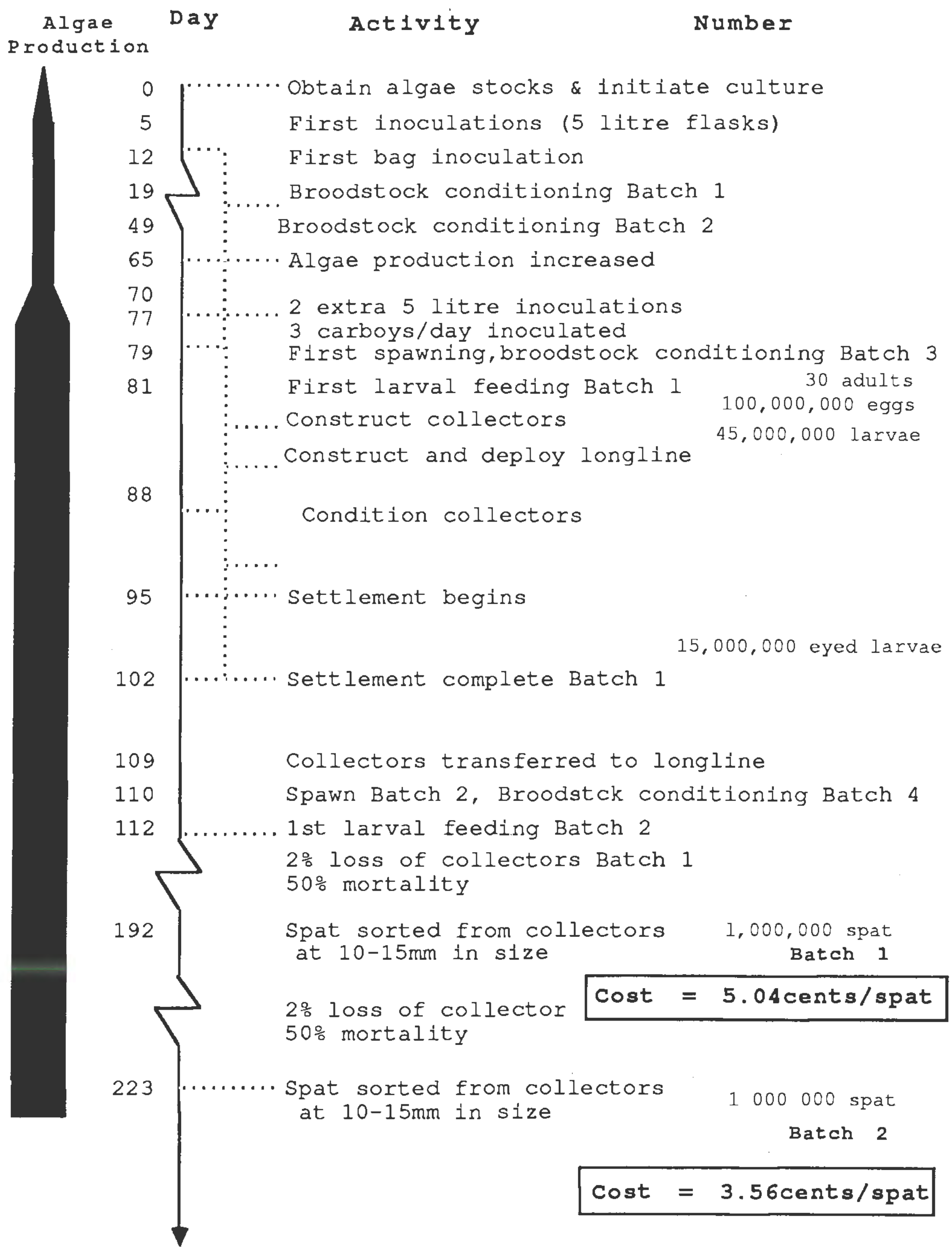

Figure 2. Timeline for hatchery operations

Table 2. Algal culture costs during broodstock conditioning

Item	Cost($)
Labour (2.5 hrs/day at $12/hr)	30.00
Electricity for pumps, aeration, lights, air conditioning and autoclave	6.88
Nutrients	1.12
Heavy duty plastic bag	3.00
Sterilization of bags, overnight chlorination and then neutralization	0.20
55 mls of standard 12% Sodium Hypochlorite and 20 mls of 1M Sodium Thiosulphate	
Filters (1 per day)	1.00
Carbon dioxide (CO_2)	2.50
scellaneous	0.30
Total per day	45.00
Total for 46 days	2,070.00

On day 49 the second batch of broodstock would be placed in the conditioning system (1,000 litre tank, Tank B). At this point sufficient algae is already being produced to condition the 200 broodstock being held.

Algae for broodstock conditioning and larval feeding (day 65-109)

It is intended that only algae from 23 L carboys should be as larval food since food quality is most critical at this stage. By day 65 algae production is increased so there would be sufficient cultures of the four algae species to allow the inoculation of four 5 L flasks (from day ; onwards). Three of these 5 L flasks are used to inoculate the three carboys (from day 77 onwards) and the remaining one can be used for inoculating a bag for broodstock. Labour includes microscopic examination and cell counts of algae, food calculations and feeding. Food consumption is assessed by cell counts of remaining food in each larvae tank and then additional food is added each day to increase this to a suitable level for the number and size of the larvae. An extra 1.5 hours is required to complete the additional tasks from Table 2. Table 3 shows the costs for algae culture, over and above those incurred during conditioning only.

The total cost represents the cost of culturing 420 L of algae each day. However, if allowance is made for bag cultures that prove unsuitable for feeding (assume one out of every three bags), then only 280 L per day will be available for use. The average count is 4,000 cells per µL and the algae fed to broodstock would be composed of at least 50% diatoms. The method of conditioning broodstock is described below.

Table 3. Additional costs during broodstock conditioning and larval feeding

Item	Cost $/day
Labour (1.5 hrs extra per day)	18.00
Electricity for pumps, lights, aeration,	
autoclave 4 extra loads per day, air conditioning	3.00
Nutrients	0.20
Filters, 2 per day	2.00
CO_2	0.00
Total	23.20

Total cost per day during the above period = $45.00 + $23.20 = $68.20, therefore, the total cost for this period (of 45 days) would be $3 069.000.

Feeding of the Batch 1 larvae would commence on day 81 and cease on day 102, ie. after 21 days. This includes a settlement period which may be as long as seven days.

Conditioning of Broodstock

If wild broodstock are available then they could be collected by either divers or dredge and used for spawning. However, this is only likely to occur over very restricted periods of the year. A safer alternative is to artificially condition adult scallops held in the hatchery. This procedure is as follows:

It is assumed that 100 adult scallops are held at 16-17^{o} C (thermostat regulated) in two 1,000 L tanks where the water is changed once per day. Each tank is fed 70 L of algae twice per day at a cell count of 4 ,000 cells per µL for up to 60 days.

Table 4 details the overall costs for conditioning broodstock in one tank which is sufficient to produce one batch of 15 million eyed larvae.

Food costs are based upon the predicted feeding rate above. However, results from recent trials indicate that the actual requirement may be a smaller daily volume than anticipated and the cost may be reduced. Regular cleaning of the tanks must be done but care should be taken to reduce the disturbance to the scallops during this period.

Table 4. Total costs for broodstock conditioning

Item	Cost ($) per day	Cost ($) 60 days
Pumping of water, 0.7 kw x 0.5 hrs x $0.0821 /kw/hr unit	0.03	1.72
Heating: Initial, for 1,000 l requires 10 kw x 1.33 hrs.(80 mins); 10 x 1.33 x 4.25 = $0.57/day	0.57	34.20
Maintenance of temperature: 5 kw x 8 hrs. x 4.25= $0.50/day	0.50	30.00
Food: accounted for in algae production costs	0.00	0.00
eration: accounted for in algae production costs	0.00	0.00
Labour: 0.5 hr/day x $12/hr	6.00	360.00
Total	7.10	425.92

Spawning of Broodstock

Heated water and algae are used to stimulate the ripe broodstock to spawn; the first batch would be stimulated to spawn on day 79. Approximately 30 adults, out of 50 put in the spawning tray, will need to fully spawn to yield the required 100 million fertilized eggs. This would generally take place over a period of several hours (Table 5) and only requires about 20 L of high density algae (>8,000 cells/μL) and running water of 18 to 21° C. At this time heated water is used to fill the larvae tanks, hence the cost of warm water for spawning is ,sumed to be negligible. The remaining 50 scallops are held in reserve in case initial spawnings are unsuccessful or if additional conditioning is required.

As soon as the first batch spawns it is removed (on day 79) and the third batch of scallop broodstock can be placed in the conditioning system. On day 110 the second batch of broodstock would be spawned and the fourth batch placed in the conditioning system.

Total costs for culturing larvae resulting from the first spawning are shown in Tables 6 and 7 a. Additional spawnings will require a further three days of algae culture just for broodstock conditioning ($45 per day), 28 days of algae culture for broodstock and larvae ($68.70 per day) prior to larval feeding commencing, a cost of 3 x 45+28 x 68.20 = $2, 044.60 (Table 7b).

Larvae Culture

After spawning, two larvae tanks (15 000 litres each) are to be used to hold the eggs at a density of 3.3 per mL, and from day 2-3, two larvae tanks (with larvae at low density, 1 per mL) are still required (assuming 30% survival). The full duration of the larval period is 23 days at which point larval settlement is theoretically complete.

Table 5. Cost for broodstock during spawning.

Item	Cost ($)
Algae, 20L	1.40
Labour, 8 man hrs x $12/hr	96.00
Total	97.40

The proposed schedule for the larvae is to begin water changes at day A2-3 and continue them every two to four days (assume two days) up until day A16-19 (depending on developmental stage of the larvae). Settlement generally occurs during day A19-23. The 15 million eyed larvae are divided into three tanks, 5 million per tank, prior to settlement. However, the spat collectors should be left undisturbed in the larvae tanks for another seven days to ensure that byssal thread attachment is firm and the spat do not fall off the mesh when transferred to the longline for ongrowing. Water changes in each tank should be performed daily using very low flow rates for the incoming water.

The labour component (Table 6) includes; sizing, counts and microscopic examination of larvae, tank cleaning, food calculations, feeding and draining of tanks.

Summary of Hatchery Operating Costs

Initial startup costs as well as the operating costs have been combined to assess the overall cost of algae culture, conditioning of broodstock, spawning broodstock to obtain 100 million fertilized eggs, and culture of the surviving larvae up to the eyed stage when only 15 million are expected to remain (Table 7a). Capital costs have not been included but are available for information in Appendix 1.

Table 6. Cost of culturing 15 million eyed larvae

Item	Cost ($)
Pumping, overall head is 8 m. Rate is 2 l/sec or 7200 l/hr	
Pump draws 0.7 kw and runs for 2 hrs/day,0.7 x 2 x $0.0821 x 23	2.64
Heating. Water is changed in each larvae tank 9 times during the 23 day cycle.	
180 kw/hr x 9 x $0.0323 x 2	104.65
Maintenance of water temperature for 23 days, assuming a loss of 3°C/day, will	
require one 5 kw heater operating for 12 hrs/day.60 x 23 x $0.0425 x 2	117.30
Aeration for algae and larvae, accounted for previously	
Labour for larvae 2.5 hrs/day x 23 days x $12/man/hr	690.00
Cost/batch of larvae	914.59

(NB: A= Larval age in days)

During a normal production season several batches of larvae would be reared. The cost of producing subsequent batches would decrease as the algae system would already be operational and conditioned broodstock would be available (continued feeding and maintenance of the broodstock would still be necessary). Costs of producing further batches are detailed in Table 7b.

Table 7a. Total hatchery costs to produce 15 million eyed scallop larvae (Batch 1).

Item	Cost ($)
Lease of hatchery for 109 days at $65.75/day	7,166.75
Algal Preparation (Table 1)	889.00
Broodstock conditioning & Larval Food (Table 2 & 3) x 45 days	3,069.00
Broodstock Conditioning (Table 4)	425.92
Spawning (Table 5)	97.40
Larval Culture (Table 6)	914.59
Total cost	12,562.66 0.0838 cents/larvae

NB: Food is provided during settlement but these costs may be reduced by using flow through of partly-filtered water.

Table 7b. Total hatchery costs to produce 15 x 10^6 eyed scallop larvae (Batch 2).

Item	Cost ($)
Lease of hatchery for 31 days at $65.75/day	2,038.25
Algae Preparation (Table 1)	0.00
Broodstock conditioning & Larval Food (Table 2 & 3) x 28 days	1,909.60
Broodstock conditioning (Table 2) x 3 days	135.00
Broodstock Conditioning (Table 4)	213.00
Spawning (Table 5)	97.40
Larval Culture (Table 6)	914.59
Total cost	5,307.84
	0.0354 cents/larvae

Spat Settlement

For larval settlement to occur it is imperative that a suitable substrate is provided in the tanks prior to metamorphosis beginning. As mentioned earlier, mesh bags (collectors) are used. These are attached to ropes (droppers; without a weight) and should be conditioned in seawater for several days before placing them in the larvae tanks. A configuration for 500 spat collectors could be to divide them into three equal groups and tied onto a total of 50 droppers (10 collectors per dropper). Each group of droppers (16-17 droppers) would be placed in one of the larvae tanks. Approximately one week after the larvae have settled, the droppers with the collecting bags can be transferred carefully to longlines for ongrowing.

The hatchery described has the capacity to produce 15 million scallop larvae from each batch of eggs spawned. The unit cost per spat depends on the percentage of eyed larvae which set. The cost includes the collectors (and droppers they are attached to), on which the spat settle (Tables 8 and 9). The unit cost has been determined at day A30 for a range of setting percentages, (seven days after settlement begins) and is shown in Table 10. Some savings may be made by not feeding out cultured food after settlement is complete; a flow through system of partly or semi- filtered water could be provided to the tanks.

On day A30 (operation day 109) the droppers, with spat collectors and weights attached, are transferred to a longline for ongrowing; this point signifies the end of the hatchery phase of culture.

Table 8. Cost of collectors for settlement of hatchery spat

Item	Number	Type	Length (m)	Unit cost	Total cost ($)
onion bags	500			$0.66	330.00
shark mesh		used	10,000	$0.00	0.00
twine		3 mm pp*	100	$0.07	7.00
dropper		508 mm pp*	10	$0.21	105.00
labour for construction				8.5 mandays	
				@ $10/hr	765.00
›tal					1,207.00

pp* = polypropylene rope

The cost of spat collector materials and construction is added to the cost of producing 15 million eyed larvae to obtain the cost of settled spat at the end of the hatchery stage of culture. This total cost using 500 collectors is shown in Table 9 and is $13,800 for Batch 1 and $6, 500 for Batch 2. The cost per spat is assessed in Table 10 below and varies according to the percentage of eyed larvae which actually settle.

Table 9. Total hatchery spat cost at day 30

Item	Batch 1	Batch 2
Eyed larvae cost	$12,562.66	$5,307.84
Collector cost	$ 1,207.00	$1,207.00
Total	$13,769.66	$6,514.84

Ongrowing

The longline design (Figure 3) is suitable for placement at a site with a water depth of 13 m. The collecting bags are attached in pairs at intervals of 0.75 m on the rope droppers, 20 bags per dropper.

Table 10. Cost of hatchery produced spat at day 30

% Set	Number of Spat	No. spat/collector	Cost(cents)/spat	
			Batch 1	Batch 2
3.3	0.5×10^6	1 000	2.7539	1.3030
6.7	1×10^6	2 000	1.3770	0.6515
13.3	2×10^6	4 000	0.6885	0.3257
26.7	4×10^6	8 000	0.3442	0.1629
40.0	6×10^6	12 000	0.2295	0.1086

If we assume that settlement of larvae results in one million spat then 1,000, 500 or 200 collectors would be required. Any of these can be held on 50 droppers which will fully occupy a 100 m longline at an inshore semi-protected site. The basic structure of this longline is shown in Figure 3. This inshore site is chosen so that regular monitoring is easy (and cheap) and virtually the whole water column can be used to hang collectors in. Sea conditions at offshore deepwater sites are generally too rough for scallop collectors placed anywhere within six metres of the surface, whereas at an inshore site as mentioned, the collectors can be placed from one and a half metres below the surface to four metres above the bottom at high tide.

As mentioned, with a settlement of one million spat, the cost varies depending on how many collectors are used and subsequently the number of spat that settle in each collector. For simplicity we can assume that the same longline and dropper arrangement (20 collectors per dropper) is used to hold all the collectors. A batch with 5,000 spat per collector (requiring 200 collectors) will only need 10 droppers. Collectors from subsequent batches could be attached at a later date, further reducing the cost per spat.

The ongrowing methodology described is one of three options after the spat are contained within collectors. These options are as follows; 1) three months after settling the spat can be transferred into pearl nets for the first stage of hanging cage culture; 2) they can have their ears drilled and be tied (or glued) onto droppers; 3) they can be left in collectors and sorted from them once they have attained a suitable size then reseeded. From previous experience it is expected that 2% of the collectors would be lost due to bad weather or construction deficiencies and there would be a 50% mortality of the spat during the 3 months of ongrowing.

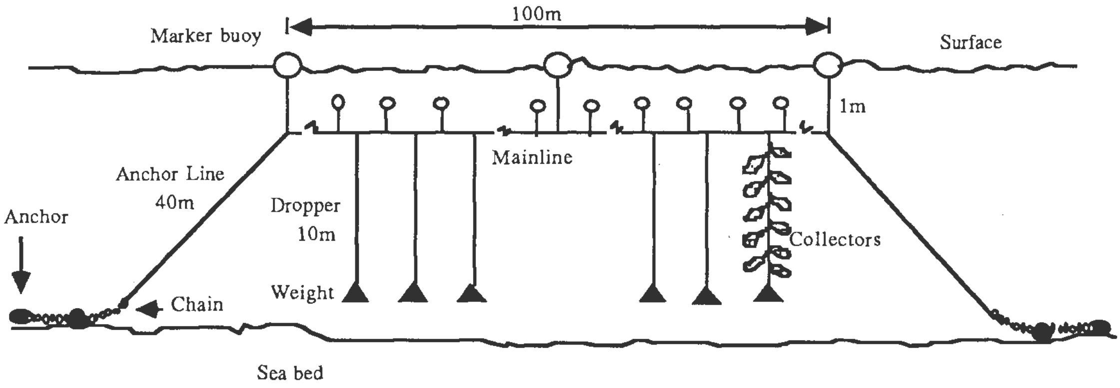

Figure 3. Inshore longline design (Not to scale)

Table 11. Longline and spat collector materials for hatchery spat.

Item	Number	Type	Length (m)	Unit cost ($)	Total cost ($)
main line	1	24 mm pp*	100	1.57	157.00
anchor line	2	24 mm pp*	40	1.57	125.60
thimbles	4	25 mm galv		4.00	16.00
anchor chain	4	9 mm black	20	3.29	263.20
anchor weights	4	bogey wheel		27.50	110.00
iackles	12	12 mm black		3.30	39.60
floats	3	250 litre		110.00	330.00
floats	10	14 litre		7.15	71.00
Basic Longline Cost					$1,112.40
onion bags	1 000	-		0.66	660.00
shark mesh		used	10 000	0.00	0.00
twine		3 mm pp*	100	0.07	7.00
droppers	50	8 mm pp*	10	0.21	105.00
dropper wts	50	steel		1.10	55.00
Collector Cost					827.00
TOTAL					$1,939.40

pp* = polypropylene rope

Table 12. Costs of deploying, retrieving and monitoring spat collecting equipment

Item	Cost ($) No. of collectors 1000	500	200
Deployment of longline and spat collecting equipment (Barge)	400.00	400	400
Monthly check on equipment (3 trips, small runabout)	450.00	450	450
Labour for retrieval of spat collectors and sorting	1,800.00	900	360
Vessel for retrieving spat collectors and longline	6,000.00	2400	1200
Total	$8,650.00	$4,150	$2,410

Table 13. Spat settlement and ongrowing costs for one million spat at selected densities.

Item	No. spat/collector No. of collectors	1,000* 1,000	2,000 500	5,000 200
Basic cost of Longline		1,112.40	1,112.40	1,112.40
Cost of collectors:-				
Twine		7.00	7.00	7.00
Onion bags		660.00	$330.00	132.00
Droppers		105.00	$52.50	42.00
Dropper weights		55.00	$27.50	11.00
Total material cost		1,939.40	1,529.40	1,304.40
Labour to construct longline (1 manday at $10.00/hr)		90.00	90.00	90.00
Labour to construct collectors and droppers		1,440.00	765.00	450.00
Cost of deploying/retrieving, monitoring equipment and sorting collectors (see Table 11)		8,650.00	4,150.00	2,410.00
Total cost of Labour		10,180.00	5,005.00	2,950.00
Total cost (Materials and Labour)		12,119.40	6,534.40	4,254.40

Hatchery Spat Cost

The total cost per spat from the hatchery has been assessed on a conservative 6.7% settlement rate of eyed larvae. The subsequent one million spat are settled in conventional spat collectors at varying densities of 1,000, 2,000 and 5,000 spat per collector. As the number of collectors used decreases, the number of spat settling in each collector increases at a corresponding rate. High numbers of spat per collector result in increased mortalities but to economise, spat would be removed from collectors early and hence would be smaller than originally planned. For this example we can assume an ongrowing period of three months, after which the spat are sorted from the collectors at a size of 10-15 mm. Mortality of the spat during ongrowing and total loss of collectors needs to be included in costings and as mentioned previously, this is expected to be 50% and 2% respectively. Overall figures are ..own in Table 14. Costs clearly fluctuate depending on how many batches of larvae/spat are produced.

The flow diagram (Figure 4) illustrates how the various figures were derived and also gives the three price alternatives for buying eyed larvae, 30 day old settled spat or 10-15 mm spat.

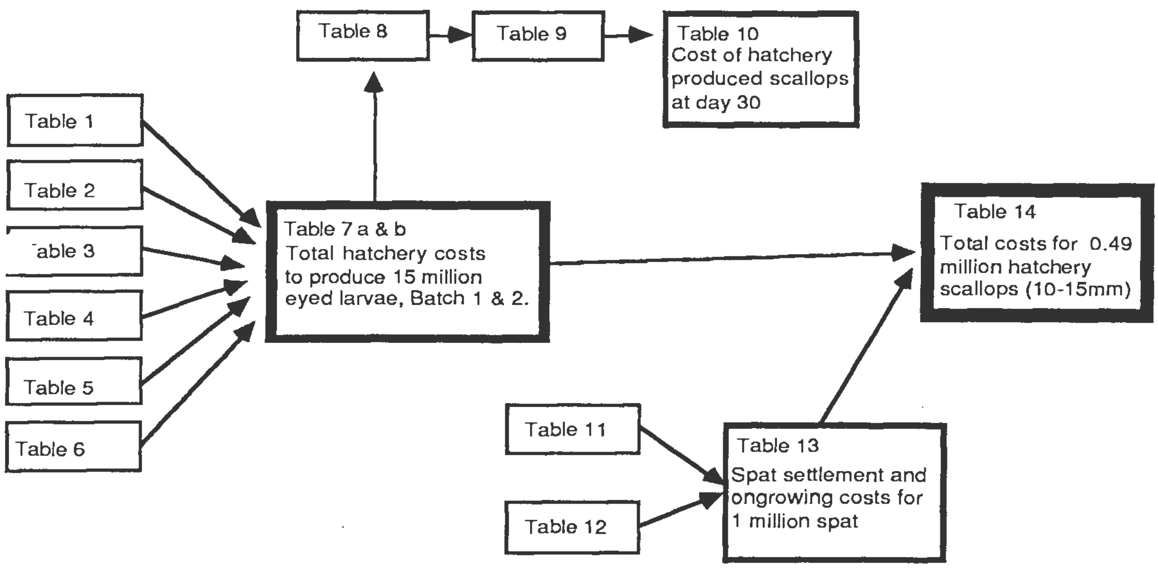

Figure 4. Flowchart for hatchery costings

Table 14. Summary of costs for hatchery reared scallops at 10-15 mm in size

Item	No. spat/collector	1,000	2,000	5,000
No. of collectors		1,000	500	200
Cost of producing	Batch 1	12,562	12,562	12,562
eyed larvae	Batch 2	5,307	5,307	5,307
Ongrowing costs		12,141	6,556	4,276
Total	Batch 1	24,704	19,119	16,839
	Batch 2	17,449	11,864	9,584
Cost/spat (Excluding	Batch 1	2.47	1.91	1.68
collector and spat losses)	Batch 2	1.74	1.18	0.96
But assuming 2% loss of collectors and 50% mortality in collectors, leaving 490 000 spat				
Cost/spat	Batch 1	5.04	3.90	3.44
	Batch 2	3.56	2.42	1.96

Collection of Natural Spat

Methodology

Collection of scallop spat from the natural spawning of adult scallops at sea has been adapted from techniques used in Japan for many years. The schedule of major operations for a Tasmanian operation is shown on a timeline (Figure 5). After several trials a suitable longline and collector arrangement for a semi-sheltered offshore site has been determined. This design can be modified to withstand very rough weather. For example, the three 250 L surface floats would be replaced by 14 L floats (buoys) and several more 14 L floats would be added to the mainline to provide sufficient buoyancy. Modifications are also possible for calmer conditions incurred at shallow water sites (see Figure 3).

The longline detailed in Table 15 is for an oceanic site where the water depth is 30 m; it is shown schematically in Figure 6. A total of 2,000 collectors are attached to droppers (40 per dropper) so that they span the depths between 7 and 27 m when they are hung vertically from the mainline.

Labour requirements for construction of equipment have been conservatively over-estimated so that the work could be completed by inexperienced staff within the time frame shown. Obviously, as staff develop more expertise this labour cost would decrease.

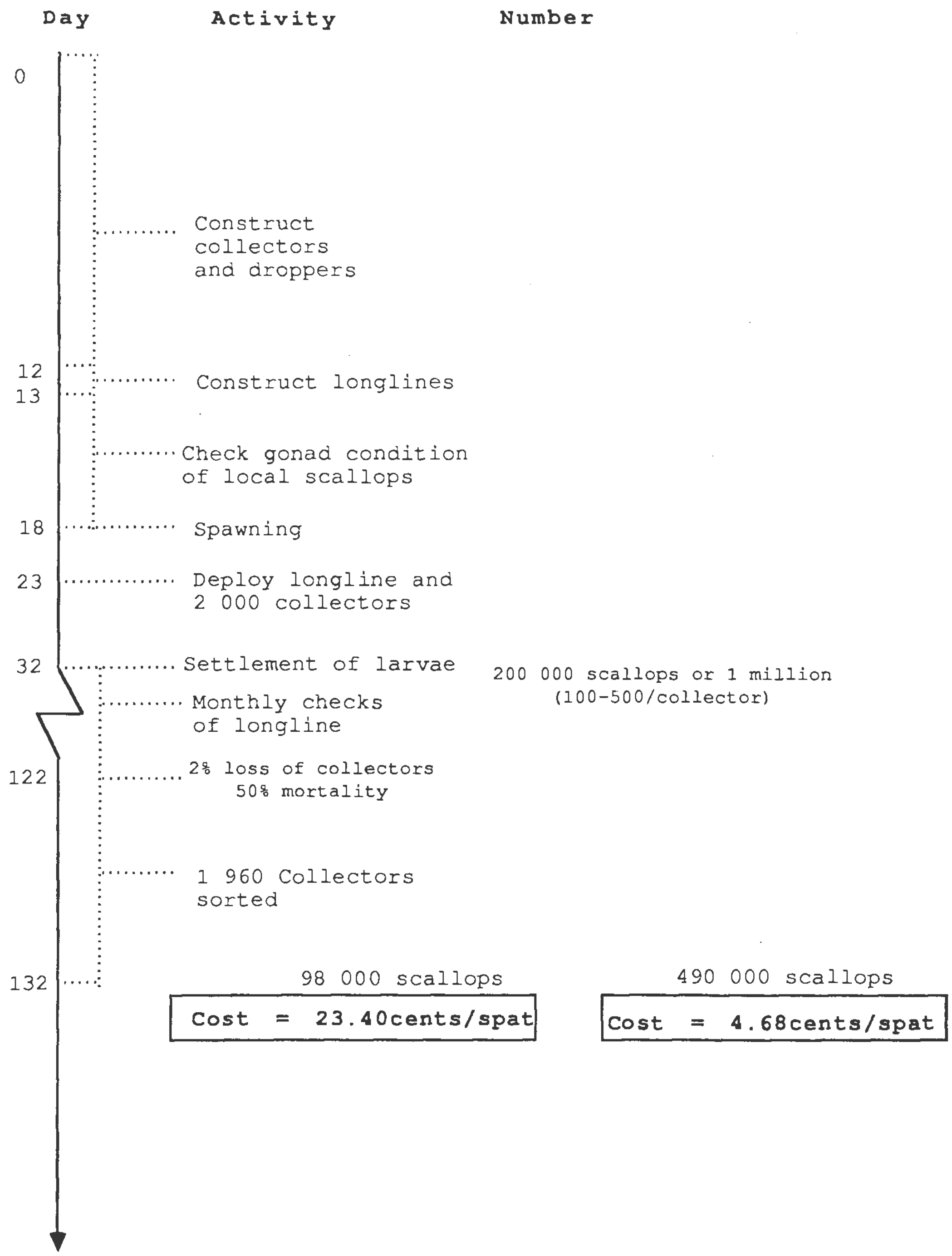

Figure 5. Timeline for natural spat collection.

Table 15. Longline and spat collector materials

Item	Number	Type	Length (m)	Unit cost ($)	Total cost($)
main line	1	24 mm pp*	100	1.57	157.00
anchor line	2	24 mm pp*	90	1.57	282.60
thimbles	4	25 mm galv		4.00	16.00
anchor chain	4	9 mm black	20	3.29	263.20
anchor weights	4	bogey wheel		27.50	110.00
shackles	12	12 mm black		3.30	39.60
floats	3	250 litre		110.00	330.00
floats	10	14 litre		7.15	71.00
droppers	50	8 mm pp*	20	0.21	210.00
dropper wts	50	steel		1.10	55.00
onion bags	2,000			0.66	1,320.00
shark mesh		used	10,000	0.00	0.00
twine		3 mm pp*	100	0.07	7.00
TOTAL					$2,861.40

pp* = polypropylene rope

Table 16. Cost of labour required to construct longline and spat collectors

Item	Number	Man-days	Cost($)
Construct longline	1	1	90.00
Construct collectors2 000	21	1	890.00
Construct droppers 50	8		720.00
TOTAL	30		$2,700.00

NB: Labour cost is $10/hr @ 9 hrs/day.

Deployment of Spat Collectors

Once the equipment has been constructed it is conveyed to a vessel, transferred to the longline site and deployed Monthly inspections of the equipment to ensure that floatation is sufficient (as fouling accumulates), and that no damage has been caused by shipping, algae or weather conditions, are essential. The costs of these procedures are detailed in Table 17.

Table 17. Costs of deploying, retrieving and monitoring the equipment

Item	Cost ($)
Transport of equipment to vessel (including labour, 1 day)	200.00
Deployment of longline and spat collecting equipment (large vessel, 1 day)	1,200.00
Monthly check on equipment (3 trips, small runabout)	375.00
Labour for retrieval of spat collectors and sorting (40 man days x $90/man/day)	3,600.00
Vessel for retrieving spat collectors and longline (10 days)	12,000.00
Total	$17,375.00

Natural Spat Costs

The sorting of 1,960 spat collectors (assuming a 2% loss) three months after their deployment should produce from 200,000 to one million juvenile scallops ranging in size from 10 to 15 mm with 100 to 500 per collector. The cost per scallop will vary depending on the catch rates as shown in Table 19. These are calculated by using the total cost figure (Table 18) of obtaining spat from the wild (at sea). At the present time research has suggested that there would be 100 scallops settling initially per collector.

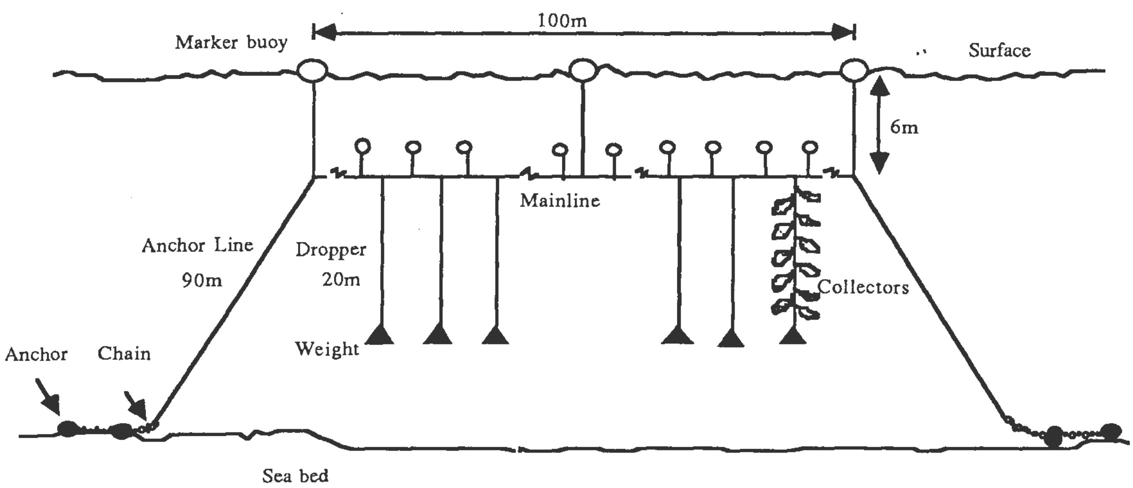

Figure 6. Offshore longline design (Not to scale)

Table 18. Total labour and materials for natural spat collection

Item	Cost($)
Cost of materials	2,883.40
Labour costs of constructing longline equipment	2,700.00
Costs of deploying/retrieving and monitoring equipment	17,375.00
Total	$22,958.40

If there is a 50% mortality of these scallops up to the time of sorting, the cost becomes 23.40 cents per scallop (Table 19). If the number of scallops per collector was to increase in future years there would be a marked reduction in the cost per scallop (as much as 10 cents per scallop).

Table 19. Summary of natural collecting costs for 100,000 to one million scallops

Item	Number of spat per Collector		
	100	500	1,000
Total cost	$22 936.40	$22 936.40	$22 936.40
Number of scallops	200 000	1 000 000	2 000 000
Cost/spat (cents) (Excluding collector and spat losses)	11.47	2.30	1.15
Assuming 2% loss of collectors and 50% spat mortality			
Number of scallops	98 000	490 000	980 000
Cost/spat (cents)	23.40	4.68	2.34

Discussion

The establishment cost of the hatchery has been evaluated (Appendix 1), but only the lease amount has been included in assessing the cost per spat. However, if the hatchery is to be built and used solely for producing scallops then the whole capital cost would be taken into consideration. For the analysis conducted here the leasing cost of an established hatchery has been used. Basic profit margins, administration and staff costs such as superannuation, workers compensation, leave loading etc. have not been included. Although this type of arrangement may be possible in some instances, Tasmania is somewhat restricted at present (as are other parts of Australia) by having only three hatcheries capable of culturing bivalve molluscs.

Realistically, most hatcheries are designed for cultivating a range of species and hence preliminary work for the culture of scallop larvae (ie. broodstock conditioning) could be carried out whilst the hatchery is actually culturing another bivalve species. In this manner, algae culture would probably be already established. As long as potential broodstock is available, conditioning of gonads can be scheduled such that the hatchery transforms its operations from one bivalve species to another (in this case scallops) without passing through a non-productive change-over period.

Producing algae as food for bivalves is clearly an expensive operation as it is in many shellfish hatcheries (Laing 1985) and it is important to schedule the various cycles of culture in conjunction with the changing requirements of the scallops so that unnecessary production and/or wastage of algae is avoided. As well, quality or nutritional value of the algae is a major concern and again, it is necessary to plan algal production so that harvesting of algae occurs at the optimum time (Lewis *et al.* 1986; Whyte 1987).

The study here shows that eyed scallop larvae could be produced for less than 0.1 cents each. However, the crucial stage is metamorphosis of the eyed larvae and survival rates during metamorphosis have a significant effect on the cost per spat. Settlement of the spat onto a suitable substrate also involves additional costs. If one million settled spat (day A30) are obtained then the cost would be 0.1-2.8 cents per spat. Investigations are already underway to assess the viability of settling spat in a downwelling system or an upwelling system similar to that used in settlement of Pacific oyster spat . Handling of the spat at this stage should be kept to a minimum as they are very small and fragile and large numbers can easily be damaged or lost. Losses incurred during settlement of larvae onto collectors would thereby be avoided.

Once the spat have been ongrown to 10-15 mm in size and removed from the collectors, the cost is then 2-5 cents each. In addition, it is important to note that the cost of rearing scallop spat decreases considerably after the first batch. In this report, the full costs of algae preparation and broodstock conditioning are included in the cost of producing the first batch of spat; however the actual cost of producing Batch 2 is approximately 40% of the Batch 1 cost. This illustrates that if operating costs were to be spread over a culture season or over a large number of batches of spat then the cost per spat would decrease markedly, in fact, to around 2.0-3.6 cents per 10-15 mm spat.

Overall it seems likely that being able to produce scallop spat for a cost of between $0.02 and $0.04 (2-4 cents) each could be profitable given that the value of two year old scallops of 8-9 cm in size is currently about $0.23 each (assuming a meat weight of 70 scallops/kg; range 60-80; price: $16/kg meat weight). The economics of ongrowing scallops in hanging cages or trays up to this size has previously been examined. (Cropp 1984, 1985 and 1987).

In Tasmania it appears that the collection of natural spat at sea is presently too costly due to the low catch rate per collector as a result of very low numbers of adult scallops in the catch areas. At this stage, a catch of natural spat in excess of 500 per collector would be required before it could become economically viable. As vessel costs are a substantial component (52%) in obtaining natural spat, the reduction of the charter rate from $1,200 to $800 per day would result in spat costing 3.9 cents each (instead of 4.7 cents) at 500 per collector. This component is not so significant for hatchery reared spat as the vessel charter costs are $600 per day. On the figures presented here, hatchery reared spat is currently the most economically viable method of obtaining large numbers of scallop spat.

Acknowledgements

We wish to thank the Tasmanian Shellfish Company (Manager: Ian Cameron) and Shellfish Culture Pty Ltd (Manager: Malcolm Fraser) for allowing the hatchery work to be carried out at Dunalley and Bicheno respectively. The Winston Churchill Trust is thanked for assisting in overseas study which has contributed to this report. Dr. Trevor Dix is thanked for his involvement and advice on the project and his criticisms of this report. Roger Cropp helped compile data and information. Ivor Growns is thanked for his help in final preparation and Ann Gschwendtner provided assistance with technical details.

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GENERAL DISCUSSION

Bell: Is the 50% mortality in collector bags a realistic figure or is it based on mortality in hatchery collection bags?

Cropp: In past years we have seen mortality levels of 50% in natural spat, and overall we expect spat survival to be better than that. Survival depends on the number of spat in the collector, and the number of ascidians which settle in the collectors. I think 50% is a safe figure to apply to wild spat.

Bell: At what size does mortality occur? Does mortality associated with ascidians occur when the spat are fairly large?

Cropp: Larger spat can suffer high mortality through the ascidian problem, but if collectors are sorted earlier you're got increased risk of damage and increased stress because you are handling them at a smaller size.

Zacharin: What is the highest number of scallops you have seen in a collector in the wild?

Cropp: To date, 1260 commercial spat from a collector at Maria Island in 1984. We attained surprising numbers during the second settlement of spat off Maria Island in 1987. One collector produced 800 spat.

Harrison: Do you have some idea of how much of your work was done at a site with sheds and land available, and how much this would cost?

Cropp: What I have incorporated into this model was the fact that you would actually have to make the gear, transport it to the site, deploy it and monitor it. I've incorporated all these costs, but I didn't cost a shed or land in the system.

Harrison: Does anyone have any idea of the costs from the stage of thinking about a marine farm to inception?

Dix: If the application is one in which an appeal can be lodged, there can be costs of several thousand dollars involved even after writing the application and advertising sites.

Cropp: The costs associated with requirements for sheds and land would, relatively, put the scenario of collecting spat at sea in an even worse situation than I've presented here.

Harrison: I would have thought the requirements for a site would not have altered the balance between hatchery spat and wild caught spat.

Cropp: The hatchery, which has been costed in the model, would have these facilities available.

McLoughlin: You showed that the number of spat collected in the wild rose to a peak and then dropped off over time. That followed the catch statistics for Tasmania pretty closely for the past five to eight years. Have you any comments about future conflicts between culturists and fishermen trying to fish wild stocks?

Cropp: The only scenario I can see is that increasing the numbers of broodstock, either tificially or naturally, will enhance the situation of both wild fisheries and culture operations.

Bull: Are your spat count numbers from the past five years based upon total catch or the numbers that were alive on count?

Cropp: The figures were based upon recoverable numbers in March/April each year, with the basic unit being count per black mesh bag.

Bull: Could you reduce the cost by scaling up the operations?

Cropp: Considerably. However, I've been generous with labour costs and equipment costs. We don't want to present an unrealistic or excessively rosy situation.

Anon: It is apparent that the unpredictability of collecting spat from the wild and the potential relationship between number of broodstock and number of spat will affect the viability of a project. Japanese experience suggest that spat can be predictably collected. At the same time they have a huge broodstock biomass. What was the situation at the start of the Japanese experience? Did they have the same degree of uncertainty in spat collection? Can we, by using their technology, look at more reliable spatfall?

Cropp: I can quote the classic example from Dr Ito's work in Mutsu Bay. In a six year period commencing at the time when scallop culture really began, spat collection per collector rose from 200 per collector to 44,000 per collector, and the number of broodstock increased tenfold.

Appendix 1

Capital costs of a proposed hatchery.

Item	**Cost ($)**
Building	
- superstructure (10 x 12 m)	26,000
- concrete slab and drains	11,700
- internal laboratory and algae room	11,700
Amenities block	5,500
Electrical- switchboard, internal wiring, etc.	15,600
PVC pipes and fittings	2,500
Algae lights (32 units)	2,900
Steel mesh bag holders (8)	640
Air conditioning unit	1,040
Autoclave (manual)	8,800
Refrigerator (secondhand)	250
Oven	250
Larvae tanks (3 x 15 000 litre)	13,500
Sand filter	690
Pump	1,400
Rainwater tank (5 000 litre) and pressure pump	2,300
Airblower	5,400
Titanium heaters (12 x 5 kw)	2,900
Larvae screens, spawning trays, buckets, etc.	1,800
Hot water system	280
Laboratory equipment	
- glassware, carboys, microscope, algae stands, haemocytometer, volumetric flasks, balance, etc.	13,000
Contingency	6,000
Total	134,150
plus labour for construction, estimated at	25,000
Grand Total	**$159,150**

Appendix 2

Guillard's "f/2" Algae culture medium (from Holliday, 1985)

Composition of enrichment "f/2"

Major nutrients		Cost (cents)
$NaNo_3$	75 mg (883 µM)	0.13
$NaH_2PO_4.H_2O$	5 mg (36.3 µM)	0.02
$Na_2SiO_3.9H_2O$	15-30 mg (1.5-3 mg Si or 54-107 µM)	0.08
Trace Metals		
$Na_2.EDTA+$	4.36 mg (ca 11.7 µM)	0.05
$FeCl_3.6H_2O$	3.15 mg (0.65 µg Fe or ca 11.7 µM)	0.01
$CuSO_4.5H_2O$	0.01 mg (2.5 µg Cu or ca 0.04 µM)	0.01
$ZnCl_2$	0.022 mg (5 µg Zn or ca 0.08 µM)	0.01
$CoCl_2.6H_2O$	0.01mg (2.5 µg Co or ca o.05 µM)	0.01
$MnCl_2.4H_2O$	0.18 mg (0.05 µg Mn or ca 0.9 µM)	0.01
$(NH_4)_6Mo_7O_{24}.4H_2O$	0.006 mg (2.5 µg Mo or ca 0.03 µM)	0.01
Vitamins		
Thiamin.HCl	0.1 mg	0.01
iotin	0.5 µg	0.01
Cyanocolalamin (B_{12})	0.5 µg	0.01
Seawater	to oneL	
Total cost		0.37

Note : Silicate may be omitted for organisms other than diatoms.

GENETIC VARIATION IN SOUTHERN AUSTRALASIAN *PECTEN*

Lynette Woodburn
Department of Genetics and Human Variation
La Trobe University
Victoria 3083.

Abstract

Genetic relationships between and within species of Pecten in southern Australasia are investigated using protein electrophoresis. The specific status' of Pecten from Western Australia (nominally, Pecten modestus Reeve, 1852) and from New Zealand (P. novaezelandiae Reeve, 1852) are supported. However, similarities at seventeen loci indicate that P. meridionalis Tate, 1887 (Tasmania) and P. albus Tate, 1887 (Victoria, South Australia) are synonymous with the earlier described P. fumatus Reeve, 1852 (New South Wales). The level of differentiation amongst populations of this species (particularly in the Bass Strait region) is very low.

Introduction

Five species of *Pecten* have been described from southern Australasian waters: *Pecten novaezelandiae* Reeve 1852 (New Zealand), *Pecten modestus* Reeve 1852 (Western Australia), *Pecten fumatus* Reeve 1852 (New South Wales), *Pecten albus* Tate 1887 (South Australia, Victoria), and *Pecten meridionalis* Tate 1887 (Tasmania). However, gradations in shell morphology have long fostered suspicions concerning the taxonomic validity of these species. Tate himself suspected that *P.albus* may be conspecific with *P.fumatus* and recommended the examination of specimens from localities between South Australia and New South Wales (Tate 1887). Although a commercial *Pecten* fishery exists in this region, the number of species on which it is based is still unknown.

Knowledge of whether the target is single or multi-species is fundamental to the continuing development of management strategies for this fishery; the type and complexity of biological and technological interactions that need to be examined are thus defined, as are the bounds of investigations into population structure.

The accessibility of this knowledge, traditionally gained through measures of physiological, behavioural and morphometric characters, and population parameters such as growth and mortality rates, has been increased recently as a result of developments in biochemical genetics. Since the 1960s, protein electrophoresis has provided an efficient means of revealing patterns of variation in characters under direct genetic control.

Patterns of genetic variation between and within species of *Pecten* in southern Australasia are investigated using this technique. Emphasis is placed on determining the species composition and population structure of *Pecten* in the south-eastern Australian fishery.

Materials and Methods

Between October 1985 and January 1987, *Pecten* aged one year or older (estimated from left valve hinge-to-margin length) were collected from two sites in New Zealand, one in Western Australia and 15 in south-eastern Australia (Figure 1). During this period, repeated samples were taken from four sites: Port Phillip Bay (PPHB) King Island (KING), Banks Strait (BANK) and Cape Conran (CCON). Animals were dissected fresh when possible, or freighted on dry ice to the laboratory. Striated adductor muscle was homogenised in an equal volume of grinding buffer (Selander *et al.* 1971) and centrifuged at 10,000 g for six minutes. The supernatant was stored at -70°C prior to electrophoresis.

The products of 17 presumptive loci (Table 1) were visualised using two methods of electrophoresis: cellulose acetate (according to Richardson *et al.* 1986) and horizontal starch [gels of 11% w/v starch, modified after Shaklee and Kennan (1986)]. Running and staining procedures recommended by these authors were followed unless otherwise indicated in Table 1. Allozymes were labelled sequentially according to their mobility, the least anodally-migrating form designated one.

Allelic frequencies at 17 loci were determined for a sample of 21 individuals from each of 11 sites (• in Figure 1). The proportion of polymorphic loci, mean number of alleles per locus, observed and expected heterozygosities (Nei 1978) were calculated for each sample. Nei's unbiased genetic distance, D, (Nei 1978) was calculated between pairs of samples and a dendrogram constructed using the unweighted pair group method (UPGMA).

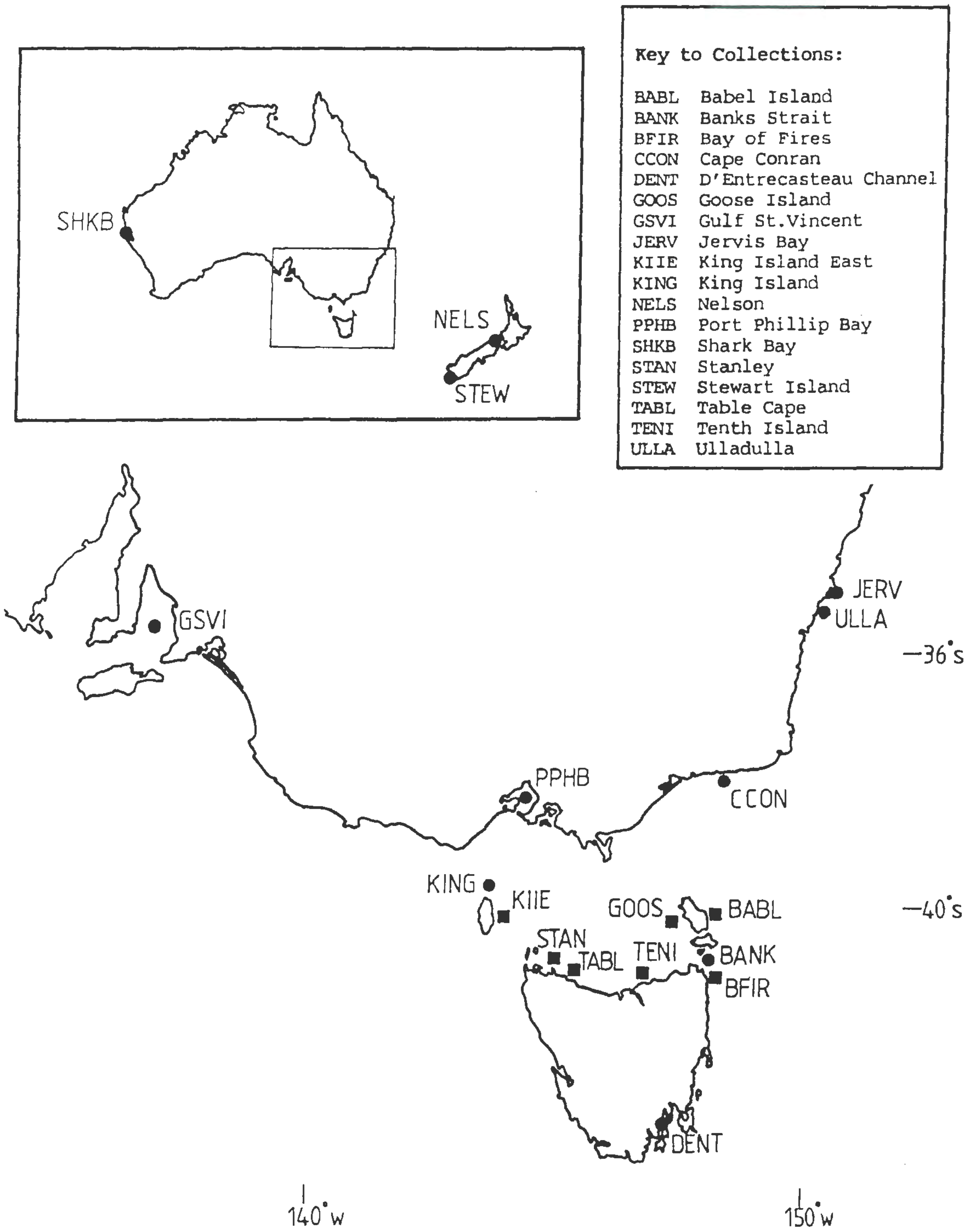

Figure 1. Pecten collection sites in Australia and New Zealand.

The remaining individuals in collections from sites labelled • in Figure 1, and *Pecten* from additional sites, , were scored for the 12 most highly polymorphic loci (average sample size = 152). Differentiation among collections was assessed using a X^2 test of homogeneity of allele frequencies (Workman and Niswander 1970). In addition, an estimate of the parameter, F_{ST}, was calculated according to Weir and Cockerham (1984) as the correlation of genes of different individuals in the same collection. The null hypothesis, $F_{ST} = 0$, was evaluated by $X^2 = 2nF_{ST}(k-1)$, d.f. = (k-1)(cf-1), where n = total number of individuals and c = number of collections. Modified Roger's genetic distance (Wright 1978) was calculated for each pair of collections, and the resulting matrix ordinated by nonmetric multidimensional scaling (MDS) (Pimentel 1979) in two dimensions. A minimum spanning tree (in which the sum of the connecting lengths is minimised) (Rohlf 1970) was superimposed.

These analyses were largely accomplished using GENSTAT (Black and Krafsur 1985) and NT-SYS (of Dr. F.J. Rohlf) computer programs.

Results

Variants were found at all 17 loci, and a total of 89 alleles recognized. The percentage of polymorphic loci (by the 0.99 criterion, see Table 2) per sample ranged between 58.8% (New Zealand) and 88.2% (Ulladulla). The mean number of alleles per locus was correspondingly low in New Zealand (1.9 ±0.2 for Nelson), and highest for Shark Bay (3.4 ±0.6). Individual heterozygosity measures were also indicative of a low level of genetic variation in New Zealand [observed heterozygosity (by direct count) = 0.121 ±0.036, Stewart Island] compared with 0.333 ±0.061 for Gulf St. Vincent (Table 2).

A (virtually) fixed difference was found at the PK locus between Australasian and New Zealand samples. New Zealand *Pecten* were homozygous for allele three. Australian samples were fixed for allele two, with the exception of Ulladulla where a single heterozygote was found (genotype 1,2).

Nei's unbiased genetic distance between samples ranged from 0.0016 (Cape Conran - D'Entrecasteaux Channel) to 0.5436 (Nelson - Shark Bay). The dendrogram based on all pairwise distances (Figure 2) clearly illustrates the high level of divergence between New Zealand (combined) and Australian collections (D = 0.3296). Within Australia, the average genetic distance between *Pecten* from Shark Bay and south-eastern Australian collections was 0.2234 (S.D = 0.0526), an order of magnitude greater than the average distance among the latter (0.0294, S.D = 0.0184).

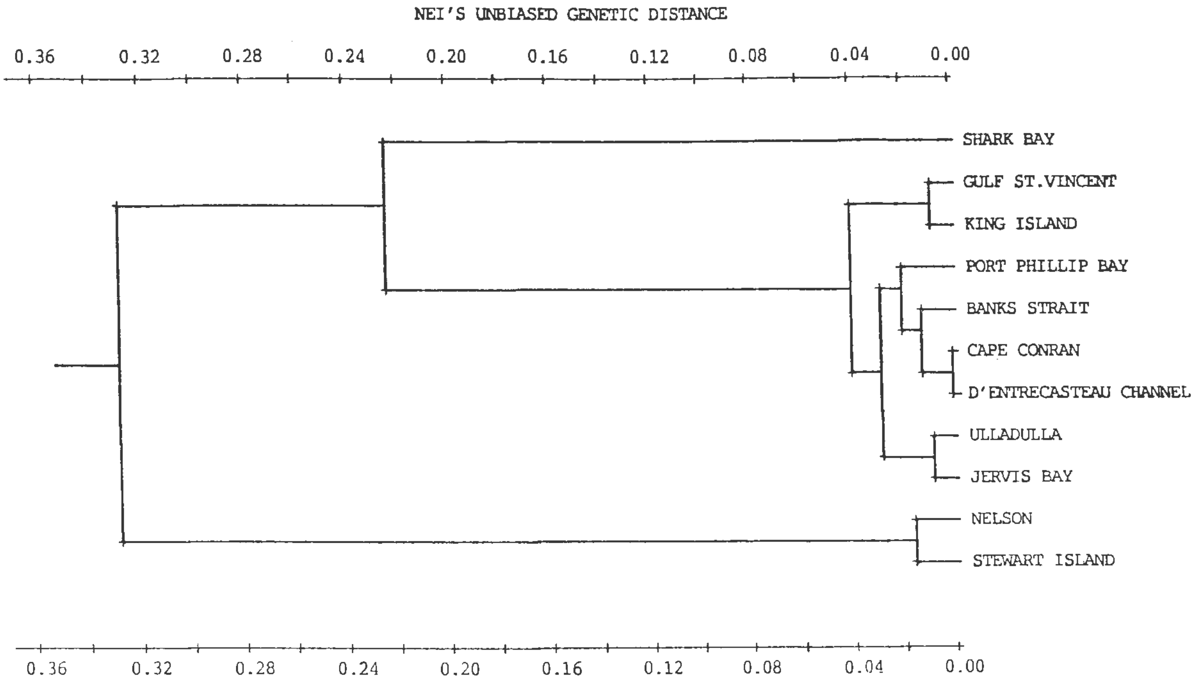

Figure 2. Cluster analysis, using UPGMA, of collections according to Nei's unbiased genetic distance (Nei 1978). (cophenetic correlation = 0.944).

Allelic frequencies at 12 loci for 15 collections of *P. fumatus* from south-eastern Australia were calculated. Within each of the Port Phillip Bay, King Island, Banks Strait and Cape Conran collections, multiple samples were not significantly heterogeneous, and were therefore combined.

Among collections, however, significant heterogeneity of allele frequencies was observed [homogeneity $X^2{}_{1106} = 4517.16$, $p<0.001$)]. Modified Roger's distances between pairs of collections ranged from 0.0307 (Stanley - Cape Conran) to 0.2603 (Gulf St. Vincent - Jervis Bay) (equivalent to Nei's unbiased genetic distances of 0.0000 and 0.1094 respectively).

Modified Roger's distance was used in subsequent ordination procedures since it satisfies the conditions of a metric quantity (Farris 1981) while Nei's unbiased distance does not. Figure 3 illustrates the ordination of collections in two dimensions by nonmetric multidimensional scaling (cophenetic correlation = 0.99). The superimposed minimum spanning tree links collections at the lower (Gulf St. Vincent) and upper (Ulladulla, Jervis Bay) extremes of dimension one to a central cluster. Port Phillip Bay and D'Entrecasteaux Channel collections are at the periphery of the central group, which otherwise consists of collections from the Bass Strait region (King Island, King Island east, Stanley, Table Cape, Tenth Island, Goose Island, Bay of Fires, Banks Strait, Babel Island and Cape Conran).

Table 1. Polymorphic proteins and their coding loci: conditions for analysis.

Enzyme	E.C. No.[1]	Locus	Buffer[2]	
Cellulose acetate electrophoresis:				
aspartate aminotransferase	2.6.1.1	AAT	L	
aconitase	4.2.1.3	ACON	C	
adenosine deaminase	3.5.4.4	ADA	I	
arginine kinase	2.7.3.3	ARGK	C	3
enolase	4.2.1.11	ENOL	B	
esterase	3.1.1.-	EST-1	C	4
		EST-2	C	4
isocitrate dehydrogenase	1.1.1.42	IDH	L	
leucine-amino peptidase	3.4.11.-	LAP	C	
octopine dehydrogenase	1.5.1.15	ODH	L	5
6-phosphogluconate dehydrogenase	1.1.1.44	6PGD	L	
phosphoglycerate kinase	2.7.2.3	PGK	B	
phosphoglucomutase	2.7.5.1	PGM	L	
pyruvate kinase	2.7.1.40	PK	L	4
triose-phosphate isomerase	5.3.1.1	TPI	L	
Starch gel electrophoresis:				
malate dehydrogenase	1.1.1.37	MDH-1	Tc-1	
		MDH-2	Tc-1	

1. Enzyme Commission Number (Anon. 1978)
2. cellulose acetate running buffers of Richardson *et al.* (1986), starch running buffer of Shaklee and Keenan (1986).
3. visualized routinely with a general protein stain, Amido Black (Richardson *et al.* 1986).
4. stain method A, Richardson *et al.* (1986).
5. volume of stain reduced to 2 ml for cellulose acetate (modified after Shaklee and Keenan (1986).

The similarity of this spatial representation of genetic distances with the map of collection sites (Figure 1) is striking: as much as 78% of variation in genetic distance may be accounted for by geographic (great circle) distance between sites [normalised Mantel statistic $Z = 0.8804$, p (random Z > observed Z) < 0.01, (Sokal 1988)].

F_{ST} also provides a measure of differentiation amongst collections: values were significant at each of 12 loci among collections from south-eastern Australia. The mean F_{ST}, (F_{ST}), was 0.0295 ±0.00216, a value reduced by one-third following the exclusion of Gulf St. Vincent, D'Entrecasteaux Channel, Ulladulla and Jervis Bay from the analysis. Further removal of the Port Phillip Bay collection reduced F_{ST} to 0.0295 ±0.0086. Among the remaining "Bass Strait" collections, eight loci exhibited no significant heterogeneity, while at the other four, (TPI, MDH-1, PGK and ARGK), the greatest contributions to heterogeneity were made by collections towards the eastern and western extremes of the region.

Table 2. Genetic variability at 17 loci in 11 samples of Australasian *Pecten*. (standard errors in parentheses)

Sample	Mean No. of alleles per locus	Percentage of loci polymorphic 0.95[1]	0.99[2]	Mean Heterozygosity direct-count	H-W expected[3]
Western Australia:					
Shark Bay	3.4 (0.6)	64.7	82.4	0.272 (0.064)	0.320 (0.073)
South-eastern Australia:					
Gulf St. Vincent	3.2 (0.5)	76.5	76.5	0.333 (0.061)	0.370 (0.068)
King Island	2.9 (0.5)	58.8	64.7	0.305 (0.070)	0.301 (0.069)
Port Phillip Bay	2.2 (0.3)	64.7	70.6	0.275 (0.061)	0.291 (0.060)
Banks Strait	2.4 (0.3)	64.7	76.5	0.246 (0.049)	0.269 (0.055)
Cape Conran	2.5 (0.3)	76.5	76.5	0.238 (0.049)	0.299 (0.056)
D'Entrecasteaux Channel	2.2 (0.3)	76.5	76.5	0.235 (0.047)	0.287 (0.052)
Ulladulla	2.5 (0.3)	64.7	88.2	0.266 (0.058)	0.275 (0.055)
Jervis Bay	2.3 (0.3)	58.8	76.5	0.238 (0.056)	0.257 (0.059)
New Zealand:					
Nelson	1.9 (0.2)	52.9	58.8	0.174 (0.047)	0.194 (0.053)
Stewart Island	2.0 (0.2)	47.1	58.8	0.121 (0.036)	0.174 (0.051)

A locus is considered polymorphic if the frequency of the most common allele is
1. <0.95
2. <0.99
3. Unbiased estimate of heterozygosity (Nei 1978).

Discussion

The validity of the specific status of *Pecten* from Shark Bay, Western Australia, (nominally *P. modestus*) and from Nelson and Stewart Island in New Zealand (*P. novaezelandiae*) is supported by the relatively high genetic distances associated with collections from those localities (see Figure 2). Fixed differences and allelic substitutions at more than 15% of loci (D > 0.15) typically reflect the absence of gene flow between species (Thorpe 1983).

The comparatively low level of genetic differentiation amongst collections of *Pecten* from south-eastern Australia suggests that a single species is present in these waters; genetic distances (see Figure 2) are well within the range of values found for conspecific populations a variety of organisms (Thorpe 1983), including the Pectinids *Pecten maximus* (Huelvan 1985) and *Patinopecten yessoensis* (Yamanaka and Fujio 1983, cited by Kijima *et al.* 1984). Although summary measures such as D provide "guidelines, not absolute yardsticks for making taxonomic decisions" (Rosenblatt and Waples 1986), similar evidence was provided support for the recognition of synonymies in many other bivalves: *Pecten maximus* = *jacobaeus* (Huelvan 1985), *Crassostrea gigas* = *angulata* (Mathers *et al.* 1974; Buroker *et al.* 1979), *Triostrea chilensis* = *lutaria* (Buroker *et al.* 1983) and *Mytilus edulis* = *galloprovincialis* (Gosling 1984). Of the three names hitherto applied to south-eastern Australian *Pecten*, *P. fumatus* should be retained, and *P. albus* and *P. meridionalis* considered synonymous with it.

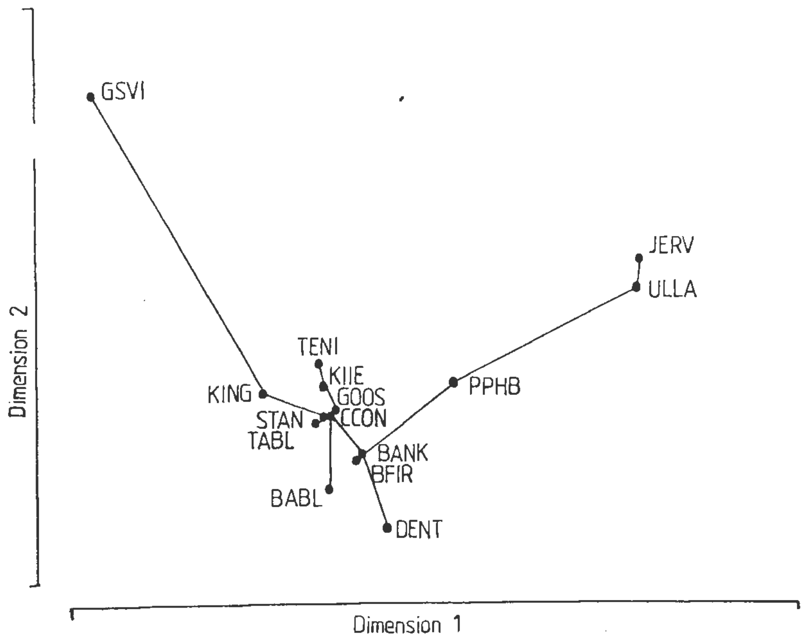

Figure 3. MDS of collections of *Pecten fumatus*.

The level of genetic variation attributable to differentiation amongst populations of this species (only 0.8% in "Bass Strait") is very low, yet consistent with values reported for other marine molluscs [*Crassostrea virginica* (Buroker 1983), *Mytilus californianus*, *M. edulis* (Levinton and Suchaneck 1978), *Siphonaria* sp. (Johnson and Black 1984)] and those fishes (Winans 1980, Waples 1987) which have pelagic larval stages. In contrast, viviparous and estuarine species commonly exhibit values of F_{ST} an order of magnitude higher (Winans 1980, Waples 1987). Homogeneity may be a consequence of:

(i) similar selective regimes throughout the geographic range, (assuming that the frequencies of a large proportion of alleles sampled are significantly affected by natural selection), and/or

(ii) gene flow (affected perhaps by the movements of planktonic larvae and/or the loc*r* extinction and recolonisation of populations) of sufficient strength to counter evolutionary forces promoting divergence [e.g. selection favouring different alleles in different populations, or random changes in allele frequencies due to finite population size (genetic drift)].

Contrary to the expectations of scenario (i), the locus which most strongly displays characteristics consistent with the action of natural selection, PGK, (L.W. unpublished data) exhibits significant heterogeneity of allele frequencies, suggesting that 'disruptive', rather than 'homogenising' selection may be operating at (or near) this locus. Under the assumption that the evolutionary dynamics of alleles may be described by models of neutral (or nearly neutral) genetic markers (Kimura 1968), the effectiveness of gene flow in preventing the differentiation of populations depends on the product of effective local population size (N), and the fraction of the population per generation that is immigrant (m). The larger 'N', the smalle the sampling effects generating drift, and hence the lower the proportion of the population which must be exchanged to counter them.

The product 'Nm' may be estimated from observed distributions of allele frequencies: the results of this study are consistent with the exchange of tens of individuals per population per generation, (estimates among the highest reported in the literature [Waples 1987], and an order of magnitude greater than is necessary to negate the differentiating effects of genetic drift [Wright 1931] [Woodburn unpub. data]). However, an assessment of the values of the components 'N' and 'm' must be made independently. A clue to determining whether homogeneity of populations is largely due to a lack of stochastic change, and not to the effects of migration, may be obtained from patterns of variation in extra-nuclear genes (such as those maternally inherited in mitochondrial DNA).

The evidence presented in favour of a low level of genetic divergence (probably resulting from a high level of gene flow) between populations of *Pecten* in south-eastern Australia supports the contention that *P. albus* and *P. meridionalis* are synonymous with *P. fumatus*. The gene pool in 'Bass Strait' appears to be especially cohesive, with populations in Port Phillip Bay, southern Tasmania, New South Wales and South Australia relatively isolated from it. Two additional species were detected in southern Australasian waters: one in Western Australia (nominally *P. modestus*) and another in New Zealand (*P. novaezelandiae*).

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GENERAL DISCUSSION

Joll: If I've interpreted your dendrogram correctly, the Western Australian population is most distantly spaced from other Australian populations and the Jervis Bay and South Australian samples were more closely spaced. Is that a correct interpretation?

Woodburn: The dendrogram indicates greater differences as the intersects move to the left. The intersects to the right indicate genetic similarity, so the Western Australian sample is dissimilar to the remainder.

Zacharin: What is the correct terminology for the southern *Pecten* now?

Woodburn: Subject to acceptance in the literature, *Pecten fumatus*.

Coleman: In Tasmania where the numbers of wild broodstock are small and the next generation may be produced through hatchery production, there may be implications for heterozygosity in this artificially produced population. Can you comment on the numbers of individuals which should be used in our hatchery breeding program?

Woodburn: Since the loss of heterozygosity decreases with increasing population size, the more brood stock you use the better. Loss of heterozygosity is not substantial when effective population size is greater than 50: in a hatchery, allowing for mortality, this number probably translates to something like 100 animals.

Zacharin: When we collect broodstock from around the state, if we can't give it to the hatchery we take it to the hanging longlines near Maria Island. In some instances, when they are taken from the north coast of Tasmania, their condition doesn't improve when they are moved to a more favourable site, whereas other scallops improve. So are environmental, rather than genetic factors, associated with this failure to put on condition when moved to different areas?

Woodburn: Although, within this region, there appears to be little variation in the frequencies of the genes I've studied, this does not exclude the possibility that the frequencies of other genes, including those controlling growth rates, do vary from place to place.

Zacharin: So genetics still may play a role in growth rate variation?

Woodburn: Certainly.

Young: I've always had a problem with this effective sort of mixing: the magic numbers you talked about earlier. Accepting what the geneticists and number crunchers say. You're talking about nine individuals or 15 individuals within a population of indeterminate size to enable ffective mixing of genes between two populations.

Woodburn: My 'magic numbers', as you call them, are simply interpretations of the observed levels of differentiation, based on simple models. Assuming that there is no selection, exchanges of tens of individuals per generation between populations in the Bass Strait region are sufficient to explain the observed pattern of genetic variation. That is, tens of individuals migrating, breeding and contributing genetically to those populations.

'Nm', the absolute number of effective migrants is used, and not a proportion of the population size, because 'Nm' reflects the resultant genetic effect of two opposing forces: gene flow promoting homogeneity among populations, and genetic drift promoting divergence (i.e. random changes in gene frequencies from one generation to the next which result from sampling a finite pool).

For example, in order to balance the effects of drift, the proportion of the population which needs to be exchanged, 'm', is inversely proportional to effective population size, 'N'. If the average population size is large, genetic drift will be weak, and the proportion of the population that needs to be exchanged to counter its effect will be small. In small populations, drift will be strong, and 'm' must be high to prevent divergence.

So for any given value of the product of 'N' and 'm' (Nm), whether 'N' is large and 'm' small, or 'N' is small and 'm' large, the expected level of divergence amongst populations will be the same.

Gwyther: Is the observation that in Port Phillip Bay scallops grow faster now than they did 20 years ago relevant to the discussion? Twenty years ago we had a size limit larger than the size scallops actually reach now. That size limit was gradually eroded, and now that we don't have a size limit, we're fishing one-year-old scallops that hit L_∞ faster than they did 20 years ago. Is that in some way genetically driven, greater heterozygosity enabling scallops to respond to whatever has changed and grow faster?

Woodburn: Significant correlations between heterozygosity and growth have been found in oysters and mussels, and may be true of our scallops, although I found no evidence for it in the CSIRO cage experiment discussed by Dick Martin. There's a body of general evidence which suggests that heterozygotes may be better able to cope with changes in their environment than homozygotes.

Anon: But that would only be 20 generations.

Woodburn: If there is strong selection, substantial changes are possible.

Thomson: On the one hand you're saying heterozygotes are better for growth and then on the other hand you were giving the example of Japanese culture scallops, scallops which are selected presumably as homozygotes. So I think you gave me the answer in that heterozygotes are better able to withstand changing environmental conditions, but in fact the whole of agricultural selection for higher growth is on the basis of line-breeding and in-breeding, which is selective of homozygotes.

Woodburn: I don't know what the underlying genetic basis of growth in scallops is.

If genes with additive effects contribute greatly to the overall genetic variance (i.e. if narrow heritability is high), directional selection should be successful in increasing mea population growth rate. This strategy, where the top x% is chosen as broodstock for the next generation, appears to have been successful in Japan.

However, if genes whose effects are non-additive predominantly control growth rate (i.e. if narrow heritability is low), greater gains would be made by line-breeding, and then crossing those lines: the 'crossbreds' would be expected to be highly heterozygous and exhibit high growth rates.

THE GROWTH AND MORTALITY OF *PECTEN FUMATUS* SPAT IN COLLECTORS IN BASS STRAIT: A PRELIMINARY STUDY

R. J. McLoughlin, P. C. Young and R. B. Martin
Division of Fisheries, CSIRO Marine Laboratories,
G.P.O Box 1538, Hobart
Tasmania 7001.

Abstract

Simple linear models were used to examine the growth and mortality of spat of Pecten fumatus in collectors at six sites in Bass Strait. The relationship between the growth of settled spat after the 1985 and 1986 spawning to measurements of water temperature, chlorophyll a, spat density, and spat size was examined by multiple regression techniques. The growth of spat smaller than 15 mm shell height was positively related to the concentration of chlorophyll a in the water column. This relationship was only marginally significant after the 1985 spawning, but highly significant after the 1986 spawning. Spat mortality was estimated by cohort analysis of dead spat shells collected from the spat bags, but the data may be biased by the loss through the bag meshes of shells less than 4 mm shell height, and also by shell commination and dissolution. It is concluded that estimates of spat mortality in collectors cannot be made with the present information.

Introduction

The pectinid mollusc *Pecten fumatus* (Reeve) occurs over a wide area of the south-eastern Australian continental shelf, and has supported a major fishery in Bass Strait since the early 1970s.

Management's need for information on the biology and ecology of this species in Bass Strait led, in 1985, to CSIRO establishing a major research program on factors influencing its distribution, abundance and productivity. As part of this research program, the mechanisms of dispersal, settlement, growth and survival of *P. fumatus* spat in Bass Strait were examined.

These included the relationship of spat to the distribution, abundance and reproductive behaviour of adults, prevailing water conditions, and phytoplankton abundance.

Apart from reports of settlement on spat collectors in eastern Bass Strait (Hortle 1983; Cropp unpub. data) and off Lakes Entrance (Gwyther 1984), little was known about the timing or distribution of spatfall in Bass Strait, and nothing was known about the influence of environmental conditions on spat growth and mortality. This paper presents a preliminary examination of the growth and mortality of spat in collectors, based on data collected from the 1985 and 1986 spawning seasons. It also examines their growth with respect to their density in the collectors, and to the phytoplankton abundance and temperature of the surrounding waters.

Methods

Spat collecting bags were deployed at six locations (Figure 1). They were placed as close as possible to existing or previously fished scallop beds, in water depths between 45 and 50 m. The bags were made of a 4 mm polypropylene mesh, filled with approximately one kilogram of aged monofilament nylon gill netting, and were attached in pairs on a vertical rope. Following the 1985 spawning the bottom pair were attached five metres above the sea bed, ten pairs thereafter being attached at three-metre intervals up to fifteen metres below the surface. Due to operational constraints, fewer bags were deployed following the 1986 spawning. The bottom pair was still attached to the vertical rope at five metres above the sea bed, but thereafter only three pairs were attached at six-metre intervals towards the surface.

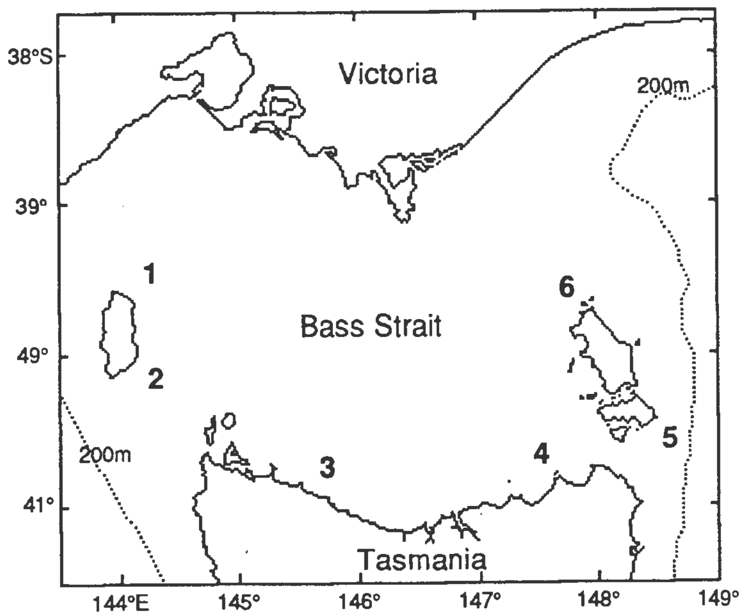

Figure 1. CSIRO spat collector sites in Bass Strait

Three anchored lines with their attached collecting bags were placed at each site, and each month the oldest line was replaced by a new one. Apart from the first set of lines in 1985, each line of collectors remained in the water for three months and shared the same water conditions for a month with the preceding and succeeding line. A diagrammatic illustration of the procedure is shown in Figure 2. Collectors were in the water from before the stocks spawned until after significant settlement could no longer be detected (eight months in 1985/86, nine months in 1986/87).

To ensure conformity between samples and to approximate the natural conditions on the sea bed, the second pair pair of bags above the bottom was used in the present analysis. In the first year these were attached at eight metres above the sea bed, and in the second year, at 11 metres above the sea bed.

Upon retrieval of the spat-line, the contents of the bags were washed into a 0.5 mm mesh plankton net held in a rigid frame, and the catch frozen for subsequent sorting, identification, and measuring in the laboratory.

Concurrent with retrieval of the spat-lines, water samples were taken from the surface, midwater and bottom with eight-litre Nisken bottles and profiles of temperature, salinity and depth were made with a 'Platypus' submersible data logger. Chlorophyll *a* concentration in the water samples was determined using the method of Jones (1979), and the nutrients (silicate, nitrate, nitrite, phosphate and ammonia) were measured with a Technicon model AA2 autoanalyser.

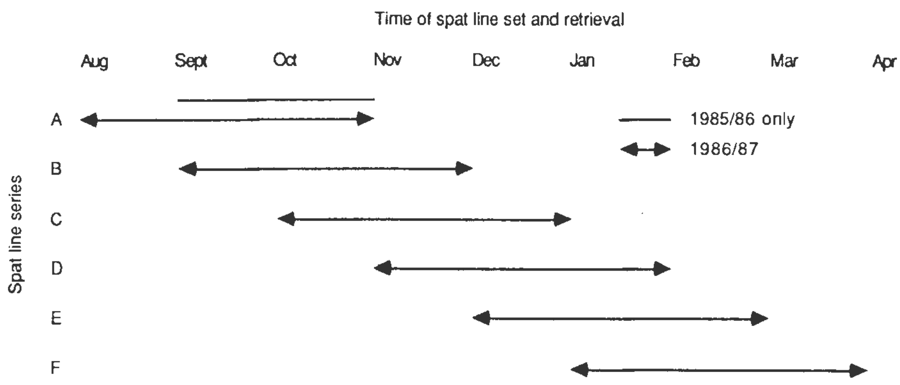

Figure 2. Temporal arrangement of spat lines at each site over both years. Note that in 1985/86 the first spat line was placed in September, and thus was in the sea for only two months.

The population growth increment each month was determined, for each pulse of settlement, by examining the progression of modes between successive samples. This was done only for samples containing more than 50 individuals. The modal analysis method used was that of McDonald and Pitcher (1979) as implemented in their modal analysis program MIX 2.3 (Icthus Data Systems). This program calculates the mean shell height, standard deviation, and the relative proportions of individuals in each mode in the sample.

Measurement of growth across the whole size range of individual species enables calculation of growth parameters, usually based on asymptotic models, that are well described in the literature (eg. Von Bertalanffy growth model). However, small segments of asymptotic curves may be approximated by linear models (Pryce 1973). In this study, we have examined small growth increments of spat ranging in shell size from 1-12 mm only, and use a linear model to investigate these growth increments.

The growth of adult bivalves has been shown in various species to be variously related to density (Gruffydd 1974), water temperature (Macdonald and Thompson 1985; Brown 1988), size of the individual (Muus 1973), and phytoplankton concentration as measured by chlorophyll *a* or *b* (Broom and Mason 1978; Brown 1988).

If it is assumed that any growth increment in scallop spat measured over time is related to some function of these environmental variables above, then :

$$L_1-L_0 = a + b\ (\text{shell height } (t_1+t_0/2)) + c\ (\text{chlorophyll } (t_1+t_0/2)) + d\ (\text{temp.}(t_1+t_0/2)) + e(\text{density } (t_1+t_0/2)) \qquad (1)$$

and hence by reduction,

$$L_1\text{-}L_0 = a+[\ b\ (\text{shell height}) + c\ (\text{chlorophyll}) + d\ (\text{temp.}) + e\ (\text{density})]\ (t_1+t_0/2), \qquad (2)$$

where L_0 = modal shell height at time t_0 and L_1 = modal shell height at time t_1, and a, b, c, d, e are constants. As spat density varies widely between sampling sites, the frequency data were transformed by taking the logarithm of the number of spat in each sampling period. This gave the final form of the growth increment equation as

$$L_1-L_0 = a+[b\ (\text{shell height}) + c\ (\text{chlorophyll}) + d\ (\text{temp.}) + e\ (\text{log density})]\ (t_1+t_0/2) \qquad (3)$$

This equation may be used to investigate, by multiple stepwise regression, the relationship between the dependent (growth increment) and the independent variables (size, temperature, etc), and was carried out using the statistical package 'GENSTAT' on a VAX 11/750. The mean values of sequential monthly samples at each site were used as the independent variables. The significance of each of the variables after each addition to or subtraction from each model run was calculated by an F test from an analysis of variance after each step.

Results

Mortality

Of the various models describing natural mortality that have been proposed for fish and molluscs, few relate to the juvenile phase only. In this study, we investigated three questions:) Is mortality directly measurable in juvenile scallops? (2) Is it a function of size or density? and (3) Does it change with time? The measurement of natural mortality assumes dead spat leave behind a recognisable shell, so from any cohort the proportion of spat that die, P_D, between sampling times j and j–1 is given by

$$P_D = \frac{N_{Dj}-N_{Dj-1}}{(N_{Dj}-N_{Dj-1})+N_{Lj}} \qquad (4)$$

where ND and NL are the number of dead and live spat, respectively, in that cohort.

The mortality model was fitted to 1985/86 length frequency data for those sites where an identifiable population of spat appeared in two or more consecutive samples at a site. This occurred only at sites three and six, both of which had spat in three consecutive samples that appeared to be from a single spatfall. At both sites a successively smaller proportion appear to have died between each sampling period (Figure 3), until ultimately the value of P_D becomes negative. This can only occur if dead shells are being lost to the bags between sampling periods, producing a negative value for the numerator in equation one.

Growth

Summary statistics of the variables measured at each site are shown in Table 1. The mean chlorophyll *a* concentration for all sites was 24.6% greater after the 1986 spawning than after that in 1985, the number of spat in the bags was 295% greater, and the mean water temperature was 0.8° C colder.

The analyses of variance of the regression model for each year, and for addition or subtraction of each variable to the model are summarised in Table 2. The only variate showing a relationship with the growth increment was chlorophyll *a*, which had a significant positive coefficient of + 0.0755 ± 0.013 after the 1986 spawning ($P \leq 0.001$, $F(1,21) = 30.68$).

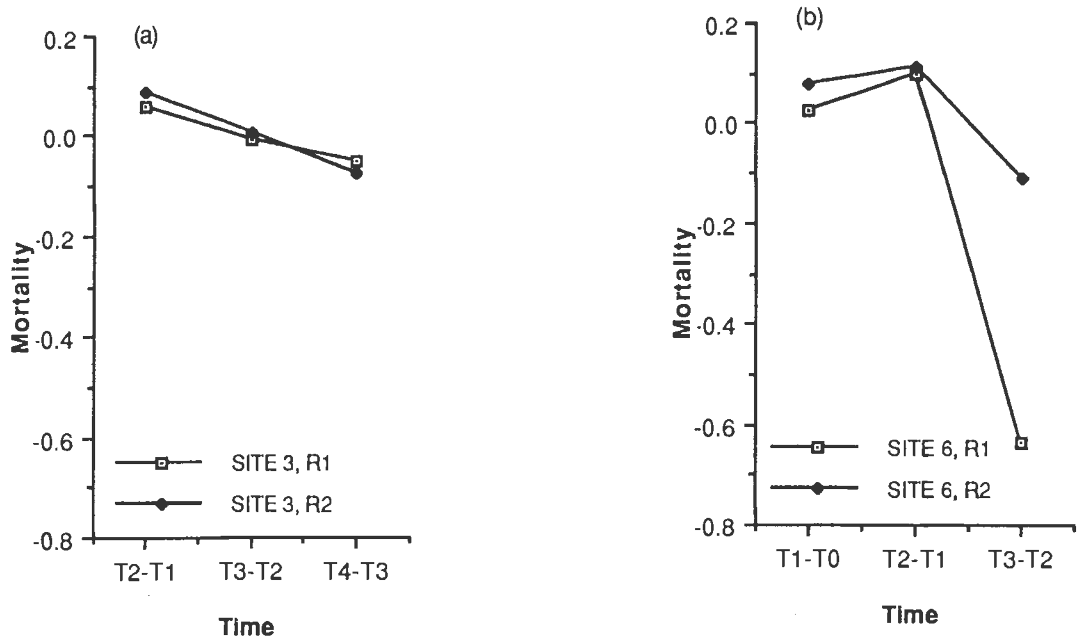

Figure 3. Mortality model results for 1985/86; (a) site three and (b) site six.

Table 1. Summary statistics of regression variables used in the growth model (number of samples: 1985/86=28, 1986/87=24)

Variable	Minimum		Mean		Maximum	
	1985/86	1986/87	1985/86	1986/87	1985/86	1986/87
Time (days)	27	28	31	41	43	71
Height increment (mm)	0.40	1.40	2.95	3.75	7.20	7.30
Chlorophyll (ug/L)	0.31	0.55	0.84	1.12	1.15	1.88
Temperature (°C)	14.60	13.80	16.54	15.72	18.20	16.90
Density (spat/bag)	44	27	125	366	669	2762
Shell height (mm)	3.50	2.60	6.76	4.90	12.46	9.20

None of the other independent variables contributed significantly to the regression. The growth rate for the spat of *P. fumatus* in Bass Strait after the 1986 spawning period is therefore given by:

Growth rate (mm/day) = 0.0120 + 0.0755± 0.013 (chlorophyll (ug/L)) (5)

Discussion

The use of the ratio of live to dead shells to estimate mortality in scallops is not new; the method was used for *Placopecten magellanicus* (Merrill and Posgay 1964) and, more recently, for *Chlamys islandica* on the Georges Bank (Naidu 1983). Our preliminary analysis suggests that this approach cannot be applied to our samples due to an apparent post-mortem loss of ιells from the collectors; no dead spat shells smaller than 4 mm shell height were found.

Presumably they detach from the monofilament netting substrate after death, and were lost through through the 4 mm mesh of the collectors. This, and the loss from crushing by crab or fish predators, would explain the decreasing proportions of dead spat described by the model.

Table 2 . Anova of multiple regression modelling at each step

1985/86 Initial constant 'a' = 0.0984 (S.E. = 0.0142)

1986/87 initial constant 'a' = 0.0120 (S.E. = 0.0165)

Terms	d. of f.		F		significance	
	1985/86	1986/87	1986/87	1985/86	1986/87	1985/86
initial constant	27	23				
+ spat height	27	22	0.38	27	n.s.	n.s.
+ chlorophyll	25	21	2.94	0.77	*	* * *
+ temperature	24	20	0.35	0.68	n.s.	n.s.
+ log density	23	19	0.18	3.30	n.s	n.s..
– log density	24	20	0.18	0.31	n.s.	n.s.
– temperature	25	21	0.35	0.46	n.s.	n.s.
– spat height	26	22	0.39	2.85	n.s.	n.s.
– chlorophyll	27		2.94		*	

where * = P< 0.1, ** = P< 0.05, *** = P< 0.01

The metabolic requirements for growth and survival of scallops have received scant attention in the literature, but the few studies completed suggest that food availability is limiting for some species, particularly when temperature is taken into account. (McLusky 1973; MacDonald and Thompson 1985; Bricelj *et al.* 1987).

Mikulich and Tsikhon-Lukanina (1981) described different food types ingested during periods of growth or spawning of *Patinopecten yessoensis*. Greatest variation was shown by scallops living in cold waters.

A relationship between the growth of adult scallops, phytoplankton concentration, and temperature has been reported. Broom and Mason (1978), for example, found a relationship between all three environmental variables and the growth of *Chlamys opercularis* in water temperatures as low as 3° C. They argued on theoretical grounds, however, that this did not necessarily imply a single causal relationship because, in general, as long as food is not limiting, the growth rate of poikilotherms tends to increase with temperature. Conversely, if the temperature is too low, then no amount of food will result in higher growth rates (Jorgenson 1966).

In a study of the effects of temperature and food levels on the Bay scallop *Argopecten irradians*, Kirby-Smith (1970) predicted that the growth rates of scallops less than two cm in shell height would be independent of chlorophyll *a* levels at all times of the year, and that lack of food was limiting for adults only during summer when water temperatures were high. In winter the growth was said to be limited by low water temperatures. This degree of cold-water inhibition of growth is presumably species specific, for Wallace and Reinsnes (1985) found that temperatures as low as 2° C did not significantly affect the growth of adult *Chlamys islandica*, while food levels were critical at all temperatures.

In the present study, the growth of spat was positively related to chlorophyll *a* concentration, but not to the size and density of the spat, or the water temperature. The absence of a relationship with temperature is presumably because the water temperatures in Bass Strait did not vary sufficiently to affect the metabolism of the spat at the time (Figure 4), even though the observed temperature range was 5-6° C. Although the absence of a relationship with the animal's size may be because its growth is controlled directly by food availability, we cannot explain of the lack of relationship of growth with density in a similar way.

This absence of a relationship is puzzling because the significantly increased growth with chlorophyll *a* concentration would also be expected to be reflected in a negative relationship with density.

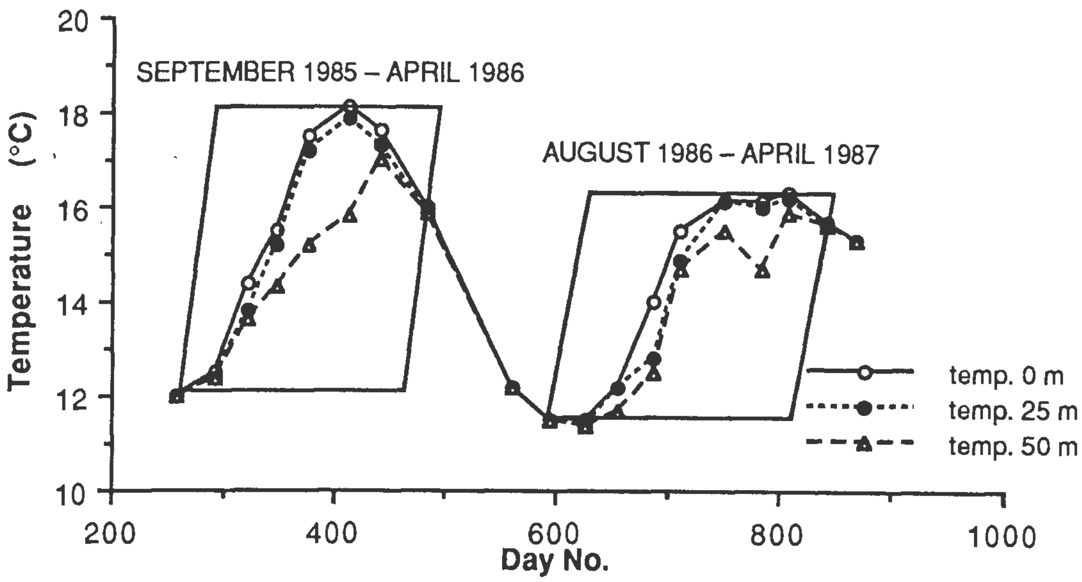

Figure 4. Water temperatures at 0 m, 25 m, and 50 m at site three, with temporal extent of spat sampling. Days are counted from 1 January 1985.

This study has shown, however, that the growth rate of the settled spat of *P. fumatus* is extremely variable, and the fitting of a conventional (asymptotic) growth curve over small ranges of total growth is likely to be fraught with problems, as has has been found in other studies of bivalve species (Conan 1984). Further investigation of growth rates would be better done by physiologically based experiments in which the anabolic and catabolic energy requirements are evaluated and compared with those provided by their food, as has been suggested for *Argopecten irradians* (Kirby-Smith and Barker 1974) and *C. opercularis* (Broom and Mason 1978).

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GENERAL DISCUSSION

Thomson: In your demonstration of the use of satellite imagery to measure chlorophyll levels, have you considered if turbid water in coastal areas, such as those influenced by river flow, may affect apparent algal density?

McLoughlin: We hope that in the near future, sensors carried by aircraft will be able to verify satellite imagery data on areas of primary production.

Gwyther: I'm not surprised by the shape of your mortality curves of spat in bags given that the animals are trying to move around in a three dimensional environment. The bigger they get, the more likelihood they would have of being trapped in the mesh, particularly if they were in the middle of the bag. If this happened, they wouldn't be able to open their valves, and therefore might starve. Likewise, the ones in the middle wouldn't get so much of the water flow as compared to the ones in the corners, and so wouldn't grow so well.

McLoughlin: There are any number of reasons why we could add to the analytical techniques we used to examine these data. I think we've used a reasonably rigourous approach in terms of considering what might be happening with three or four variables. But there could be any number of explanations at this stage.

Cropp: I noted you had considerable difference in growth from animals from King Island and Banks Strait in January and February. Did you notice anything that would indicate why such a difference occurred?

McLoughlin: No direct observations. Chlorophyll levels for these areas and dates might give some idea, but monthly resolution of environmental parameters isn't good enough for this type of assessment. In areas like Bass Strait, where high volumes of very different water can move in and out quickly, monthly resolution doesn't tell us very much.

Zacharin: Did spatfall occur in areas where there were high chlorophyll levels?

McLoughlin: We recorded spatfall in dribbles through most of our observation time, but in terms of five or six spat per bag. The high levels of spatfall, of the order of 50 to sevei hundred per bag, occurred in October and November in 1985 but earlier in 1986. This appeared to be about a month after the spring bloom.

LESSONS AND MISTAKES FROM RECENT TRIALS OF METHODS FOR SPAT CATCHING AND GROW OUT OF SCALLOPS IN NEW ZEALAND

Mike F. Bull
Ministry of Agriculture and Fisheries
Nelson
New Zealand

Abstract

Some of the methods used in New Zealand over the last 15 years for developing a knowledge of spat catching and on growing techniques for scallops are described. Recommendations are given as to how resources might have been better used to provide information necessary for the establishment of an enhancement operation in a new area. It is concluded that for establishing the best timing and location for commercial spat collection a trial and error approach is preferable to a more theoretical approach involving studies of hydrology, spawning activity and larval distribution. Large numbers of commercial type collectors can be economically deployed over a wide area and time period and the results of such trials can be directly applied to subsequent commercial operations.

Introduction

This paper briefly describes the approach taken and some of the methods used in trials of spat catching and seeding of scallops that have been carried out in New Zealand over the last 15 years. These trials have included small scale university studies (Bull 1976), a number of spat catching and hanging culture trials carried out by private industry (1978-81) and the pilot commercial scale seeding operations carried out by the Ministry of Agriculture and Fisheries (MAF) and the Overseas Fishery Co-operation Foundation (OFCF) of Japan in the Nelson area since 1983 and in Auckland area since 1987. By looking at some of the experiences gained from these trials and others in Australia and elsewhere it will hopefully be possible to make improvements in the planning for this type of study in future.

Trial Objectives

Clear definition of objectives is an obvious requirement for any trials and has been a major weakness of some of the New Zealand trials, particularly those carried out by private industry. For a trial of an enhancement operation based on a natural spat catch the following would appear to be the major questions to be answered:

(1) When, where and how reliably can spat be caught in the wild?

(2) What survival rates can be expected from different methods of release?

(3) What factors affect survival and yield and how can seeding practice be modified to maximise these parameters?

(4) What costs are likely to be involved with a commercial enhancement operation and are these justified in light of likely yields?

In addition to providing answers to most of these questions the enhancement projects carried out by MAF and OFCF in New Zealand have served a major function in training local people in the use of new technology and raising public awareness of likely benefits from such operations. It is expected that the involvement of local people in the trial projects will prove extremely useful in helping overcome opposition from other users of the sea area concerned as a move is made to the development of full scale commercial operations.

Assessing Spat Availability

Availability of an abundant, cheap and reliable supply of spat is the first and most important consideration in assessing the likely viability of any large scale enhancement operation. The approach we have followed in the last few years in extending our knowledge of the best time and location for spat catching is a trial and error approach using gear as similar as possible to that used in a commercial situation.

During the spat settlement season test collector bags of the type used for commercial spat collection were placed in the water on a fortnightly basis on independently buoyed ropes and held two to four metres off the seabed. These bags were removed for counting of the spat catch after ten weeks (Figure 1). Catches in these test bags have generally correlated well with catches in bulk collectors placed nearby at the same time and this direct applicability is of considerable advantage.

In the early 1980s some effort was put into forecasting dates of main settlement peaks as a guide for the setting of bulk lots of collectors. This involved:

(1) Monitoring changes in gonad condition in adult scallops as an indicator of spawning activity,

(2) Following changes in abundance of late stage scallop larvae in plankton samples collected on a weekly basis during the spawning season,

(3) Monitoring settlement of scallop spat on lengths of christmas tree mussel rope sampled at weekly intervals.

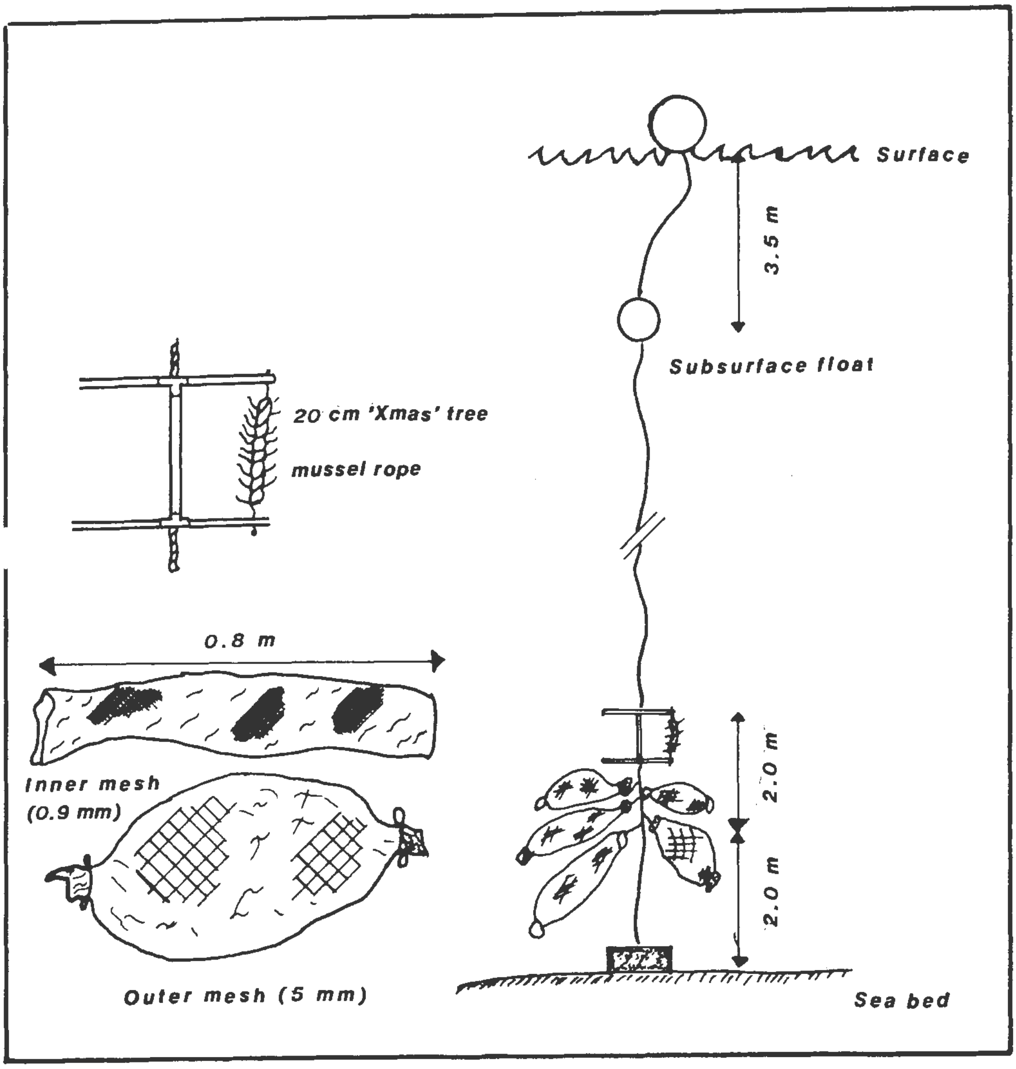

Figure 1. Equipment used for monitoring spat settlement.

In several cases the data obtained showed the expected sequence of a drop in general condition of adults, an increase in larval numbers and a subsequent increase in settlement success. However this sampling was eventually discontinued because as an indicator of future settlement peaks it was not always reliable and it gave insufficient lead time to allow for organising the placement of large number of collectors. It was found that in the trial area collectors were effective in catching spat for at least a month after placement and it was better to place bulk collectors on a preset date rather than rely on a time consuming and unreliable spat forecasting system. We did persist with the gonad sampling but mainly with the intention of giving background information so that in the event of a spat failure there might be some information available to point to its cause.

The Value of a Pilot Commercial Scale Operation

Once a suitable spat source has been identified, the next major step in investigating the feasibility of a commercial enhancement operation must be to develop the appropriate methodology and provide information on survival yield and costs.

Some aspects of this work are probably best investigated using a small scale experimental approach but others, such as development of commercially applicable handling techniques and realistic cost assessment, require a medium scale pilot operation as has been carried out in New Zealand. Experience from the small scale releases carried out by MAF in 1982 indicated that even minor levels of dispersal could rapidly reduce densities to such a low level that monitoring of survival by dive sampling rapidly becomes impractical. This was one of the reasons why the larger scale mass seeding approach was followed in the subsequent trials. Such an approach also has the advantage that by approaching the commercial scale of operation as nearly as possible, unknowns associated with the experimental scale (such as the effect on predation levels associated with scaling up the release numbers) become irrelevant.

Choice of Longline Structure

In the early 1980s tests were carried out on the relative effectiveness of spat collector bags constructed of a variety of outer meshes and inner material. Both onion bags of one mm mesh stuffed with used monofilament gill net and the currently used collectors of five mm outer mesh and 0.9 mm inner mesh were found to be satisfactory. The latter type was chosen as fouling of collectors of hydroids, bryozoa and mussels was usually very severe in Golden Bay and smothering of spat within collectors was less of a problem if large outer mesh was used. In a commercial operation these collectors also have an advantage in that the outer mesh is relatively cheap (26 cents per bag) and can be discarded after use, avoiding costs of recovery and cleaning.

Trials carried out to investigate any relationship between the level of the collector in the water column and subsequent settlement success have shown that settlement is generally least near the surface, but that mortality of spat within bags is greatest close to the seabed (Bull 1980). This information was used in designing the spat bag longlines used in the Golden Bay enhancement operation in that the lowest collectors on the droppers were held at least two metres off the seabed (Bull this volume). However other practical considerations such as the need to have the backbone at least five metres below the surface to reduce the effects of surface waves and minimize the risk to passing vessels dictated the uppermost level for spat bag placement. As the original spat catching site in Golden Bay was only 16 m deep this effectively meant that spat collectors had to be placed within 2 - 11 m from the seabed thus determining dropper length and longline design. Such practical considerations played a large part in determining the development of the seeding trials in Golden Bay and this should be borne in mind when planning investigative work of this type. There is little point in proving a certain method or location for spat collection if practical considerations eliminate its use on a commercial basis.

Choice of Methods for Assessing Survival and Dispersal

For any trial of the viability of an enhancement operation it is essential that survival of seeded spat is monitored on an on-going basis to provide information on the timing and possible causes of mortality peaks and allow for necessary modifications to be made to management practices during the trial period. It is also vital that accurate figures of survival from seeding to harvest under different management regimes can be obtained for use in cost/benefit analyses.

In the Golden Bay trials the on-going monitoring of survival consisted of dive surveys carried out approximately three months after the initial release and then at six monthly intervals. In most cases the areas concerned were square plots of 1 km^2 and the surveys were carried out using transect lines of at least 630 m in length which were laid from the centre of the plot and passed through and beyond the mid way point of each of the plots margins (Figure 2). As a diver swam along the line from the centre to the outside he counted the scallops in a 0.4 m wide band along each 30 m section of the line.

In some cases, where a mixture of seeded and wild scallops or scallops seeded by different methods existed the diver collected the scallops in each strip and they were later taken to the surface for counting, measurement and identification as to origin (Bull 1986).

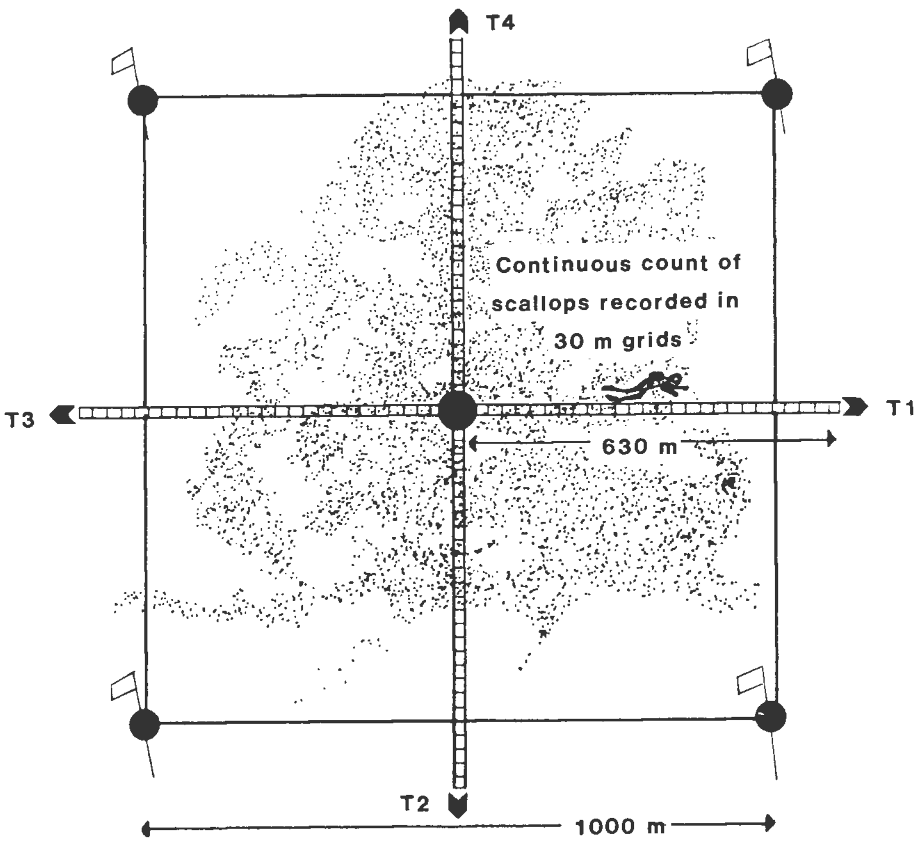

Figure 2. Survey method used for assessing scallop distribution and abundance on release plots.

The data gathered using this method were used to plot the distribution of the scallops and a simple estimate of the number of scallops within the plot was obtained by multiplying the estimated density of scallops in each successive 30 m square band from the centre by the area of each band and summing the estimates.

Sampling within the plot was not random and it was therefore not possible to get a good idea of confidence limits on the population estimate using this method. However the method had the major advantage of being practical to carry out in a situation where diver bottom time and problems with precision positioning of sample sites were major limiting factors. It also provided good information on changes in distribution of scallops within the plot and the extent of their movement outside the plot boundaries.

To assess overall survival of scallops in the Golden Bay trials, the main method used was experimental harvesting of seeded plots. Recapture of tagged scallops which had been released on to the plot just prior to harvest was used as an indicator of fishing mortality. These methods were of little value where scallops on a harvested plot originated from more than one seeding method and in such cases reliance had to be placed on percentage recovery of small numbers of scallops that were tagged at the time of spat release. Recently scallops as small as ten mm shell height have been successfully tagging using flexible 'Hallprint' tags and cyanoacrylate glue and in light of experience gained from the Golden Bay seeding trials tagging is recommended as a cost effective and reliable method for assessing survival to harvest.

Technical Problems

One of the major difficulties experienced in the Golden Bay seeding trials was a lack of an ability to precisely identify the boundaries of seeded plots once site markers had been removed. In these trials radar range finders on the local fishing vessels were used to record the distances of the corners of the plots from suitable land marks. However, with some of the lots being five nautical miles or more from the nearest land and with a variety of different vessels being used this did not give the required accuracy. In some cases it was impossible to be sure whether absence of scallops on a survey transect was due to poor survival or inaccurate position fixing.

Use of a more accurate navigation system (e.g. Motorola Miniranger or Del Norte Trisponder) would have overcome this problem.

Planning for Future Management

One of the major failures of the Golden Bay enhancement trials was an inability to come up with a suitable system for managing a commercial enhancement operation by the time the trial program ended.

Any proposals for bottom seeding operations are likely to face considerable problems because they inevitably involve alienation of large areas of sea bed which is generally considered a common property resource. This is likely to be particularly difficult in an area where fishermen have historical scallop fishing rights. In the case of the Golden Bay trials, the problem was made worse by allowing fishermen to develop expectations of future involvement which could not be delivered.

It is strongly recommended that in the establishment of any future trials of the type carried out in Golden Bay it is either clearly defined who will share the eventual benefits of any success or alternatively that absolutely no commitments to future involvement are given.

Conclusions

In recent New Zealand trials of scallop seeding methodology, studies on where, when and how to collect scallop spat have been conducted using a broad scale trial and error approach with the emphasis being on practical, commercially relevant considerations. This approach is considered preferable to more theoretical studies set at a lower level such as studies on hydrology, spawning activity and larval distribution.

Testing the feasibility of a seeding operation on a pilot commercial scale is seen as having several advantages over smaller scale trials and is recommended provided there is a reasonable basis for expecting adequate levels of spat settlement and survival. Advantages include a training function, easier assessment of the distribution and abundance of survivors and realistic assessment of costs, survival rates and likely yields.

Tagging is seen as one of the most effective methods of assessing survival of seeded stock to harvest.

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GENERAL DISCUSSION

Zacharin: Why have you chosen to use the stick-on tags and not the ones with the small steel sleeve which you drill a hole through the ear?

Bull: Speed, efficiency and less likelihood of damage to the animal. Also, much smaller animals can be tagged using cyanoacrylate glue than could be tagged using the wire-on method.

Zacharin: I'm just wondering about the tag retention time. I suppose it depends on how clean your scallops are?

Bull: We believe tag retention is very good when you use epoxy grout (epigloss ER 270/EH 210) to stick on plastic tags. We have had shells returned with tags intact up to 7 years after tagging and some early double tagging experiments using the epoxy grout system suggested tag retention rates were better than 90%. We have not yet done any work on tag retention using mini tags with cyanoacrylate glue but plan to do some work in the near future.

A minor concern with the use of mini tags is how easily will they be seen when the scallops are recovered as legal size fish by fishermen two to three years after tagging? Last year we carried out a small experiment to test this. Just prior to last years harvest of seeded stock we tagged and released two batches of legal size scallops on the area. One batch was tagged with mini tags (8 mm x 3 mm) the other with large yellow penny tags (25 mm diam.). During the subsequent harvest fishermen were asked to return any tagged scallops they found. We ended up getting similar rate of return for the small tags as for the large ones so I'm now fairly confident the small ones can be seen okay.

Dredge: I could probably add to that. We did see multiple tagging tests with *Amusium* using super glue and found that we had an initial tag loss which you'd expect and then after that our retention rate was very high over a period of about a year or a year and a half.

Bull: I certainly recommend tagging as the cheapest and most productive way of assessing survival rates to harvest. This can be particularly useful if you are looking at survival of different groups of animals within the one release plot. In one of our trials of survival of scallops released after intermediate culture we made the mistake of relying on the presence of encrusting tube worms on the intermediate culture scallops as a means of distinguishing them from scallops seeded naturally. Unfortunately the tube worms died after the scallops were released and the tubes continually fell off making it impossible distinguishing between the two batches of scallops. We would have been much better off if used tags to start with.

Anon: That slide you had of the longline showed a relatively short dropper length compared to the amount of water above (perhaps nine metres above). It seemed to me obviously a function of the water depth. If in the situation of having just that depth, would it have been possible to have bags going higher up. Also did you look at having the weights suspended off the bottom and if that had an effect on the amount of wave action effecting the bags?

Bull: The length of the droppers was partly in consideration of trying to avoid tangles when putting the gear down. We didn't want them too long and found that seven metres length was pretty good.

Actually we used tucks. What we did was to shorten the droppers for ease of handling on shore using a daisy chain loop stitch. After the daisy chain the shark clip is clipped onto the last two to hold it in place. When you come to setting the dropper you unhook the shark clip, attach it to a weight and throw it overboard. The daisy chain then automatically unzips to give the full seven metres dropper length.

The other part of the question - the practice of having the weights sitting on the bottom - that was really a matter of convenience. Our spat catching site was at least three hours away from our base at Nelson. We wanted to minimize the need for frequent refloating of gear and therefore chose to add more floats than you would normally do and to hold these down using heavy dropper weights.

Forrest: If you've got a free swimming predator there some years and not other years, like a small shrimp or something like that, then perhaps that is affecting survival of the small animals.*

Bull: Each year we are getting the spat successfully settling on clean grounds, but they're not settling on the ground where there is already a scallop bed.*

*An interesting observation made during the study was test we only got successful recruitment of spat onto the seabed below spat collector longlines when the gear was sited on a new area of ground carrying low scallop density.

1983/84 summer. Spat collectors were placed over areas b and c and successful settlement occurred on the seabed in both areas (previously the seabed was almost bare of scallops).

1985/85 summer. Spat collectors were again placed over areas b and c. Spat settlement on the seabed was less successful than the previous year. In August 1985 large numbers of 1+ scallops were up to 80/m^2 and some 0+ scallops up to 20/m^2 on areas b and c. In September 1985 a proportion of the scallops on area b was removed by dredging.

1985/86 summer spat collects were placed over areas a and b. In July 1986 areas a, b and c were surveyed. Area (a) carried large numbers 0+ scallops (up to 200/m^2); Area (b) carried low numbers of 0+ scallops ($x \approx 0.3$/m^2); Area (c) carried even lower numbers of 0+ scallops ($x = 0.03$/m^2).

In August 1987 areas a, b, c and d were surveyed. Areas a, b and c had numbers of other scallops (0.6 - 6/m^2) and Area d had few other scallops and large numbers of 0+ scallops (20/m^2).

Bell: Which way would you expect the spat to move if they are swimming in the prevailing current?

Bull: Rather than move up and down they would probably move with the current.

Bell: There was a funny looking christmas tree one in your Figure 1. What is that used for?

Bull: We were looking at spat settlement in bags which were put down and left there for 10 weeks and also at settlement on a weekly basis. For the weekly assessment we used small lengths of christmas tree rope held by a plastic frame.

Bell: Any success?

Bull: Yes, we got small numbers of spat perhaps 20 per 20 cm length of christmas tree rope. However, I don't feel the weekly spat monitoring was worth while. It was difficult to relate weekly catches to the catches in a bag held over ten weeks and was little use in a predictive sense.

ADMINISTRATIVE, LEGAL AND SOCIOLOGICAL DIFFICULTIES OF SCALLOP CULTURE AND ENHANCEMENT

John D. Thomson
Department of Sea Fisheries
G.P.O. Box 619F, Hobart
Tasmania 7001.

Abstract

Scallop culture and enhancement create what may be previously unencountered administrative, legal and sociological difficulties. Those discussed include: the 'exclusive occupation' of a moving fluid; alienation of land and water which hitherto has been in the public domain; the legal status of the authorisation to occupy; conflicts with fishermen who fish the same species or different species; poaching and proof of ownership; determining the size of an economically viable area to be alienated; political will of governments to promote culture and enhancement; and determining if enhancement is farming, fishing or ranching.

Introduction

In the mid-1960s the collapse of the D'Entrecasteaux Channel Scallop Fishery led to a community expectation that the government should 'do something'. The Sea Fisheries Research Division was created as a result of this expectation, and scallop spat were collected at Promise Bay within Great Oyster Bay and grown to legal size (90 mm at widest diameter) by research staff. The discovery of large beds of scallops in Bass Strait by DSF staff working from the research vessel 'Challenger' in 1972 removed the urgency of culture work and it was suspended in favour of hatchery work until 1975. Hatchery production proved to be unsuccessful and was abandoned in 1977.

In the period between 1972 and 1976, Tasmanian fishermen explored and fished the scallop grounds on the east coast of Tasmania, in Port Phillip Bay and at Lakes Entrance. In 1976 an enquiry into shellfish farming was instituted by the Tasmanian Legislative Council, and in 1977 the Tasmanian Fisheries Development Authority was created to accelerate development in the fishing industry. In 1979 a hatchery for oysters was built and operated at Taroona Laboratories.

In 1982 the Fisheries (Marine Farming) Amendment Bill was passed. Tape culture of scallops was attempted by fisherman Adrian Cuthbertson. In 1984 a research project on tape culture of scallops was carried out and in 1985/86 scallop reseeding using hatchery reared spat was attempted. Insufficient spat were obtained for large scale experiments.

Atlantic salmon were imported from NSW in 1985-1987. The salmon farming industry developed far more rapidly than expected, being two years ahead of schedule by 1987. This resulted in a proliferation of salmon and trout farms. By 1987, the Department of Sea Fisheries was administratively unable to cope with the number of applications for, and objections to, marine farms. A moratorium was placed on the processing of new marine farm applications for 12 months, as of October 1987.

In mid 1987, a joint project agreement was signed between the Japanese Overseas Fisheries Co-operation Foundation and the Department of Sea Fisheries (DSF) for a three year scallop reseeding project. DSF determined a policy on reseeding which included private reseeding by persons other than licensed commercial scallop fishermen. DSF also determined that scallop reseeding was a marine farming activity. A Fisheries Amendment Bill was passed that allowed for the issue of reseeding leases, and fishermen rushed to stake their claim for reseeding leases around Tasmania.

In the 1987/88 spat collection season, wild collection failed and hatchery spat production was limited to 100,000 spat.

Legal Implications

Section 15 of the Fisheries Act 1959 was amended in 1988 to allow for the creation of reseeding leases. Section 1A states:

"A reseeding lease, while it is in force :-

(a) confers on the holder of the reseeding lease exclusive possession of the area of seabed to which the reseeding lease relates for the purpose of the culture and subsequent harvesting of fish (in this sub-section referred to as "specified fish"), being fish of a kind specified in a marine farm licence for the time being held by the holder of the reseeding lease and in force in relation to the area of seabed to which the reseeding lease relates; and

(b) prohibits the carrying on of any activity in the waters above that seabed that in any way interferes with the culture of specified fish in that area of seabed, and, for the purposes of paragraph (b), it is declared that the use by recreational fishermen of hand lines for the taking of swimming fish or of crayfish-pots for the taking of crayfish at times other than those during which operations connected with the culture of specified fish in that area of seabed are being undertaken does not constitute an interference with that culture".

A marine farm permit for the purpose of culture of scallops "confers on the holder of the permit exclusive occupation of the waters specified in the permit."

Alienation of terrestrial areas has become an accepted practise but the rights to possess and occupy marine areas that were previously in the common or public domain has yet to be tested both politically and legally in Australia. Questions still to be clearly answered include: Is it legally sound to grant 'exclusive occupation' of waters that move in and out of the permit area with the tide? Does a State government have the right to lease to an individual part of the sea bed? Presumably States have established precedents in recent years that extend their jurisdiction beyond low water mark.

The notion that the high seas were free and unfettered, and that alienated land only went as far as high water seems to have been swept aside by these new presumptions. Traditionally, coastal areas contained right of ways and public reserves to allow access to the coast - beyond which governments had no claim.

Administrative Problems

The DSF, newly organised into Divisions of Wild Fisheries and Marine Farming, determined that scallop reseeding activities were marine farming. This creates administrative problems for the Department as prior to reseeding, marine farming was conducted in discrete lease or permit areas with structures fixed or anchored to the sea bed. Scallops, once reseeded, act exactly as a natural bed. They may move out of a small fixed area. Once caught it would be difficult to distinguish between natural and reseeded scallops. Proof of ownership of scallops poached from a reseeded lease would be very difficult. Once reseeding is permitted for one species, pressure will be applied by licence holders for others. Abalone and rock lobster are two species with potential for reseeding or ranching.

Public pressure for recreational boat usage has produced thousands of objections to proposed salmonid farms in Tasmania. The Marine Boards of Tasmania are charged with responsibilities 'to regulate navigation' and 'to regulate the use of harbours and the good order and government of vessels in any harbour' under the Marine Act. This has been interpreted by Marine Boards to include all vessels including recreational users. A 'vessel' is defined in Section 4 of the Marine Act as: vessel means any ship, boat, or other description of vessel used or designed for use for any purpose of navigation and includes:

(1) A dinghy, lighter, punt, raft, houseboat, pontoon, or other thing declared by the regulations to be a vessel for the purposes of this Act;

(2) A seaplane; and

(3) An air cushion vehicle;"

The Marine Board under Section 17 of the Fisheries Act 1959 may veto a Marine Farm permit on the grounds of it constituting a 'hazard to navigation'. The Marine Board may also object to a Marine Farm lease or reseeding lease application.

It would seem to be becoming more difficult to obtain a Marine Farm lease or permit due to the number of Governmental organisations that feel Marine Farms impinge on their area of responsibility. Organisations that fall into this category include Departments of Environment, Health, Lands, Parks & Wildlife, Tourism, Town & Country Planning Commission and local Councils.

Sociological Problems

As mentioned in the legal section above, Tasmanians regard coastal waters as public property rather than a crown preserve. The right to fish with nets, and catch crayfish by pots is considered sacrosanct by the Tasmanian citizenry. Marine farms and particularly salmon farms have aroused the ire of yachtsmen and amateur fishermen. In a state with Australia's highest unemployment rate it is difficult to understand why recreational interests come before job creating marine farms. Perhaps Commonwealth dole payments made without work performed, contribute to this attitude.

Traditional fishermen also see no attraction in what they see as aquacultural pursuits but they resent aquacultural interests taking over 'their waters'. Reseeding of scallops would interfere with other fishing activities and a potential conflict exists with inshore bottom trawling. It seems difficult to persuade the few active fishermen in a low value trawl fishery to step aside for more people to participate in a high value fishery.

In 1986 the Tasmanian fishermen agreed to keep areas closed to protect scallop spawning stock and preserve spat for the 1987 season. They agreed to voluntarily restrict themselves to one trip per day and to fish a quota based on vessel length. They also agreed in principal that scallop dredging should proceed in a fashion like strip-grazing to maximise the catch and minimise scallop damage.

This agreed position turned to one of greed and vessels fished at will over the Banks Strait beds. Much damage was caused. Some vessels did more than one trip and once catch rates fell on the main beds poaching began in the closed areas. Unless this attitude changes, reseeding of scallops cannot work in Tasmania.

Changes in the fishing industry are greeted with suspicion. Fishermen who have been used to doing what they want, where they want, have been placed under increasing restrictions of time, area, gear and species taken. They see scallop culture and enhancement as one more restriction on their activities.

The major reason that Tasmania has appropriate legislation and a growing aquaculture industry would seem to be political will. Other State governments lacking in political direction have not developed aquaculture to the same extent as Tasmania. If political will falters in Tasmania then scallop culture and enhancement will fail.

Problems to be overcome in establishing scallop culture and enhancement

Before scallop culture and enhancement can become a commercial reality in Tasmania, a number of problems, many related to government policy and public attitudes, need to be clarified. These include:

(1) The perception that large areas of seabed and associated water will be lost to the public;

(2) The potential for conflict between fishermen and reseeders sharing marketing and other rights to a common species, and to fishermen and reseeders using common areas. For example, traditional users, such as inshore trawlers in Great Oyster Bay have historically fished an area which may be used for scallop reseeding;

(3) Control of scallop predators will be a major problem;

(4) The relationship between reseeding and culture techniques needs to be determined. It remains to be established whether the two techniques can be practiced together in Tasmania;

(5) The minimum lease area required for reseeding to attain economic viability in Tasmania is unknown at present;

(6) Effective policing against poaching in leasehold areas may be very difficult;

(7) Most Australian states have no marine farm legislation and lack the political will or motivation to enact such legislation;

(8) Definition of scallop culture and reseeding is unclear. Are these activities farming, fishing r ranching?

GENERAL DISCUSSION

Bull: Do your normal leases involve a fairly hefty rental fee?

Thomson: No, I don't think so. When we started the leasing procedure, we wanted to encourage people into marine farming. An oyster farmer pays $100 a year plus an additional fee per hectare. Total rents are of the order of $500 but can be up to $1000. When dealing with the salmon farmers, because of their potential earning as so much higher, their rents are in the range of $1000 to $1500 or there abouts. This needs overhaul.

Bull: I wonder if rental can be used as a mechanism of giving back to the public something of what they have lost in the way of common property resource to the reseeders.

Thomson: That's the philosophy the Tasmanian government has adopted for abalone divers. They see that abalone divers make a lot of money so therefore they should pay a resource rent. I think that was always the intention with marine farming but a lot of entrants into the industry didn't have a lot of money to start with and they were going to spend it all on operating equipment. Oyster farmers in particular tended to be family operated small business, whereas salmon and perhaps scallop reseeding are likely to be company operated. If you are trying to encourage the industry you don't want to over-tax them first up. You wait until the industry is proven and then gradually raise the fees.

Evans: I would like to ask you to consider access by individuals or companies. I'm pretty familiar with what's happening in Japan where areas of seabed were given to groups of people to hold a joint licence. Now knowing that their system was successful, how are we going to make a successful industry unless we plan to distribute seabed rights?

Thomson: If the Government still maintains control and lease areas to individuals for a period, or puts a tender out, then that's fine. It depends if we are trying to keep the scallop fishermen in work or whether culture and enhancement is just considered to be another part of marine farming. If its considered to be another part of marine farming then we can go ahead and do it. But I'm suggesting that if the community opposes these projects, they're losing something. An additional point about the Japanese experience is that the co-operative ethic there is fairly new, post second World War. In Australia co-operatives went out of fashion after World War two and we don't have this recent history of working well together in co operatives.

Evans: From what you're said, there are differences in scallop habitats around Tasmania and obviously the fishing patterns in these areas have been different over the last 30 years. Therefore you have to manage different areas differently.

Thomson: That's quite true. A potential problem here is if you manage as we intended to at Great Oyster Bay, quite differently to the rest of the State then there may be a perception that the people aren't being treated fairly or equally in other parts of the State. I think that this will be a major problem for anybody managing marine farms and fisheries. Some people who come into the industry make a lot of noise and get what they want while others sit back and wonder why they aren't getting what they're asked for. if someone comes in and discusses a project in one year, seeing one persons in authority, it is difficult to deal equitably with another person who comes in three years later with the same project.

The first thing is that we have always maintained is that in any of the marine farming activities which are undertaken two and a half to three jobs are created as a result of the development, in addition to people who directly work on the marine farm. I guess that fishing is exactly the same.

Bell: What is the size of area you are enhancing in Great Oyster Bay?

Thomson: We musn't lose sight of the fact that the OFCF project and our current SERP activities are feasibility studies. Now in our wisdom last year, 50 hectares was the figure decided upon for people to experiment. We now realise that it is too small for commercial activity. So it means there won't be 50 hectare plots when enhancement work is permanently underway. There will have to be larger areas.

Anon: If we're prepared to spend the money I'd like to know whether it is going to be worth our while?

Thomson: Everybody wants to jump in now. We've got a feasibility study from which we hope to demonstrate whether scallop mariculture is worthwhile or not. The study won't be finished for at least another two years. I wouldn't be jumping in with my millions just yet.

Harrison: I think John's right in suggesting that if we've had numerous requests for enhancement leases, there will be a strong and adverse community reaction if there are further suggestions that the whole of the coastline is to be taken up by marine farms. I don't think there is any possibility that the community will allow the whole east coast or a quarter of the east coast or even 10% of the east coast to be alienated.

Thomson: Depending whether scallop mariculture is seen as an extension of a fishing activity or a marine farming activity will have great influence on community attitudes. This concerns me. Everybody is quite happy with traditional fishermen fishing out there and if they become the same people who are reseeding there may be no problem. But if companies are perceived to be coming in and speculating on areas there will be major problems.

FORUM

Costs and benefits of hatchery reared and wild caught spat for grow-out and fisheries enhancement

Chair: P. Neville

Introduction

This forum deals with the costs and benefits of hatchery reared versus wild caught spat for both private growing out and fisheries enhancement. The two principle speakers dealing with these subjects will be Derek Cropp and Mike Bull, who presented some details ι projections on relative costs and profitability of both the natural wild caught and the hatchery reared production.

In Derek's model spat of 10 to 15 mm cost three or four cents per spat in the hatchery operation. In the best possible scenario wild caught spat costs about 23 cents to get it to that size.

On the other hand Mike Bull looked at overall returns from the harvested scallop as opposed to getting it to a spat stage ready to be reseeded. So Mike looked at the overall dollar returns from harvesting the end product and considered the Japanese method of intermediate culture and then looked at two other techniques, natural release and direct release.

Mike's conclusions were that the natural and direct release mechanisms gave a very profitable result. The only technique that was unprofitable was intermediate culture, which happens to be the preferred Japanese method.

It was also pointed out that not all costs have been included in both exercises, so the picture wasn't quite so rosy. Nevertheless I think the end result suggests that scallop enhancement can be profitable, but is a high risk venture at present in both New Zealand and Tasmania. From the experiences we've heard in the last few days you're either going to get everything or nothing.

The preferred Japanese method wasn't profitable in New Zealand despite its profitability in Japan. Therefore we may be looking at a scale factor even though Mike said he was trying to do his costing based on a fairly large scale. I assume the Japanese are enhancing stocks on a greater scale that reflects directly on the economics of the operation.

The Japanese have had to face the allocation issue to a much greater extent than we have. We might profitably pursue their experience in this matter. How they handled allocation may be of value to Australia.

Can we please have questions or comments from the floor.

Bell - The scale of the operation needs to be in the million to ten million mark to be profitable. What area do we look at to reseed and what densities should we reseed for an economical harvest ?

Bull - When we started we seeded at ten per m^2. We found with 20% survival we had a density that was too high at harvest, and that growth rates were less than expected. We are now looking at five or six per m^2 at release, giving one to one and a half per m^2 at harvest.

The area necessary for a profitable operation is quite large. I would imagine you may require at least 300 hectares with minimum survival.

Bell - That should be a couple of kilometres square, wouldn't it?

Bull - A hundred hectares is one kilometre by one kilometre. But I must say that relates specifically to our area where the carrying capacity is quite low because of the muddy substrate.

There are other areas in New Zealand where the natural beds support 10 or 12 per m^2, so if you can find an environment like that, a smaller area would be required.

Bailey - Is that for an ongoing operation or just one year?

Bull - That's for an ongoing operation.

Cropp - Perhaps Mr Sasaki might comment about buffer zones in Shibetsu.

Sasaki - There are small buffer zones used. In Shibetsu there are no large suitable areas suitable for reseeding. If there are buffer zones the places for reseeding are even more limited.

Zacharin - When the New Zealand project started, in the year prior to commencement there were zero scallop in the area. The following year you had 32.5 million spat, the next year 5.9 million spat and last year none. Is that correct ?

Bull - That was from the natural release method.

Zacharin - Are you pursuing that natural release method?

Bull - Until earlier this year we had intended to try and shift towards natura release. This method looked quite encouraging and our forecasting was on the basis that we progressively shifted to entirely natural release.

With the setback this year of total mortality of spat that settled on the sea bed, we are now re-examining the direct release method from spat bags.

McLoughlin - Before we look into the Tasmanian and New Zealand *Pecten* fisheries, *Amusium* appears to be nearly a perfect candidate for culturing. It has a one year turnover and we have spawning, growth and harvesting data from both Queensland and Western Australia. Has there been any thoughts at all about the potential culture of the species ?

Neville - In regard to Queensland, there has been interest from fishermen themselves. The trouble is that they are ill-informed and think what's occurred in Japan can be transferred readily to Queensland. Fishermen are of the view that spat catching technology is readily available. Ongrowing is then relatively simple and we throw the scallops in to the ocean and their problems will be solved.

We've all heard that enhancement is far more complex. I'm not sure what work the Japanese have done on *Amusium*, but maybe we can have a comment from the Japanese participants ?

I think it will be a point of some value for this conference to consider.

Joll - We are proceeding cautiously with the idea. We've seen the potential in terms of the very rapid growth rate of the animal which is a favourable point but it is not susceptible to the current generation spat catchers. If we proceed with wild spat catching, we will have to develop a new type of spat catcher, or alternatively we may look at hatchery culture. We're not rushing in to it.

We think enhancement of *Amusium* has potential but we see a lot of problems along the way as well, and we're going to proceed cautiously.

Dredge - I agree with Lindsay that the problems associated with spat catching make the animal far more difficult to work with. We did deploy some spat catches last year on a trial basis. We got one species of *Chlamys* in very large numbers, but only seven individual *Amusium*.

From the little bit of hatchery work that has been done with *Amusium* it appears the animal doesn't have a byssal stage, but I would like to see further work in that area. As Lindsay pointed out that means we must go back to hatchery operations.

Zacharin - Are hatchery operations being considered in New Zealand?

Bull - I certainly hope not. I can see that only as a last desperate measure.

Cropp - It's all a matter of relative economics.

Zacharin - If our wild spat collection in Tasmania is as bad this year as it was last year where do we go ?

Cropp - My view is that until wild spat collection increases to at least 500 per collector and possibly over 1,000 per collector, it is far cheaper to raise spat in the hatchery.

Bell - Given that you are looking for higher catches in your spat bags, what research is being done on prediction of spat settlement?

Cropp - The SERP program is now trying to increase the broodstock numbers in the Great Oyster Bay area. Hopefully we can combine this work with current larval studies being conducted jointly by CSIRO and the Tasmanian Sea Fisheries Department staff. If we can get a feel of where larvae are being transported we can place broodstock in a suitable location and collect spat when they spawn.

Bell - Are you conducting plankton tows for scallop larvae?

Cropp - We're going to establish a regular larval monitoring program very shortly.

Joll - One of the things which seems to have come through these discussions is that the best areas for reseeding are areas suitable for wild fisheries. In the past these areas have been used by wild fisheries. There will be questions of ownership of the reseeded material versus natural spat coming in. If the demand for lease areas covers those areas that have the best potential for natural spatfall as well, there's going to be conflict between scallop fishermen and lease holders in the future.

Neville - The problems that Lindsay has raised could be very real in the Tasmanian experience. I'm not sure whether or not a non-fishing company could get a lease. In other words a private investor who has no experience in the industry and doesn't know boats may have access to a lease.

If then he were to get a lease and put the capital in to reseed an area where traditionally scallop fisherman have worked in the past, presumably the operator may not necessarily have to use existing fishermen to harvest the scallops. He may introduce his own vessel for harvesting. You then face the situation where although you have a freeze on vessel numbers or licences, you may end up with more capital equipment and boats in the industry.

You could even get the ridiculous situation where an individual takes out a lease, reseeds it and either the reseeded scallops move from his lease area or fail completely, but natural stock moves on to his lease area. He then harvests the wild stock which has spawned outside his lease, using a new boat in the fishery. This would have normally been harvested by traditional fishermen.

Yates - I have been in the oyster aquaculture business for some time and would like to comment on costs. I believe Mr. Cropp has been extremely pessimistic with his costings. We've found that a 1,000 m longline will house one million scallops according to our experiments.

By adapting oyster gear we were able to grow scallops from five mm to 85 mm in 12 months. The cost of doing that was A$7.80 per kilogram. The present market price is A$14.40 per kilogram so you can see there is quite a good profit providing the price remains above A$10.00 per kilogram.

The only problem I can see with hanging culture is the lack of expertise in the hatchery operation. Personally I have not got a lot of patience for reseeding in the wild. I can foresee many problems in Tasmanian with predators and conflicts of interest. But I am quite sure that hanging culture is an economic and feasible proposition.

Gwyther - The debate on how many farms can be put in a given volume of water is a problem that we're encountering in Port Phillip Bay with our mussel industry. Leases were originally sited through a series of compromises. Harbour authorities, access to shipping, yachting marinas and housing sites have dictated where our mussel farms are located.

We are in the process of extending the size of these farms from three to six hectares and increasing the number. Because we are restricted as to where we can site them, some farms will be totally surrounding by other farms. So some poor guy in the middle is going to be surrounding by ropes on all four sides.

The question is now arising as to how much food is available for mussels. We are considering whether we should stagger them so every farm has access to clear water. The subject is causing a lot of argument at the moment.

Thomson - We recently obtained information from the Scottish Department of Agriculture and Fisheries. They have a set distance for the separation of farms of the same type. Oyster farms are probably a nautical mile apart the salmon farms and oyster farms are a bit closer. I think there are about 400 farms on a coastline probably much the same as ours.

Tasmania does not have any hard and fast rules for the density of farms. We start with a policy of one salmon farm per bay. In the Huon River we've got half a dozen now. In general we are applying a three kilometre separation but that's broken down because some applications got though before the policy was established.

I think that having one farm or a series of farms surrounding another is just bad management practice.

Forrest - Another thing you should consider is the potential for biological problems. The ones growing in the middle may not being fed properly and therefore they are prone to diseases.

Neville - The key to all the cost models is the yield and that's the unknown over which no-one has any data at this stage. Costing figures become a bit academic a. this stage as the cost of hatchery spat runs from about three cents to 23 cents depending upon the assumptions that are made about the yield.

Lowth - So in a few years if we keep the wild fishing as it is now we won't have an industry.

Forrest - It will revert back to wild spat collection or a hatchery operation as in the oyster industry. We found it was too unreliable to rely on wild spat catches every year. For oysters, it was too unreliable and we've had to revert to the hatchery.

Cropp - But in Japan the reverse is the case. There is no need for hatchery produced spat in Japan because the wild caught spat is reliable.

Forrest - We haven't got the organization.

Cropp - We haven't got the scallops!

Harrison - I was just asking is it common accepted theory that you're going to lose 50% of scallops after the spat stage per annum from the spat collector to final harvest. I think Derek's used 50%.

Bull - I don't believe the natural mortality of scallops in New Zealand is that high. I would accept a figure of 30% per annum. The costing on the enhancement work assumes an overall survival from release to harvest of about 15%.

Harrison - 15% from release to harvest ?

Bull - Yes, to harvest in the third year. The highest percentage of that mortality occurs immediately after release.

Harrison - One would assume then from putting those two points together that if survival in New Zealand scallops is 15%, the assumption is that natural mortality in the adults is only 30%.

Neville - I think we're still in the range of unknown and both presenters in their papers have erred on the side of caution.

Bull - Another consideration is the size at release. In our situation our experience has shown we don't get a greatly improved survival by growing them through for three months in pearl nets. This is not the situation in Japan. I understand that survival rates after release from intermediate culture are very high. That could really change the economics of the picture. If you can get up to 78% survival, then it puts a different picture on the method you use.

Forrest - This is 78% after you put them in the nets?

Sasaki - In Shibetsu they reseed scallop of 5 cm shell length after being in intermediate culture for one year and if reseeded on a suitable bottom they get 40-50% recapture.

Neville - I gather they are grown for one year in intermediate culture to 5 cm and then I gather another three years before they are finally harvested?

Hoshino - All of these data depend upon local conditions. So you cannot say that the data from Golden Bay in New Zealand can be applied everywhere else. Golden Bay is one of the best areas for reseeding work.

Neville - You are looking at variable survival rates on an area by area basis and with experience you hope to identify better areas. But in the initial development stages of any industry you would probably be looking at very poor survival rates because you may well try unsuitable areas.

Forrest - What sort of survival rates of 5 cm scallops do we get in the lantern cages after we put the spat out?

Neville - Well I think the Japanese were saying that was of the order of 40-50% after 5 cm.

Thomson - When they're in the cages?

Cropp - Well in our experiments we had survival of 90% or better to harvest.

Neville - So, even if survival is high, costs still appear to be prohibitive according to the New Zealand experience. But again the Japanese experience is that it's not a loss situation and that may a function of scale.

Gwyther - In cage holding experiments in Port Phillip Bay we've found very high survival. In the first six months we didn't lose a single scallop. So we had about 95-96% survival, yet on the bottom in Port Phillip Bay mortality is high.

Have we written off the idea of hanging culture though to harvesting? What happens if in future years it becomes more attractive? What will happen if people have three hectares or 50 hectares reseeded and then find that cage culture is the way to go?

Thomson - I expect in Tasmania that we will initially have a hanging culture industry, secondly a reseeding industry, and thirdly a wild fishery again. Unfortunately if we have a wild fishery again, it will probably make the other two techniques uneconomic. So the first thing we'll have is cage culture. If we have a large number of scallops produced locally the price will then drop to a level where cage culture becomes uneconomic, which means that reseeding will be a major part of the industry.

Cropp - Survival is very high in lantern cages but this method only becomes economically viable if the price of scallop meat is very high. The alternative is to make a hanging culture system in which cage costs are reduced. That's what a number of people are doing in Tasmania.

Forrest - There's a question on the economics of scallop supply and demand.

Dredge - I don't think there's any doubt that scallop prices in Australia are driven by an international market not an Australian market. The thought that Tasmania's scallops prices are structured by Tasmanian demand is just not true.

Neville - Despite the best attempts by Governments to regulate the market, supply and demand still does prevail.

McLoughlin - The point has come out in this session that we seem to have a trade off between whether hatchery spat or wild caught spat offer better returns. What's more economic, hatchery breed spat or wild caught spat? Don't forget wild caught spat are dependant upon having broodstock in the wild.

Now Thomson made the point about the social costs of marine culture around the Tasmanian coast. But by the same token can society afford a natural fishery in which we have a rape and pillage mentality? This appears to be going on every time a bed appears. It is fished to extinction within a month, therefore we have no wild stock and a fishery that is employed for only four weeks of the year. Can we afford a wild fishery in Tasmania ?

Thomson - One of the concerns I have about Great Oyster Bay, is that if enhancement is successful in a short period of time, fishermen are going to be clammering to get into the bay.

Now we told them that they won't be able to harvest in the traditional manner and it's quite possible that it will either be a Keta-ami dredge fishery or a dive fishery. I think if it's a dive fishery we can stop the same kind of rape and pillage mentality.

Neville - Wouldn't you affect the cost of production and harvest?

Thomson - Yes.

McLoughlin - Will the cost be higher? Are the social costs of the wild fishery in its present form higher than those of mariculture projects ?

Thomson - Well I think social costs are hidden. I'm really concerned that if we go into the reseeding of seabeds, unless we give traditional fishermen a major input or consider it an extension of their activities there would be a community backlash.

Neville - Mr Sasaki: How in a Japanese situation are the harvesting rights given for beds that have been reseeded ?

Sasaki - An licence is issued to the Fisheries Co-operative as a Co-operative licence and the Co-operative Association decides which men will utilise that licence.

Neville - So effectively there is a strong co-operative arrangement which I guess is largely self-policing. The Co-operative looks after an area., Do they have legal rights over that area of seabed ?

Harrison - All fishing rights of the area of the Co-operative belong to the Co-operative itself by law. No one else can fish and the Co-operative decides what methods can be used within their area.

Neville - We've got 26 branches of our fishermen's organization in Queensland. They all want their own areas zoned off.

Thomson - Just an extension on that. We've got some 170 licensed scallop fishermen. If the Great Oyster Bay enhancement project is successful there maybe up to 10,000 tonnes of harvestable scallops. Twenty vessels could harvest all of that, so what do we do with the other 150. We don't have area restrictions and this will be the major problem.

We have to resolve the fact that we have too many people fishing for a small resource. One of the present approaches is for fishermen to group together and request rights to a certain area of sea bed. We're at that stage where we don't have traditional Co-operatives, or co-operative rights to small areas of the coastline. Perhaps we ought to consider this. Work out if people who live together can fish together, whether they like it or not.

Zacharin - Maybe we could get the views of Bob Lowth. Bob's the president of the Scallop Association of Tasmania.

Lowth - I can't speak for the Association because we don't have a specific policy on the matter. But my personal opinion is that we need leases that individuals in the fishery can have exclusive access to.

Mr. Cropp; Do you have any information on the size and control of exclusively leased areas ?

Cropp - In Shibetsu, which is an area similar to Tasmania, there is a predator problem. By using a rotational fishing system an area they can adequately control the predator problem. The boundary around the lease is of the order of five times the actual stocked area. So if we're talking 50 hectares of reseeded bottom we're talking of a big buffer zone around it and that's only for one year.

Friend - It is essential that fishermen ban together in groups and work in some sort of co-operative arrangement. The future will dictate that they work together in co-operatives and I think we already have evidence of this happening by groups forming at St. Helens, Triabunna, Norfolk Bay and the D'Entrecasteaux Channel.

Neville - Port Phillip Bay is unique in the sense that it is a single area which has been consistantly productive, and which has a limited number of fishermen. I don't think the community would be too upset if those people were harvesting reseeded scallops.

Out of all the discussions we've had in the last few days if one point is clear. If reseeding or restocking is to be successful, rights of access have to be determined. There will be a limited number of fishermen who have access to the fishery in a given area. You need to be able to identify them so charges or levies can be raised.

Gwyther - I can see the possibilities. In the not too distant future, when this season's fishery is finished, which will be very soon, the question of enhancement will be raised again. How about reseeding the bay as they are doing it in Tasmania, New Zealand, and Japan ?

Our commitments have been to mussels and oysters. If we do start a reseeding program the main problem will be the lack of a hatchery supply. This will take a long time to overcome.

Returning to the access question I can't see any way that we would be looking at leases for areas in Port Phillip Bay on an individual basis, or even a group basis. Areas necessary for reseeding are simply too big. All our mussel farms are presently on three hectares, so we can't be giving out 50 hectares in Port Phillip Bay for private scallop enhancement. I think there are too many fishermen, 85 boats is an excessive number.

Getting together with industry and arranging enhancement, getting hold of spat and allocation is an area where we're going to have real difficulties. I think would be totally an industry arranged organisation, involving the people already there. I don't see any way in which we could consider individual entitlements.

Neville - It would become a problem if a company were to invest half a million dollars or a million dollars on the basis of an exclusive lease over a square kilometre or so if they were to reseed it and harvest it.

Gwyther - I suppose if it comes to the point of whoever puts the money into the hatchery will obviously get some say as to who gets the rewards. Then if more people came into the project we'd be in difficulty if there was a big natural settlement.

Dredge - I noticed you assumed immediately that you'd have to use a hatchery-based operation as opposed to wild caught spat. Why do you make that assumption?

Gwyther - Well simply because our spat collectors have been so unreliable. I think if we could get 200 or 300 spat per collector reliably, or a sort of reliable minimum, we would be in business. But the last two years the biggest number of spat per collector we've seen is about 20.

Zacharin - I think that problem exists in Tasmania. If spat collection is unreliable in Port Phillip Bay what hope have we got in Tasmania where we don't work in enclosed bays?

Gwyther - If spatfall were reliable it would be a poor indicator of future recruitment. What we gain in some areas we lose in others.

Ito - I think that what's necessary now is a real attempt for artificial breeding producers to reduce costs. And of course even in natural scallop production we have to make an effort to reduce costs. This is very important.

Thomson - With the survival rate of 90% plus in culture versus 20% or less for reseeded scallops, the economics look better for culturing at the moment. Perhaps Mr. Cropp can advise on the cost of culture, but it appears to me that with a cost of four cents for culturing, it's less expensive than losing 80% of reseeded scallops.

Cropp - Given the current high price of scallops on the market and an establishment cost for our hanging culture system, we will not attain economic viability using imported Japanese equipment. However, if we reduce the cost of these capital items for culturing scallops, I believe hanging culture will be viable.

Neville - Any cost benefit analysis that is done on the end result of intermediate or lantern cage culture should incorporate the fact that risk is much lower than in reseeding. In wild release or reseeding, the risks are in much greater. The New Zealand experiments have been on the basis of trial and error. Consequently, they have taken a fairly practical approach and said we don't understand or know the reasons behind why half of these things happen or don't happen but we're going to look on a trial and error basis, and using the cheapest possible materials.

Thomson - Reseeding lease were to be 50 hectares. They will probably need buffer zones. The existing legislation allows a reseeding lease to be held for up to 20 years which is the same as oyster and mussel leases.

Bell - What is the policy for the timing on implementation of lease issue? Are we talking about this year or three years hence when you finish your research on reseeding in Great Oyster Bay ?

Thomson - I really can't answer that except to say it is my expectation that a decision will be made before next year. The Minister has to consider the current moratorium on marine farm licenses, and whether by granting reseeding leases he'd be circumventing the moratorium. If he re-imposes the moratorium on processing new applications, then it may be that nothing will happen for a further twelve months. That's a political decision upon which I am not competent to judge.

Lowth - If industry were allowed to get on with the job without the bureaucracy curtailing the fishermen, we would have a scallop industry within two or three years of reseeding.

Instead of waiting another three years to see if enhancement is going to work, people at the moment are prepared to hop in. Rightly or wrongly, I think it is up to anyone who is prepared to take a calculated risk to go ahead and try are seeding.

We're just not being allowed to get on with reseeding at the moment and it's ridiculous. It works in Japan and in New Zealand, and I can't see why it won't work here. We're completely inhibited by bureaucrats.

Thomson - The Victorians and the Queenslanders can tell us how long it takes normally to get such legislation through Parliament. I think it's amazing that only a year has elapsed since our policy was developed and the legislation passed.

Other people may care to comment. It's not just bureaucratic delay, but the Government has a responsibility to the community at large, to other fishermen, and to you yourselves. If you go ahead now and fail after spending one million dollars we would expect to hear you say, "oh you bastards shou have told us the right things instead of giving us a bum steer".

We've had people wanting to get into abalone farming for eight years. We've told them that it is uneconomic and the abalone divers are against it. There are a range of complications we haven't dealt with yet.

We are encouraging scallop reseeding but cautiously. Otherwise you'd end up with the same thing as has happened with salmon farming. It's been too successful too quickly and the community at large has reacted unfavourably.

Lowth - We'll worry about people complaining after it happens.

Thomson - Port Cygnet had one of the highest unemployment in Tasmania. There were 2,000 objections to a salmon farm there and the town has fewer than 2,000 people living there.

Thomson - Could Queensland and Victoria representatives comment on the time it takes between when they have an idea about putting legislation to Parliament, to when they it through? Research and protest can last for five years and then legislation takes further time. For us to get this through in a year has been pretty good.

Neville - By Queensland standards that is fairly quick. We've had legislation drafted for changes to our act in place for a year and a half to two years which still has not been to parliament. It is up to the Minister to allocate the priority he places on taking legislation before the house and no one can influence that.

In Queensland, the fishing industry has been lobbying the Ministers for changes. But the Minister has deemed that other legislation is more important and so it will wait its turn. If you can draft legislation from an idea to finally putting it before the house within 12 months you're ahead of just about every other state in Australia.

Gwyther - In Victoria the situation is the same. There's no real answer to how long legislation takes because it does depend on priorities. Sometimes if it's really urgent tit can be pushed through. But I can't see anything like that happening in a case involving a new fishery; that's not the sort of situation that applies.

End of Forum

Appendix I
List of Participants

Mr Ian Bailey, PO Box 105, St Helens 7216, Tasmania

Mr A Bartrom, MAF Fish. Lab, PO Box 3437, Auckland, New Zealand

Mr S Bell, PO Box 50, Woodbridge 7162, Tasmania

Mr D Boddy, C.H. Smith Marine, 14 Davies Street, Hobart 7000, Tasmania

Mr D Brother, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr D Bryan, 237 Channel Highway, Taroona 7053, Tasmania

Dr Mike Bull, Ministry of Ag. and Fish, Private Bag, Nelson, New Zealand

Ms A Byakuno, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr M Cole, Bay Aquaculture, Coles Bay 7215, Tasmania

Dr N Coleman, Marine Science Lab. PO Box 114, Queenscliff 3225, Victoria

Mr D Cropp, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr R Cropp, Department of Sea Fisheries, GPO Box 619F, Hobart 7001, Tasmania

Dr T Dix, 19 Crabtree Road, Grove 7109, Tasmania

Mr M Dredge, Fisheries Lab, Burnett Heads 4670, Queensland

Mr J Evans, 69 Hill Street, West Hobart 7000, Tasmania

Mr R Friend, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr T Fujimoto, 2298-2 Aza Shibetsu, Shibetsu Cho, Hokkaido, Japan

Dr N Gillespie, Fisheries Research Branch, Qld. D P I, PO Box 46, Brisbane 4001

Dr D Gwyther, Marine Science Lab, PO Box 114, Queenscliffe 3225, Victoria

Dr L Hammond, Victorian Institute of Marine Science, 14 Parliament Place, Melbourne 3002, Victoria

Mr A Harrison, Department of Sea Fisheries, GPO Box 619F, Hobart 7001, Tasmania

Mr T Hoshino, Fisheries Lab, Beach Road, Deception Bay 4508, Queensland

Mr M Hosoya, MAF Fish. Lab, PO Box 3437, Auckland, New Zealand

Ms J Ibraham, PO Box 11-049, Wellington, New Zealand

Dr H Ito, Hokkaido Regional Fisheries Laboratory, Fisheries Agency of Japan, 116 Katsura-Koi, Kusuiro City, Hokkaido 085, Japan

Dr S Ito, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr N Jacobs, Fish Research Institute, PO Box 21, Cronulla 2230

Mr M John, PO Box 866, Bicheno 7215, Tasmania

Dr L Joll, W.A. Marine Lab, PO Box 20, North Beach 6020, Western Australia

Mr G Legg, 64 Tasma Street, Hobart 7000, Tasmania

Mr R Lowth, PO Box 76, St Helens 7216, Tasmania

Mr N Maff, Western Seafarms, PO Box 844, Carnarvon 6701, Western Australia

Mr R Martin, CSIRO Marine Labs, PO Box 1538, Hobart 7001, Tasmania

Mr R McLoughlin, CSIRO Division of Fisheries, GPO Box 1538, Hobart 7001, Tasmania

Mr S Minsoa, Department of Zoology, James Cook University, Townsville 4810, North Queensland

Mr P Neville, QFMA, PO Box 344, Fortitude Valley 4006, Queensland

Mr T Peters, Department of Sea Fisheries, Crayfish Point, Taroona 7053, Tasmania

Mr I Rinkin, Australian Maritime College, School og Fisheries, Beauty Point 7270, Launceston

Mr T Sasaki, 2298-2, Shibetsu Cho, Hokkaido 086-16, Japan

Dr S Stanley, Department of Sea Fisheries, GPO Box 619F, Hobart 7001, Tasmania

Mr J Thomson, Department of Sea Fisheries, GPO Box 619F, Hobart 7001, Tasmania

Mr P Tong, PO Box 866, Bicheno 7215, Tasmania

Dr M Walker, PO Box 108, North Fremantle 6159, Western Australia

Mr G West, CSIRO Marine Labs, GPO Box 1538, Hobart 7001, Tasmania

Mr G Whayman, 6 Frost Street, Snug 7054, Tasmania

Mr R Williams, Fish Research Institute, PO Box 21, Cronulla 2230, New South Wales

Ms L Woodburn, Dept. Genetics and Human Variation, La Trobe University, Bundoora 3083, Victoria

Mr P Wooley, GPO Box 619F, Hobart 7001, Tasmania

Mr A Yates, PO Box 817, Bicheno 7215, Tasmania

Dr PC Young, CSIRO Division of Fisheries, GPO Box 1538, Hobart 7001, Tasmania

Mr W Zacharin, Department of Sea Fisheries, GPO Box 619F, Hobart 7001, Tasmania