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DEPARTMENT OF CONSERVATION, FORESTS AND LANDS
FISHERIES AND WILDLIFE SERVICE

Port Phillip Bay and Bass Strait Scallop Research. Final Report to Fishing Industry Research Committee (FIRTA 83/32).

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MARINE SCIENCE LABORATORIES

PORT PHILLIP BAY AND BASS STRAIT SCALLOP RESEARCH

FINAL REPORT TO FISHING INDUSTRY RESEARCH COMMITTEE

(FIRTA 83/32)

TITLE OF PROGRAM

Port Phillip Bay and Bass Strait scallop research.

AIM

To estimate yield of scallops *Pecten alba* from Victorian waters under varying levels of fishing.

OBJECTIVES

1. To define and evaluate factors affecting numbers of scallops in Port Phillip Bay.
2. To determine the biological consequences on the scallop stocks of varying the levels of fishing effort.
3. To evaluate the degree of similarity and synchrony of population characteristics of Port Phillip Bay and Bass Strait stocks.

In this report the studies which addressed Objectives 1 and 2 for Port Phillip Bay are described. The Bass Strait studies were extended for one year (FIRTA 86/38) after significant spatfall was discovered in Bass Strait waters during the early months of 1986. This spatfall provided us with the opportunity to investigate the extent to which scallop spat had settled and their rate of growth to scallops of recruitment size. A report describing all Bass Strait studies (Objective 3 above, and FIRTA 86/38) will be submitted after completion of the appropriate experiments.

SUMMARY OF ACHIEVEMENTS

Since April 1983, studies of the following topics have been completed:

1. Reproductive biology and seasonality of spawning.
2. Intensity and duration of scallop spatfall.
3. Tagging studies to determine rates of growth and natural mortality.
4. Seasonal changes in the relationship between length and meat weight due to reproductive condition.
5. Surveys of abundance of recruits and residual stock in the bay prior to each fishing season.
6. Development of a mathematical model to determine yields available under different fishing strategies.

During the 3 years of the study, scallop spatfall was observed to occur over a short period (October-December) after the scallops had spawned in spring. Growth was rapid and scallops reached an acceptable harvestable size of 70 mm within 16 months. Spatfall one year can therefore be related to recruitment during the next. Years of high and low spatfall were reflected in subsequent differences in recruitment. Though more years' data are required, indices of spatfall provide managers and fishermen with predictive information on likely recruitment strength one year in advance.

Each year the strength of recruitment and the residual stock size were estimated from the results of surveys by SCUBA divers. The results have shown that commercial viability of the fishery is primarily dependent upon recruitment each year. Residual stocks are normally insufficient to support the fishery in the event of poor recruitment.

Estimates of growth and mortality rates determined from tagging and data on seasonal changes in meat yield have been used to develop a mathematical model which can be used to determine number of scallops available each season and yields obtainable from different management strategies. Estimates from annual survey, of stock abundance and mean scallop size at the beginning of each year provide the data for the model.

As a result of the research program. the need to continue monitoring spatfall in Port Phillip Bay and to conduct surveys of recruitment strength each year has been identified. These data are necessary for fisheries managers to maintain the ability to manage the stocks by quota system.

INTRODUCTION AND JUSTIFICATION

In Port Phillip Bay, commercial exploitation of the scallop *Pecten alba* Tate began in 1963. The fishery grew rapidly and by 1967 there were 150 vessels using self-tipping dredges. A record catch of 300,000 bags was landed in 1967 but the catch declined drastically to 16,000 bags in 1969. The fishery was then subjected to a number of management changes included limiting entry, imposing restrictions on dredge width and daily fishing hours and the introduction of daily quotas. Since 1969 recruitment has continued to fluctuate and landings were good (> 150,000 bags) in 1973, 1981 and 1985. In 1985, approximately 180,000 bags, worth some $15M to Port Phillip Bay scallop fishermen, were landed. In 1986 recruitment was so low (Gwyther and Burgess 1986) that the season was closed prematurely and voluntarily in July (officially August) by which time an estimated total catch of only 20,000 crates (= 24,000 bags) had been landed. This wide variation in the annual availability is the main difficulty faced by the scallop fishery in Port Phillip Bay and its management. The research program initiated at the Marine Science Laboratories was designed to examine whether predictive information on recruitment could be obtained and to estimate what yields were available from the bay each year under different management strategies.

RESULTS

Reproductive biology

Gonadal reproductive status of scallops from two locations within Port Phillip Bay (Fig. 1) was studied for 25 months from March 1983. Detailed histological examination was carried out to determine the timing and duration of spawning : this is essential information for the understanding of settlement and recruitment. It was found that scallops were spent of gametes during summer, gonads developed rapidly throughout autumn, and sporadic winter spawning was observed before a major release of gametes in late spring. Details of this study are described by Sause et al (in press.) (see Appendix 1).

Settlement, juvenile growth and spatfall monitoring

Settlement of scallop spat in artificial collectors and the growth of juvenile scallops were examined in relation to separately obtained estimates of annual recruitment in Port Phillip Bay. Settlement during October - December was observed during each of the 3 years studied (Fig. 2). Settlement was greatest in collectors immersed for 2 months in the middle of the water column. From tagging studies, it was found that spat grew to 60 mm shell length during their first 12 months and attained a recruitment size

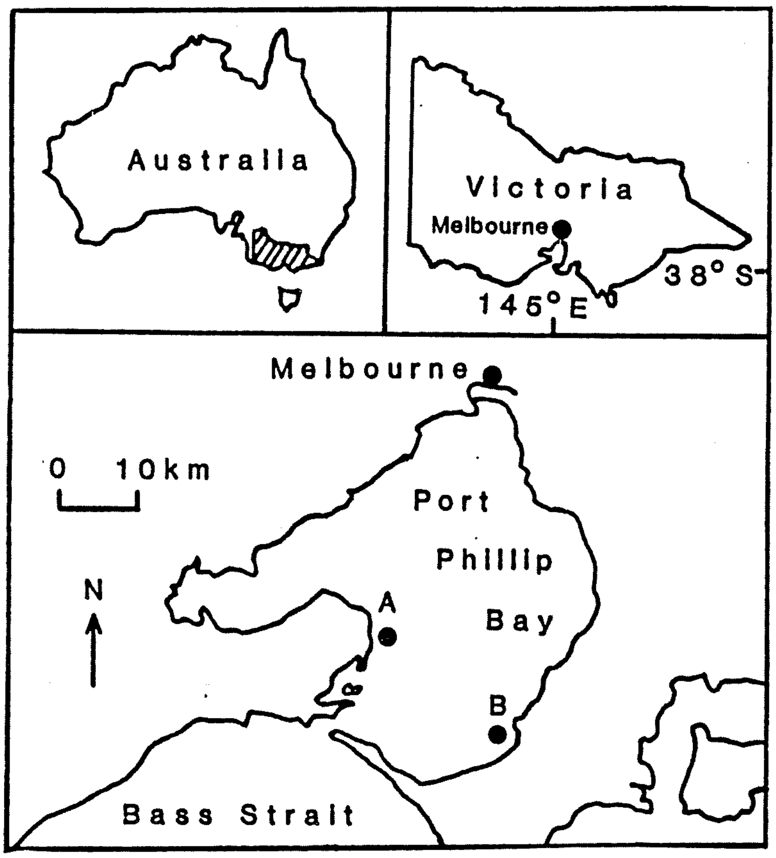


Figure 1. Location of study sites, (A) St. Leonards and (B) Dromana Bay.

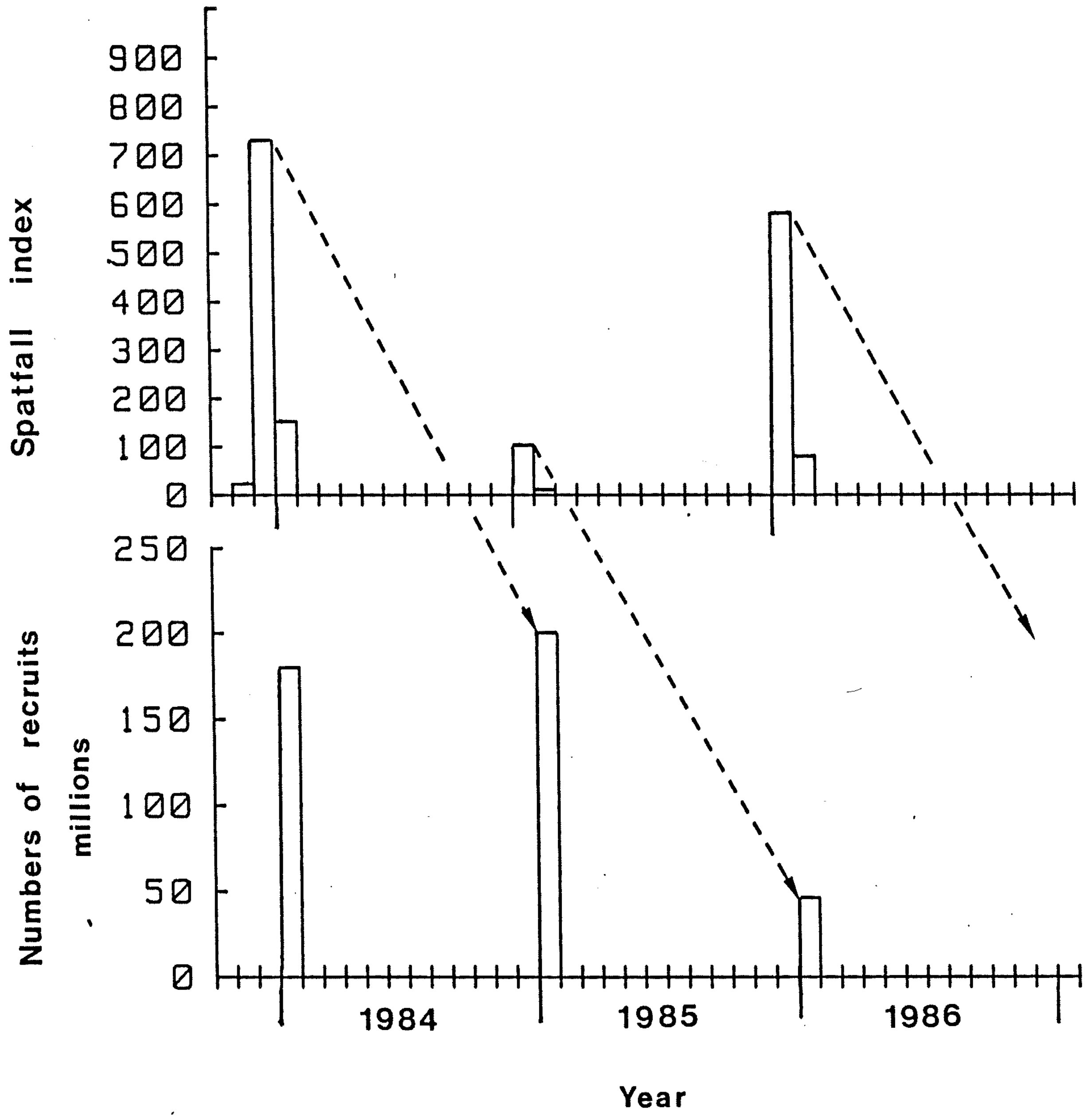


Figure 2. Relationship between spatfall index and numbers of 1-year old scallops recruited.

of 70 mm within 16-18 months. Additional confirmation that spat grow to recruitment size in a little over one year comes from observations of the size frequencies of juvenile scallops trapped by weed or shell present in commercial dredge catches. In Fig. 3, the progression of modal size of this newly settled cohort from about 20 mm in April to about 60 mm in December in each of the 3 years of the study can be seen. Settlement during one year can therefore be related to recruitment during the next.

Settlement indices for 3 years and the corresponding estimates of recruitment abundance for 2 years are available (Gwyther and McShane 1985, Gwyther and Burgess 1986). Spatfall indices of 700 per collector (east) and 450 per collector (west) in the summer of 1983-84 corresponded to recruitment estimates of 108 million and 90 million for the eastern and western sectors of the bay respectively. In the summer of 1984-85 settlement was much lower, 100 per collector, in both areas and gave rise to expectation of poor recruitment for 1986 (McShane and Gwyther 1985). This was indeed the case; recruitment was estimated to be only 30 million in the eastern and 18 million in the western sectors of the bay (Gwyther and Burgess 1986). The high settlement observed in the 1985-86 summer therefore suggests that a higher recruitment might be expected for the 1987 season. Details of this study are given in Appendix 2.

Several years' data are required before greater confidence in the predictions can be gained. However, the discrete seasonality of settlement and the rapid growth rate to recruitment size are factors which, in conjunction with the ability to obtain estimates of recruitment abundance in Port Phillip Bay (see later section), present possibilities for the use of a

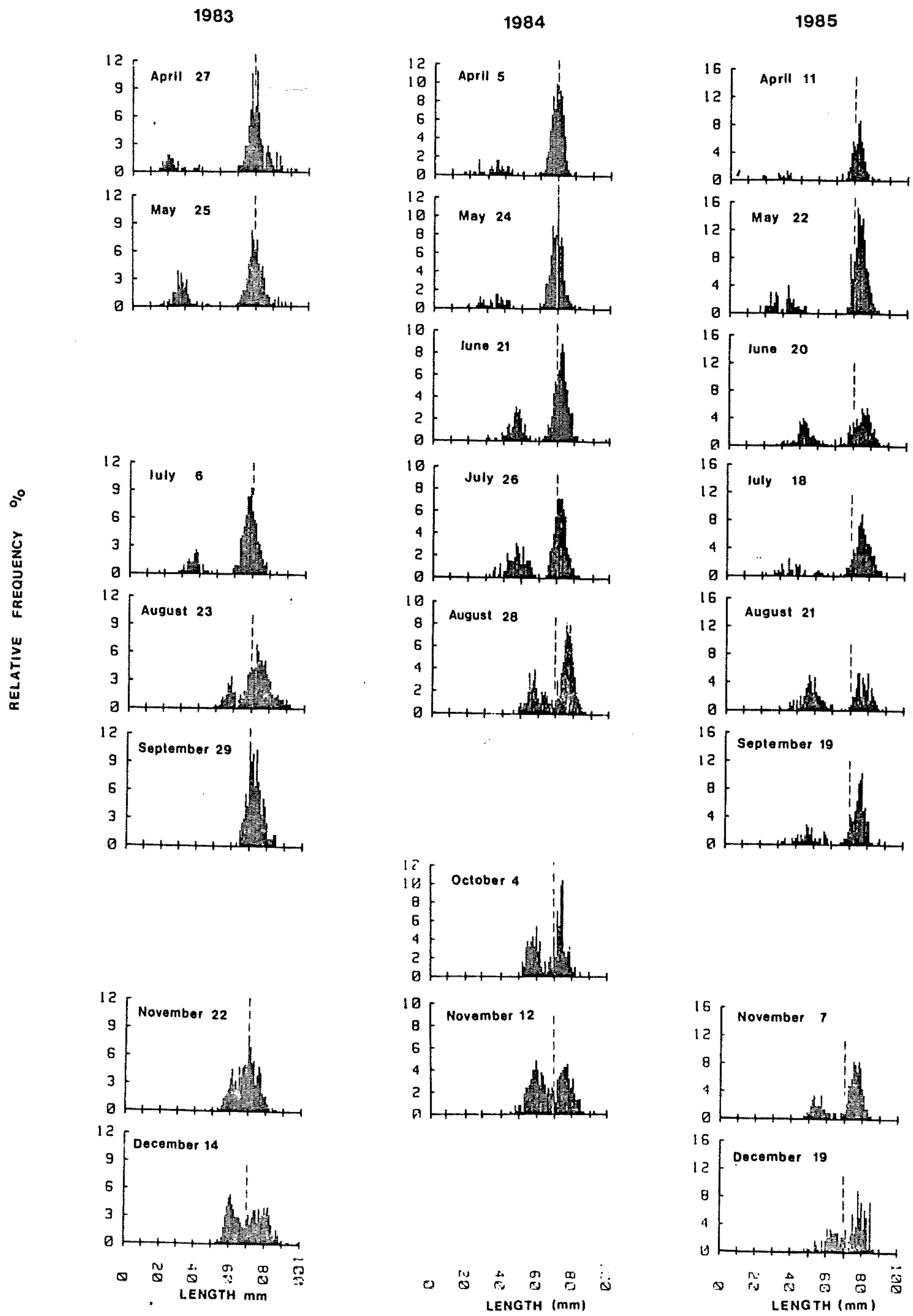


Figure 3 Length frequency distributions of commercial and pre-recruit (0+) class scallops sampled from dredgers in Port Phillip Bay during 1983, 1984 and 1985.

predictive component in the management of this valuable but widely fluctuating scallop fishery.

Rates of growth and natural mortality

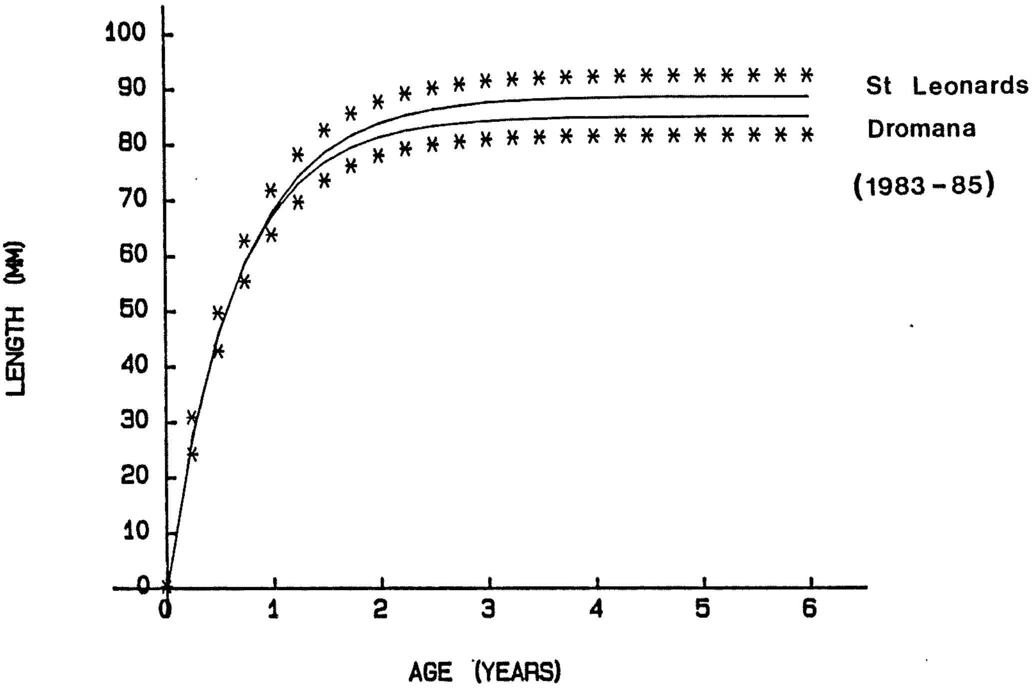
Knowledge of the rates of growth and natural mortality of scallops is essential if management is to optimise production from the natural growth and decay of populations or year classes. Because no reliable technique was found for determining age by external features such as growth rings, tagging experiments were conducted in two marked and buoyed sites in Port Phillip Bay from 1983-85. A tagged population, comprising about 1000 scallops was placed in each of the experimental sites. Natural mortality was determined from the decline in numbers of this tagged population over a 12 month period and growth rate was determined from data on length increment with time. Tagging studies of scallops in Port Phillip Bay were first carried out during 1964-67 (Sanders, unpublished data. Fisheries and Wildlife Service, Victoria). Analysis of these data enabled a comparison to be made between the present growth rate and that applicable to scallops when they were first exploited more than 20 years ago. Details of the growth and mortality studies are given in Appendix 3.

The instantaneous coefficient of natural mortality was estimated from tag-recapture experiments to be 0.52 (equivalent to 40%) year $^{-1}$. Estimates obtained independently from annual surveys ranged from 38-50% year $^{-1}$ (Gwyther and Mcshane 1985) and therefore natural mortality in Port Phillip Bay appears to have been consistently high since 1983. Values for the parameters K and L_{∞} of the von Bertalanffy growth curve were 1.6 and 86 mm respectively. In comparison with the results obtained from the earlier (1964-67) data, growth rate has increased substantially since the species was first exploited : scallops now attain a shell height of 70 mm more than 1 year sooner (Fig. 4). The significance of this is that size or age at which yield is optimum cannot be assumed to remain constant over long periods and management practices applied today would not have been appropriate had they been applied earlier in the development of the fishery.

Condition and length to weight relationship

Estimates of the functions of the relationship between shell length and meat weight are necessary for the calculation of yields available from the fishery. For scallops, the dramatic increase in weight (mostly gonad) during the developing and spawning stages of the reproductive cycle give rise to considerable variation in meat yield depending on season and state of maturity of the stocks. Measurements of dry weights of gonad and adductor muscle were made monthly for 20 scallops in each of three size groups (60--90 mm ; 70-79 mm; 80-89 mm) from April 1983 to March 1985. Figures 5a and 5b show the pronounced seasonality of changes in gonad weight as determined from monthly mean values compared with the relatively stable values for the adductor muscle (Figs 5c and 5d). It is clear that yields (gonad plus adductor muscle) are highest during winter and seasonal changes in condition therefore had to be taken into consideration when estimating yields available. Mean weight W(g) is related to shell length L (cm) by the formula $W = a L^b$. From regression analyses, mean monthly values of a and b were determined and incorporated into the model used to estimate yields (see section on yield modelling).

Figure 4. Calculated growth curves for 1983-85 data (upper) and 1964-67 data (lower), ±95% confidence limits on line of best fit (upper and lower only shown for St Leonards and Dromana respectively).



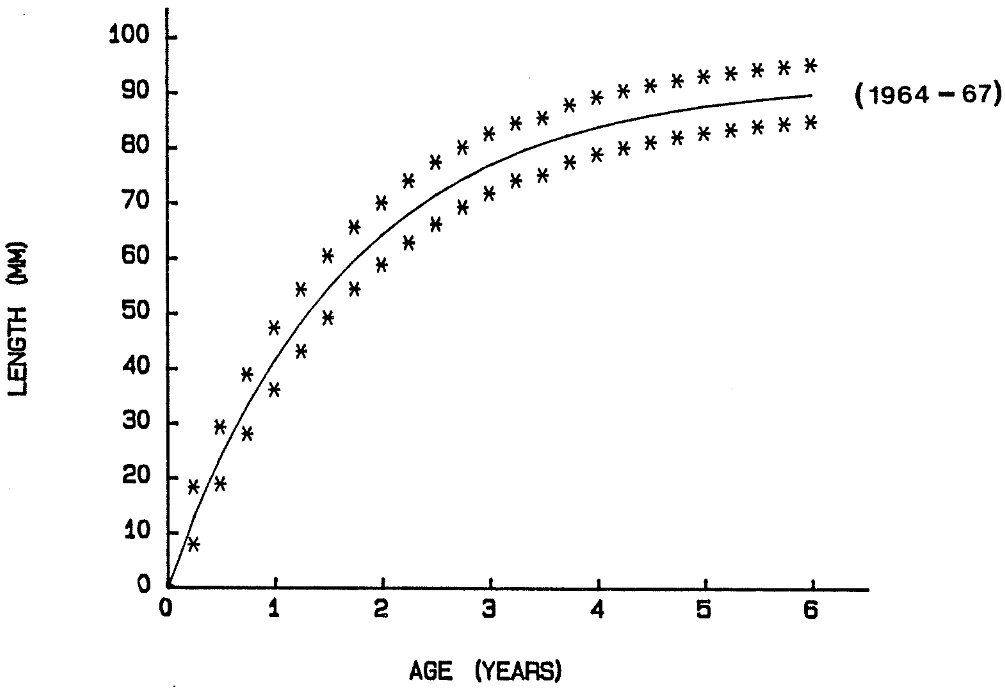


FIGURE 5 Monthly average dry gonad weight (g) (70 - 79 mm group) at A) Dromana and B) St. Leonards.

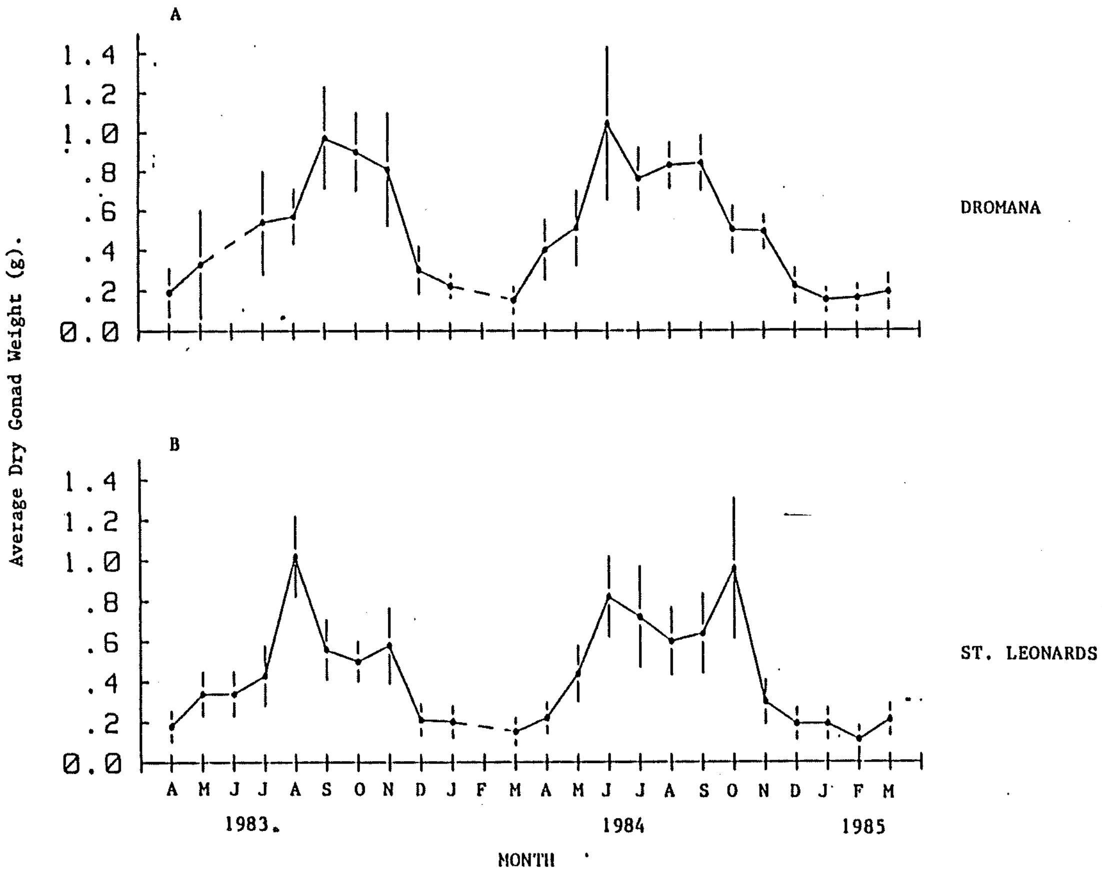
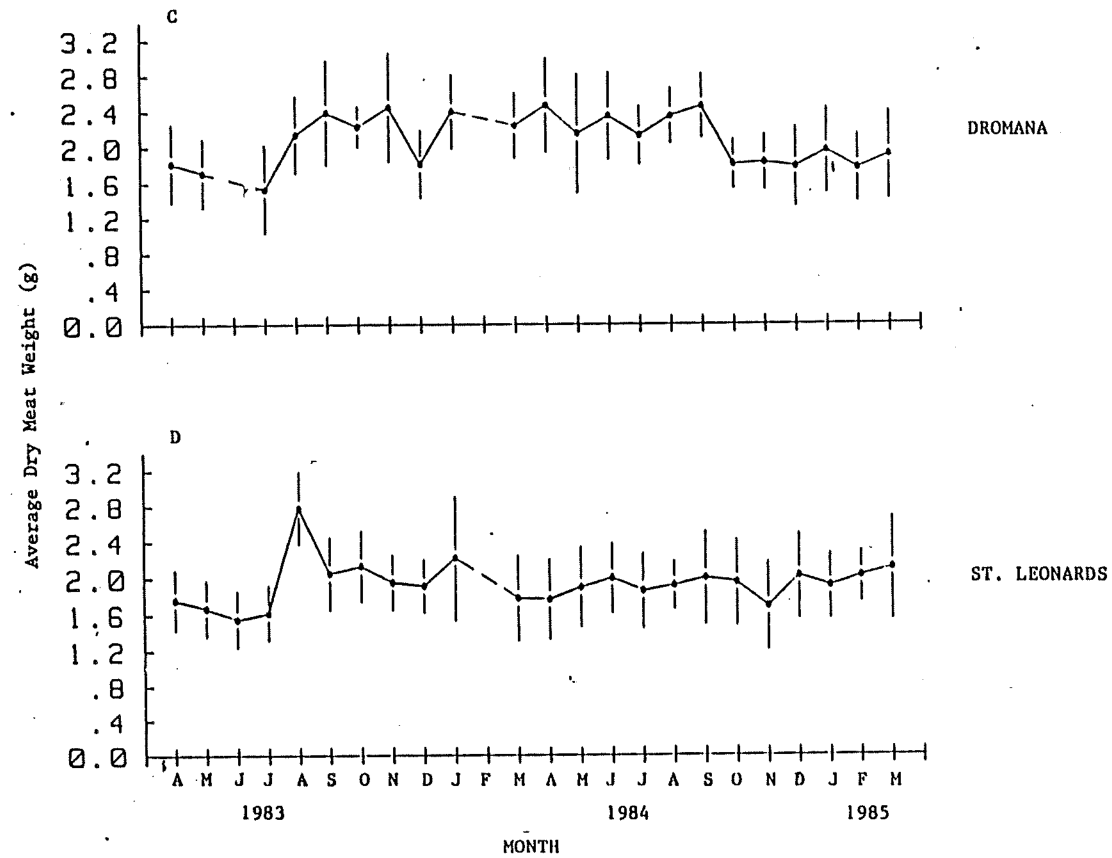


FIGURE 5 Monthly dry meat weight (g) (70 - 79 mm group) at C) Dromana and D) St. Leonards.



Annual surveys of scallop abundance in Port Phillip Bay

Daily quotas set for the Port Phillip Bay scallop fishery depend, to a large extent, on results from annual surveys of abundance conducted in the January before the start of each fishing season. Surveys by divers using a stratified random sampling strategy were first carried out in 1982 (McShane 1982b). This technique provided a more accurate estimate of relative and absolute abundance of pre- and fully recruited age classes of scallops than did dredge-survey techniques, whose selectivity factors were not known.

Annual dive surveys and their relevance to management have been a well-documented aspect of the scallop research program (see references) and results of the survey of scallop abundance in Port Phillip Bay in 1986 (Gwyther and Burgess 1986) are given in Appendix 4. Each survey provides an estimate of total numbers of scallops in the two main fishing grounds of the bay together with size composition and relative proportion of pre-recruited (1 + year old) scallops and residual (2 + and older) year classes. Since these age classes are distinguishable by size in January of each year, we have shown that since 1983, commercial viability of the fishery depends primarily upon the newly recruited age class.

From estimates of abundance, it is possible to predict mean annual catch rates if estimates of catchability (proportion of total caught per unit of fishing effort) or dredge efficiency are known. In 1984 catchability and dredge efficiency were calculated from density estimates and mean catch rates for 1983 (McShane and Gwyther 1984). By multiplying catchability by the estimated abundance in 1984, mean catch rates were predicted for that season. Subsequent estimates of catchability and dredge efficiency for each of the two main scallop grounds in Port Phillip Bay, from data for 1984 and 1985, have been constant (Gwyther and McShane 1985; Gwyther and Burgess 1986). Predictions of mean annual catch rate also proved accurate although in practice catch rates are normally very high at the start of each season, dropping well below the mean by the end.

Greater industry participation in the survey was sought in 1985 and 1986 and took the form of a pre-season charter of a scallop vessel to sample catch rates, size composition and condition of scallops before the opening of the season. This information, particularly condition, has helped to determine the most appropriate opening times.

In 1986, the survey report was extended to include the results of a mathematical model developed to determine yields available from the stock present at the beginning of the year. The model incorporated results from studies of rates of growth, mortality and seasonal changes in condition and gave estimates of yields available and indicated the effects of different fishing strategies (see next section).

Yield estimates

The mathematical model (Table 1) has been developed to estimate yields available from the scallop stock under different conditions of bag limits, time of opening of the season and seasonal alterations of bag limits. The basis of the model is application of the von Bertalanffy growth parameters (K, L_{∞}), the exponential rate of natural mortality (M) and parameters for the conversion of length to weight (a, b) incorporating seasonal variation

Table 1. Calculation of biomass (g x 10^{-6}) and effect of fishing under conditions appropriate for 1986.

a) biomass available

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Scallop shell length mm	73	75	76	77	78	79	80	81	81	82	82	83
Dry Meat Weight (g)	2.00	2.08	2.38	2.41	2.53	3.24	3.11	3.72	3.75	3.58	3.55	2.74
Numbers (millions)	150	144	138	133	128	123	118	113	109	105	101	97
Monthly Biomass (dry wt) (g x10^{-6})	300	300	330	320	323	398	367	422	409	375	357	265

b) effect of fishing

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Daily Crate Limit				6	6	6	10	10	6	6	6	0
Expected No. Vessels				85	85	85	85	85	85	85	85	0
Scallops Taken (million)				11.93	11.93	11.93	19.89	19.89	11.93	11.93	11.93	0
Biomass Taken				28.7	30.2	38.7	61.9	74.0	44.8	42.7	42.3	0
Scallops Remaining (10^6) at end of month	144	138	133	116	100	85	62	41	28	15	3	3
Biomass Remaining	288	289	317	280	254	275	195	152	105	55	11	9

Parameters : $k = 1.6$; $L_\infty = 86$ mm; $M = 0.04$ Month^{-1}; 18 days fished month^{-1};

1300 scallops per crate.

For $W = aL^b$

	J	F	M	A	M	J	J	A	S	O	N	D
ln a =	-11.92	-13.02	-11.43	-11.03	-10.93	-12.20	-15.34	-13.00	-14.60	-13.13	-16.10	-12.33
b =	2.94	3.19	2.84	2.74	2.72	3.06	3.76	3.26	3.62	3.27	3.93	3.02

to the annual survey estimates of abundance and of mean size at the start of each season, to compute monthly changes in numbers and biomass of scallops (Table 1). Biomass is highest during June–October, when scallops are between 1+ and 2 years old.

In setting daily quotas for the fishery, management is faced with the conflicting objectives of making the catching season last as long as possible while maximising the proportion of the catch taken during the months of highest yield. The different fishing strategies for which yield estimates can be compared only include variations to daily quotas or the timing of their adjustment : the number of vessels fishing is not an easily controllable input. In practice, the number of vessels fishing in Port Phillip Bay varies between about 40 and a maximum of 85, with those operators who are licensed to fish all Victorian waters choosing on the basis of viability of alternative grounds <u>versus</u> the relative profitability of the daily quota set for the Bay. For any given quota therefore, the "expected" number of vessels is subjectively assessed since viability of the alternative grounds is not always known and may vary during any Port Phillip Bay fishing season.

While a number of options can be compared (Gwyther and Burgess 1986), Table 1 shows the biomass taken and the numbers of scallops remaining under the daily quota regime permitted in 1986. The low stocks and the expectation that all the vessels licensed to fish in the bay would do so were the reasons for the low quotas : 6 crates per day rising to 10 crates in July. This strategy was designed to allow most of the catch to be taken when scallops were at their peak condition, recognising that the fishing season would not last until its normal December closure. Judgement as to what consititutes an acceptable residual stock after a fishing season is completed is subjective but in practice, residual stock of scallops have been constant at 40-70 million (Gwyther and Burgess 1986) for the past 4 years. Any strategy designed to reduce residual stock to below these numbers is likely to result in quotas becoming unobtainable during the season. The model predicted that this cut-off point would be reached in August. In fact, the 1986 season closed voluntarily at the beginning of July, when many operators could not catch the daily quota in the permitted hours of fishing.

APPLICATION OF THE RESEARCH RESULTS TO THE MANAGEMENT OF THE PORT PHILLIP BAY SCALLOP FISHERY : A SUMMARY

Every commercial fishery presents its reseachers and managers with certain unique circumstances or combinations of factors whereby generalised principles of fishery dynamics have to be adjusted. Sometimes such factors provide advantages but often inhibit the understanding of critical events in the fishery. The semi-enclosed nature of Port Phillip Bay and the annual estimates of abundance place managers in the unusually advantageous position of knowing the size of the resource to be harvested. Unfortunately, the size of this particular resource is never constant; sometimes it is not enough for the economic demands upon it.

Undoubtedly the most significant achievement of the research program has been the improved understanding of the processes of recruitment : spatfall in summer, followed by one year's growth to recruitment and the fishery's dependence each year on the size of this recruitment for commercial viability. This dependence upon recruitment and the inadequacy of residual stocks to maintain commercial viability each year render the industry most vulnerable to a recruitment failure. Very high recruitment in 1985 resulted from high spatfall during the previous summer and produced one of the most profitable fishing seasons. But even at that time fears were expressed concerning the outlook for 1986 (Gwyther et al 1985, McShane and Gwyther 1985), because of the low settlement observed during the summer of 1984-85.

The outlook for the 1987 season, however, is for improved recruitment although its strength will not be known with greater accuracy until the 1987 abundance survey is completed. In future years, continued comparisons of spatfall and recruitment data should improve our capabilities of predicting when gross changes in recruitment might be expected, even if not the reasons why fluctuations occur.

The usefulness of the yield model is that it allows fisheries managers to compare the relative merits of adopting the sociologically and economically desirable strategy of maintaining the catching season for as long as possible with the biologically more efficient strategy of short-season harvesting during times of peak condition, for any given stock size. The model is primarily a tool for estimating yields available on an annual basis. In the model, the fact that the expected number of vessels depends to a large extent on the viability of other grounds and is not easily controllable forms the main source of uncertainty in its use for the management of this fishery. Mid season adjustments to quotas would be inevitable if substantially more or less than the expected number of vessels actually fished. The question of optimum numbers of vessels fishing in the bay is thus raised. It is generally accepted that the current maximum of 85 is too high for all but the years of very high recruitment but difficulties in the derivation of a satisfactory lower maximum number of vessels arise from two sources:

i) the concept of sustainable yield is not a realistic one for scallops in Port Phillip Bay but it is one upon which any determination of optimum number would depend.

ii) despite a relatively long history of management of this fishery, it is not readily apparent what "satisfactory" or "optimum" might mean. Satisfactory for whom? Optimum for good seasons or poor ones?

Management regulations have evolved in a complex and ever-changing biological and socio-economic environment. The continued existence and profitability of the Port Phillip Bay scallop fishery (1986 season notwithstanding) may be seen as a tribute to management, imprecisely defined though its objectives might be. It is not intended to discuss the concepts of management in any greater detail here (see Sturgess et al 1982), but where fulfilment of the aims of research impinge on management, it is of course relevant. The development of the yield model greatly enhances the managers' ability to evaluate the effects of fishing on stocks and yields but does not answer all problems associated with highly variable recruitment and instances where the fortunes of other, independent fisheries impact on fishing levels in the Bay.

In the longer term, therefore, it must be the predictive information on likely recruitment strength one year in advance which should best prepare the industry to cope with fluctuations in the resource, but how should the industry use this information to its best advantage? Because of the scallop's high mortality rates in Port Phillip Bay, any strategy of allowing a good recruitment to be fished for longer than one season would not be appropriate as it would result in a nett loss of yield, there being an implicit assumption that stock size and recruitment are not related. A system of financial flexibility, such that loans can be geared to the fluctuations in the resource probably offers the best chance of stabilising the operating environment for the licence holders, particularly new entrants to the fishery. Such a strategy should aim to maximise the repayments during good years, when catches are obtained easily and to reduce the repayments in poor years when operators might be forced into excessive fishing effort, which would deplete the already low stocks.

ACKNOWLEDGEMENTS

The program team comprised D. Gwyther, B. Sause, P.E. McShane (Scientific Officers) and D.C. Burgess, R. Kehoe, S. Foley and M. John (Technical Assistants). Throughout the duration of the prgram, most staff members of the Marine Science Laboratories and many in Commercial Fisheries Branch (now Marine Resources Management Branch) contributed in some way to the completion of the program and whether in conceptual, technical or administrative form, their help is acknowledged. To the scallop fishermen and processors who have taken such an active interest in the work, the program team wish to express their thanks and their hope that the work has been, and will continue to be of benefit to this industry.

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83/32

PORT PHILLIP BAY AND BASS STRAIT SCALLOP STUDIES

SLIDES:

1. Scallop dredge emptying on to sorting tray.

2. Typical size composition showing pre-recruit 0+ scallops and fully recruited 1+ and 2+ aged scallops. Port Phillip Bay.

3. Seasonal change in length frequency in Port Phillip Bay showing growth of 0+ scallops to recuitment size in one year.

4. Density of scallops at sample sites: Port Phillip Bay annual survey, January 1982.

5. Calculation of natural mortality from estimates of recruitment, fishing mortality and residual stock; Port Phillip Bay.

6. Tagged scallops used to study growth and mortality, Port Phillip Bay.

7. Scallops in unusually poor condition, Lakes Entrance, November 1984.

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9.)Placement of scallop spat collectors off Lakes Entrance, November 1984.
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10.)

11. Retrieval of spat collector; Port Phillip Bay.

12. Natural settlement of scallops on filamentous algae and seagrass frond; Port Phillip Bay.

13.)
)Studies of growth of juvenile scallops in lantern cages; Port Phillip Bay.
14.)

FIRTA 83/32

APPENDIX 1

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Evidence for Winter-Spring Spawning of the Scallop *Pecten alba* (Tate) in Port Phillip Bay, Victoria.

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Abstract

Gonadal reproductive status of *P. alba* from two locations within Port Phillip Bay, Vic. (38°S., 145°E.) was studied for 25 months from March 1983. Samples were collected monthly by divers and analysed for reproductive status. Although the scallops were spent of gametes during summer and showed development of gonads throughout autumn, phases of winter spawning were observed before a major late spring release.

Spawning of *P. alba* and other scallop species in the Southern Hemisphere is a winter-spring phenomenon, rather than the summer-autumn phenomenon common among scallops of the Northern Hemisphere.

Introduction

Pecten alba (Tate) and the related (or synonymous) P. meridionalis (Tate) and P. fumata (Reeve) contribute most to the south eastern Australian scallop fishery. In Port Phillip Bay, Victoria, a dredge fishery for P. alba has existed since 1963. The abundance of this hermaphrodite bivalve fluctuates markedly from year to year, and annual surveys of abundance are conducted to assist management of this fishery (McShane and Gwÿther 1985). The present study was designed to investigate the seasonality of spawning by this species to help understand the problem of irregular recruitment.

Seasonal variation in gonad and meat weight for P. alba, comparing normal scallops with those parasitized by a bucephalid trematode, was investigated by Sanders (1966) and later by Sanders and Lester (1981). For uninfected scallops, the time of peak gonad weight occurred in August, this being taken as the onset of spawning. In determining major spawning periods of this and related species, histological examination provides the best evidence of spawning activity over a year and has been used in a number of studies (Sastry 1963, 1966, Naidu 1970, Taylor and Venn 1979, Shafee and Lucas 1980, Dredge 1981, Barber and Blake 1983, and Sundet and Lee 1984). Detailed histological descriptions of the stages of reproductive development have been provided by Mason (1958) for Pecten maximus and by Harrison (1961) for Notovola (=Pecten) meridionalis.

Here we describe the reproductive cycle of P. alba, and in particular, give evidence for winter-spring spawning, which is similar in timing to that of other Southern Hemisphere scallops. This timing contrasts with seasonality of spawning for scallop species from the Northern Hemisphere; the differences are discussed.

Materials and Methods

Sampling

Samples of scallops were collected monthly by S.C.U.B.A. divers for 25 months, beginning in March 1983, from the locations shown in Fig. 1. The depth of water at each location was approximately 13 m and seawater temperature was measured at the time collections were made with an Autolab Harmon model 602 temperature and salinity bridge. From each sample, the first 15 individuals whose flat shall length was between 70 - 80 mm were selected for analysis. Scallops of this size range were reproductively active, fully recruited into the fishery and available all year.

Histology

The gonads were excised and placed immediately into Davidsons fixative (Shaw and Battle 1957). After fixation, portions of both male and female tissue were processed histologically, embedded in wax and 7 um sections were cut. A set of sections was double stained with Harris Haemotoxylin and Alcholic Eosin Y, (Mallory 1938) and a duplicate set was stained with Alcian Blue.

Gonad Index

Several arbitrary stages of gonad condition were described, based principally on the system outlined by Mason (1958) for P. maximus (Table 1). Each stage of gonadal condition was assigned a points score:

spent 0; developing (1), 1; developing (2), 2; developing (3) or spawning (3), 3; developing (4) or spawning (2), 4; developing (5) or spawning (1), 5; mature, 6.

All male and female histological sections were assigned to these stages. A gonad index was calculated for each monthly sample by firstly multiplying the number of scallops at each stage by its arbitrary score. The products were then summed and the result divided by the number of scallops in the sample. The derivation of this gonad index was based on the system described by Seed (1969). An overall increase in the gonad index denoted gonad development, whereas a decrease indicated spawning activity.

Results

Histology

The histological stages shown in Fig. 2 and 3 are described in Table 1. An important finding of this study was that during the spent stage, which usually has been regarded as a stage of inactivity, the gonads were restructured. Resorption of remaining gametes occurred and old follicular membranes began to breakdown while new spherical groups of cells appeared throughout the spent gonads. The development of these cell groups is under investigation as it appears that they are associated with the development of new follicles (Fig. 2a).

Old follicular membranes broke down completely and new follicles appeared during early development (Figs 2b-2d, 3a-3c). These developing follicles clearly delineated the male from the female portions of the gonad and the later stages of development resulted in the gonadal space becoming fully occupied by follicles containing mature gametes. Reserves of mature gametes increased during the later stages of gonad development and reached maxima at the mature stages (Figs 2e and 3d).

Another important finding of this study was the partial release of mature gametes during winter, indicated by the appearence of lumina within follicles. The follicular walls remained otherwise distended (Figs 2f and 3e). Sometimes this partial spawning involved the release of substantial numbers of the gametes (Figs 2g and 3f) and subsequent regeneration of the gametic reserves to fill the follicular lumina. However, release of most of the gametes resulting in the empty follicles shown in Figs 2h and 3g was an irreversible process towards the spent stage. Furthermore, it was at this major spawning time that the number of spherical groups of cells as described for the spent stage, increased. For comparative purposes, Fig. 3h shows abnormal resorption of gametes and breakdown of mature follicles in samples taken from Bass Strait in July 1984. This phenomenon was not observed in samples of Port Phillip Bay scallops.

Gonad Index

Monthly changes in gonad index occurred synchronously, with little quantitative variation between years and sites. Values were therefore pooled (Fig 4a) to show the annual cyclic nature of the reproductive behaviour. Gonad indices were related inversely to temperature ($P < 0.001$). Corresponding with the large increase in gonad index between February and May (Fig. 4a) was a decline in the proportion of spent individuals (Fig. 4b) and an increase in the proportion of individuals with developing gonads (Fig. 4c). Development occurred extremely rapidly which could explain why only a small proportion of the scallops was observed in the spent stage. Once the gonad indices reached maxima in June (winter), they were maintained over the next five months, (Fig 4a) when the proportion of spawning individuals increased (Fig. 4d). Partial spawnings were immediately followed by redevelopment. Although, partially spawned gonads resembled the later developmental stages in size, prominent lumina within follicles were a diagnostic feature of partially spawned gonads. As gonad size did not significantly decrease throughout these spawnings, the gonad index remained high. Once spawning regression commenced (i.e. resorption of gametes and follicular membranes) during mid summer the gonad index dropped significantly as did the gonad size. The spawning period began when temperatures were lowest and the main emission of gametes (in late spring) occurred 3-4 months before the maximum temperature was recorded for the Bay.

Discussion

Based on macroscopic observations of gonads, Sanders and Lester (1981) deduced that P. alba in Port Phillip Bay spawned, as a single major event, only in spring. The present study, using monthly, histologically prepared material, has allowed us to assess more accurately the timing and length of the spawning period. In particular, we have described three stages of spawning for scallops in the Bay. Gonads classified into the first two spawning stages appear capable of redeveloping and undergoing further spawning; the overall size of the gonad is relatively unchanged. Once at the third spawning stage, however, gonads regress to the spent stage and the overall size of the gonad decreases considerably. In a study of a closely related species from Tasmania, Harrison (1961) described a single spawning stage and three regression stages. The spawning stage included gonads that were either completely or partially spawned. Queensland scallops studied by Dredge (1981) showed no evidence of partially spawning stages, although it might be possible that spawned gametes could be replaced rapidly as to preclude detection of their release.

Seasonal spawning by P. alba in Port Phillip Bay is consistent with that of other pectinid species from Tasmania, Queensland and New Zealand. Booth (1983) inferred a late winter-spring spawning for Pecten (Chlamys) striatus in New Zealand because of the greater abundance of larvae during that period. However, spawning times could not be determined with greater precision because of difficulties in larval identification. This seasonal spawning activity of Southern Hemisphere Pectinidae contrasted with published data for those from the Northern Hemisphere (Table 2), which clearly indicated that for a number of species at a number of locations, spawning was predominatly a summer-autumn activity. The only obvious exception is Chlamys distorta, which exhibited an abnormally protracted spawning period (Reddiah 1962).

This raises the question of what factors control the breeding cycle and spawning seasons for Pectinidae. The evidence that scallop species spawn during the same range of calendar months regardless of northern or southern latitudes (Table 2) suggests that there is no uniform pectinid reproductive response to temperature, photoperiod or to the rate or direction of change of these factors. Food availability is also important for adult gonad development and for larval survival (Sastry 1968) but factors responsible for correlating reproductive events and the way such factors may influence overall reproductive success are not clear.

Various spawning strategies, ranging from a short single spawning event to extended gamete release over a number of months are shown in Table 2. In

Port Phillip Bay, where spawning is observed from June through to November, it is not known whether planktonic larvae are produced for the duration of spawning. Observations using spat collectors suggest that larvae settle successfully over a very short time (Gwyther et. al. 1985). It is possible that the successful settlement resulted from the final major spawning period rather than from earlier, partial spawnings although the capacity for delayed larval development, as has been demonstrated for *Mytilus edulis* (Bayne 1965) and *P. maximus* (Beaumont and Budd 1982) has not been studied for *P. alba*.

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Table 1. Description of stages in a seasonal reproductive cycle of the scallop, Pecten alba shown in the photomicrographs (Figs. 2 and 3).

Stage.	General histological description of gonads.
Spent	Minimum size No visible differentiation into testes or ovary (Fig. 2a). The loop of the alimentary tract within the gonad is prominent and surrounded by a distinct layer of connective tissue. Spherical groups of cells distributed throughout gonads. Breakdown of old follicular membranes (=last year's follicular membranes).
Developing (1)	Size of gonads not increased. Differentiation into male and female gonads; new follicles small but show either spermatogenesis (Fig. 2b) or oogenesiss (Fig. 3a) within. Considerable breakdown of old follicular membranes.

Developing (2)

Size of gonads not increased.

New follicles larger and contain later stages of gametogenesis; sections of female follicles are characterised by half-grown oocytes (Fig. 3b).

Old follicular membranes nearly disappeared.

Developing (3)

Small increase in size of gonads.

New follicles enlarged to the state where they fill most of the gonadal space.

Radial gradation of gametogenesis from gonia near the follicular membrane to gametes in the central region; shown within broad bands in male follicles (Fig. 2d) and as a cellular size gradation in female follicles (Fig. 3c).

Developing (4)

Increase in size of gonads.

Follicles now fill entirely the gonadal space.

Gametic ducts are flattened.

Central regions of the follicles show an accumulation of mature gametes.

Gametogenesis still occurring.

Developing (5)

Further increase in gonadal size.

Increased reserves of mature gametes within follicles (Fig. 3d).

Very little gametogenesis in either male or female gonadal follicles.

Very little gametogenesis in either male or female gonadal follicles.

Mature

Maximum gonadal size attained.

Follicles contain large reserves of mature gametes (Fig 2c) and in females the packed ova become polygonal in shape.

Spawning (1)

Maximum gonadal size is maintained.

Partial release of gametes resulting each follicle having a distinctive lumen (Figs. 2f and 3e).

Remaining ova in female follicles often show some of the polygonal shapes attained at the mature stage.

Gonads can regenerate to the mature stage.

Spawning (2)

Gonad size smaller than the mature stage.

A greater release of gametes than observed in spawning (1).

Follicular lumen large (Figs 2g and 2f).

Decrease in follicular size producing intra-follicular space within gonads.

Gonads can regenerate to mature stage.

Spawning (3)

Marked reduction in gonad size.

Major and final release of gametes Figs. 2h and 3g).

Irreversible towards the spent stage.

Spherical groups of cells, common to the spent stage, first appear (Fig. 2g).

Table 2. Comparative spawning seasons of Pectinidae. Months of major spawning are given in parentheses.

Species	References	Location	Spawning season
		N. Hemisphere	
Argopecten irradians	Barber and Blake (1983)	Florida	Summer-Autumn (Sept-Oct)
Chlamys distorta	Reddiah (1962)	Irish Sea	Spring-Summer-Autumn (May-Aug, Nov-Jan)
Chlamys islandica	Sundet and Lee (1984)	N. Norway	Summer (Late June-July)
Chlamys opercularis	Brand et al. (1980)	Irish Sea	Summer-Autumn (Sept-Oct)
Chlamys septemradiata	Ansell (1974)	Clyde Sea	Summer-Autumn (July-August)
Chlamys varia	Reddiah (1962)	Irish Sea	Spring-Summer-Autumn (June, Sept-Oct)
Chlamys varia	Shafee and Lucas (1980)	Brest	Spring-Summer-Autumn (Sept-Oct)
Patinopecten caurinus	Hennick (1970)	Alaska	Summer (June-July)
Pecten maximus	Gibson (1956)	Ireland	Spring-Summer-Autumn (Apr-June, Sept)
Pecten maximus	Mason (1958)	Irish Sea	Spring-Summer-Autumn (Apr or May, Aug or Sept)
Pecten maximus	Comely (1974)	Clyde Sea	Variable-Spring-Summer (Feb-Apr, June-July)
Placopecten magellanicus	Naidu (1970)	Newfoundland	Spring-Summer-Autumn (Sept-Oct)
Placopecten magellanicus	Thompson (1977)	Newfoundland	Summer-Autumn (Aug-Sept)
		S. Hemisphere	
Amusium japonicum balloti	Dredge (1981)	Qld/Aust	Winter-Spring (Oct)
Notovola meridionalis)	Harrison (1961)	Tas/Aust	Winter-Spring (Sept-Oct)
Pecten meridionalis)			
Pecten alba	Present Study	Vic/Aust	Winter-Spring (Aug-Oct)

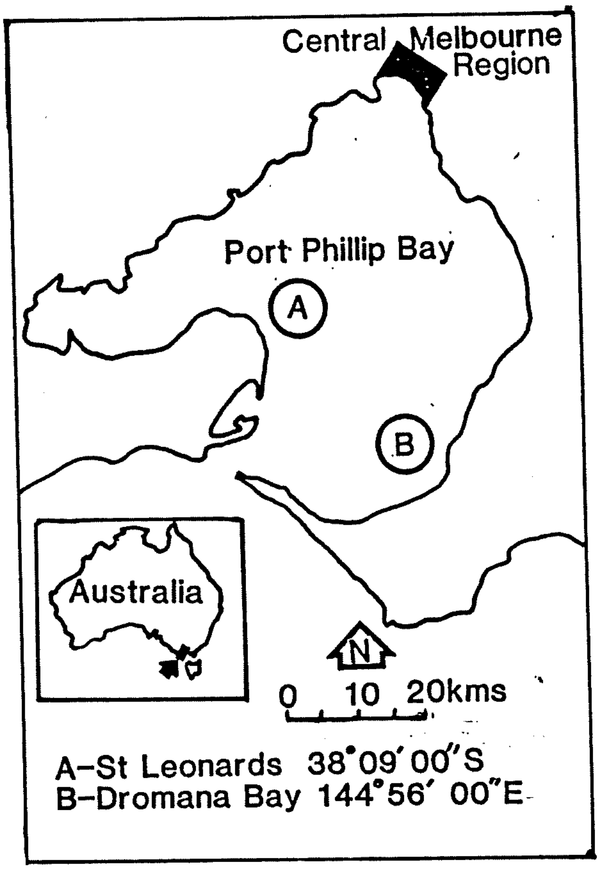

Fig. 1. Location of study sites in Port Phillip Bay

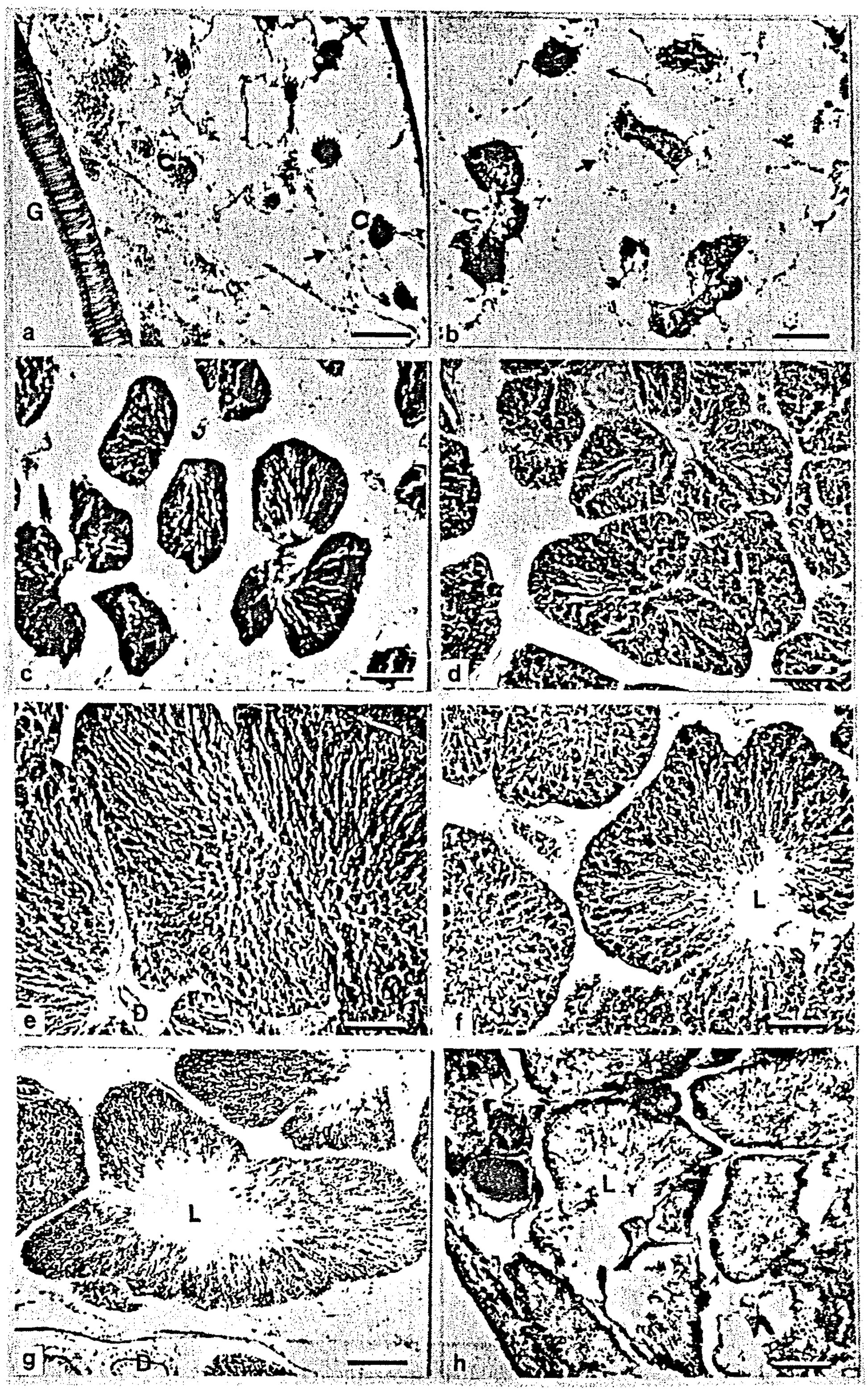

Fig. 2. Male scallop gonads at different stages of a seasonal reproductive cycle (See Table 1. for details of each stage). 2a, spent; 2b-d, developing; 2e, mature; 2f and g, early spawning; 2h, late spawning. Degenrating follicular membrances, arrows; C, Cell groups; G, Gut; D, Duct; L, Lumen (created after partial spawning). Bar lines represent 100 um.

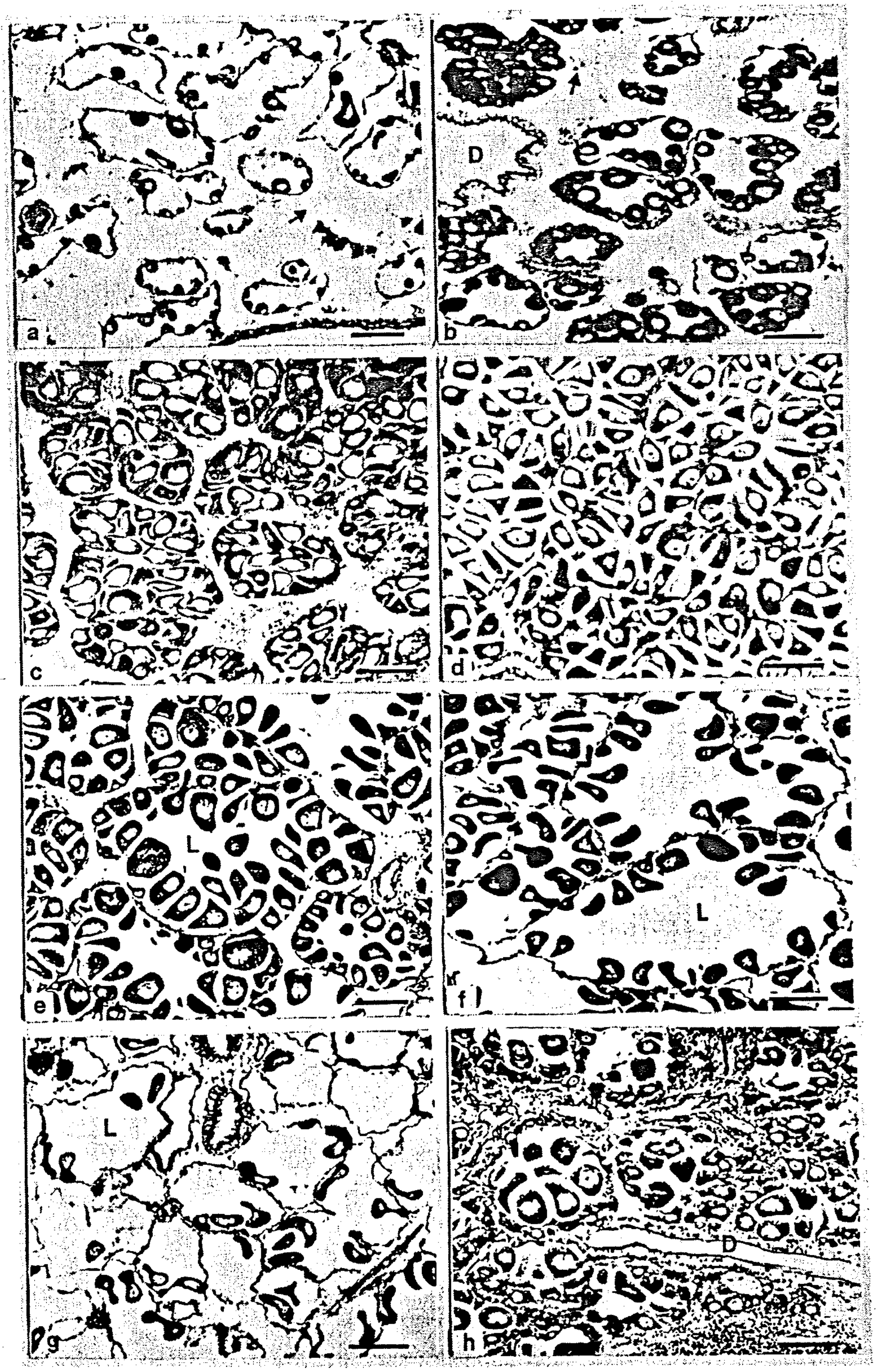

Fig. 3. Female scallop gonads at different stages of a seasonal reproductive cycle (See Table 1. for details of each stage). 3a-c, developing; 3d, mature; 3e and 3f, early partial spawning; 3g, late spawning; 3h, abnormal resorption of gametic tissue. Degenerating follicular membranes, arrows; C, Cell groups; D, duct; L, lumen (created after partial spawning). Bar lines represent 100 um.

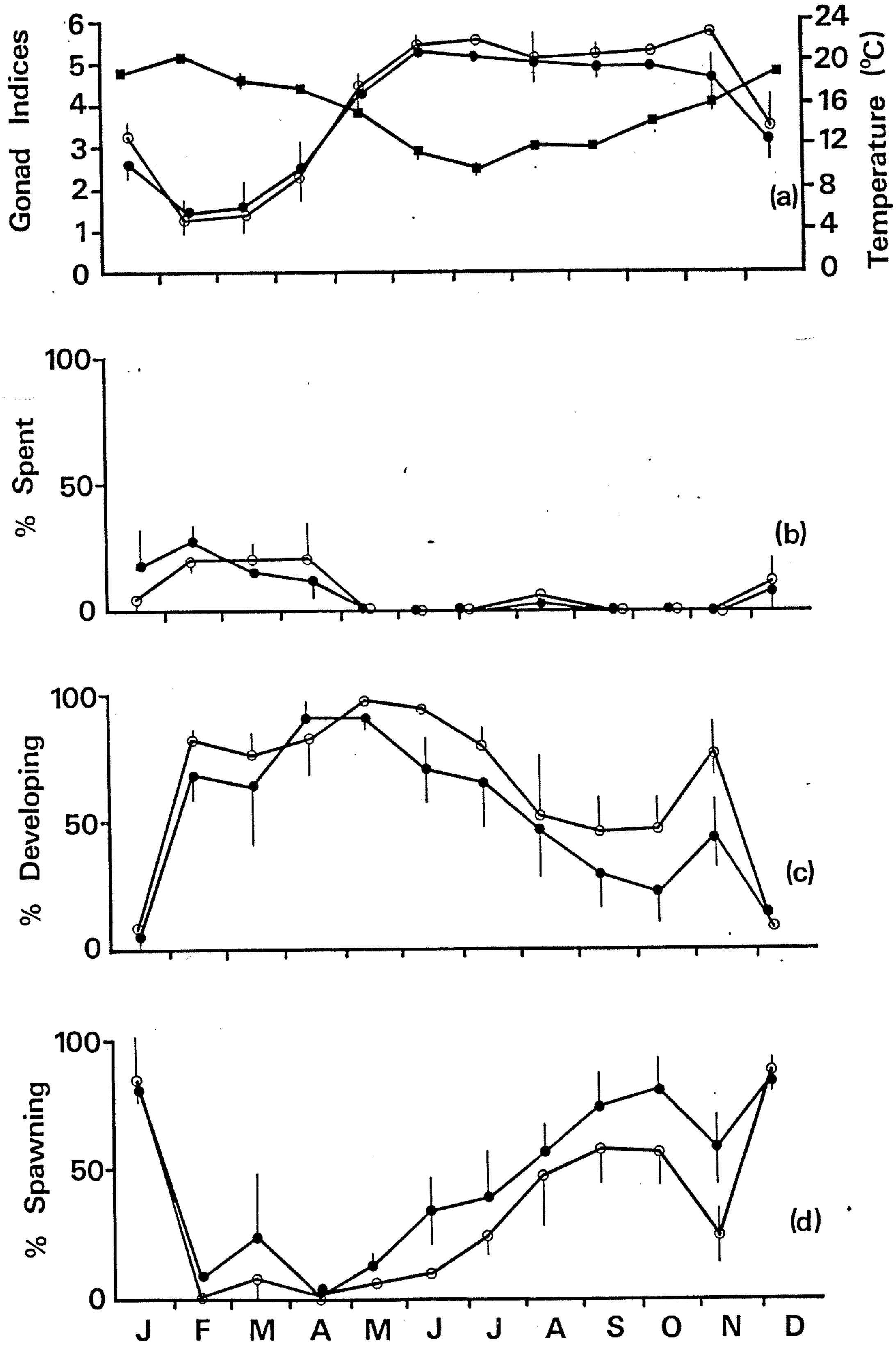

Fig. 4. Comparative aspects of the seasonal reproductive cycle of the scallop, Pecten alba. Graphs show pooled data for a 25 month period of sampling within Port Phillip Bay, Victoria. Error lines are standard errors. O male gonads, ● female gonads, ■ seawater temperature.

APPENDIX 2

Sause, B.L., Gwyther, D. and Burgess, D.C. Larval settlement, juvenile growth and use of spatfall indices to predict recruitment of the scallop Pecten alba (Tate) in Port Phillip Bay, Victoria, Australia. (submitted to 'Fisheries Research).

LARVAL SETTLEMENT, JUVENILE GROWTH AND USE OF SPATFALL INDICES TO PREDICT RECRUITMENT OF THE SCALLOP *PECTEN ALBA* (TATE) IN PORT PHILLIP BAY, VICTORIA, AUSTRALIA

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ABSTRACT

Settlement of the scallop *Pecten alba* in artificial collectors and the growth of juvenile scallops were examined in relation to separately obtained estimates of annual recruitment in Port Phillip Bay, south-eastern Australia. A single, annual settlement during October to December was observed during the 3-year study. Settlement was greatest in collectors immersed for 2 months in the middle of the water column. Spat grew to 60 mm shell length during their first 12 months and attained a recruitment size of 70 mm within 16-18 months. Settlement during one year can therefore be related to recruitment during the next. Years of high and low settlement were reflected in subsequent differences in recruitment. Though more years' data are required, indices of spatfall provide managers of this industry with the possibilities of predicting major fluctuations in recruitments one year in advance.

INTRODUCTION

The scallop *Pecten alba* (Tate) in Port Phillip Bay, Australia, supports a dredge fishery worth between 5 and 15 million dollars annually, but the fishery, in common with other scallop fisheries (Dickie 1955, Mason 1983), has to contend with large fluctuations in the number of scallops from year to year. Fortunately, the semi-enclosed nature of Port Phillip Bay allows the total size of the stock to be estimated from annual surveys of scallop abundance from which daily quotas are set (McShane 1982, 1983, McShane and Gwyther 1984, Gwyther and McShane 1985). The surveys are conducted a few months before the start of each season and provide estimates of recruitment and residual stock size but give little time for the industry to adjust to new quotas. Earlier predictive information on the likely strength of recruitment would therefore be invaluable. Recruitment strength could be estimated if the time interval between settlement and recruitment were known, and probably estimated more reliably for species in which the time interval is short. In Port Phillip Bay, where no minimum size regulations are in force, *P. alba* reaches an acceptable harvestable size of around 70 mm in its second year, as determined from length frequency distribution (Gwyther and McShane 1985), but little information is available on the timing and duration of juvenile scallop settlement and on the time interval between settlement and recruitment.

In this paper we describe the results of a study designed to determine the timing and intensity of scallop spat settlement and to discover whether indices of settlement could be related to recruitment into the fishery one year later.

MATERIALS AND METHODS

Spat collectors

At a site in each of the two main scallop beds in Port Phillip Bay (Fig. 1), six 6 m lines, into which rope loops had been spliced at 1 m intervals, were moored to concrete blocks and buoyed 5 m beneath the surface. To the rope loops, SCUBA divers could attach, as required, collectors consisting of a Netlon mesh bag (6 mm mesh diam.) filled with 300–400 g of old, nylon gill net monofilament (Brand et al. 1980). The collectors were retrieved by divers following a rotational system where, each month, collectors which had been immersed for 1, 2 and 3 months were returned to the laboratory. To minimize loss of spat from collectors being retrieved, divers placed sleeves of 220 um mesh over the collectors before their retrieval. Once the collectors had been removed from the sea, their contents were washed through a series of sieves (4 mm–220 um), and the numbers of pectinid and other settling bivalves were counted. During the initial experiments (August 1983 – August 1984), collectors were placed on each loop of the lines. During September 1984 – March 1986 collectors were placed only at midwater, because results from the initial experiments showed that settlement in midwater collectors was very much greater than that in collectors nearer the seabed (see Results section).

Growth studies

Three methods were used to establish the time interval between settlement and recruitment. In the first method spat taken from collectors placed in the sea during August 1983 were measured in January 1984 and then placed in Japanese style lantern cages (6 mm mesh size) at midwater. The scallops were remeasured in April 1984 and placed in cages with a larger mesh size (24 mm). This procedure was repeated in October 1984, but the density of the scallops in the cages was reduced to half the stocking density in April.

For the second method, staff took monthly trips on commercial scallop dredgers during the 1984 and 1985 fishing seasons (April to December) to measure size frequencies of the fully recruited and juvenile cohorts of scallops. Juvenile scallops of 15 mm or more shell length are trapped by weed or dead shell present in commercial catches. When the commercial fishing season was closed during January, divers collected juvenile scallops.

In the third procedure, divers placed 270 tagged spat on the seabed at a marked location close to the collector lines and recovered a proportion of them after 3, 5, 8, 13 and 18 months. The spat for this study had been collected with a small meshed dredge towed from the research vessel 'Melita' during April 1984. Each scallop was tagged by glueing plastic numbered labels to its upper flat valve.

RESULTS

Spat Settlement

The relationship between the numbers of scallop spat which settled in collectors placed at different depths shows (Figs. 2 a & b) that the greatest numbers settled in collectors placed at midwater. Consequently, only midwater collectors were used in subsequent years when four replicates were examined. At each site, when comparing the four replicate collectors the co-efficient of variation for the number of scallops per collector was less than 10% (where major settlement occurred).

Bivalve species which settled most commonly in the collector bags were P. alba, Mytilus edulis planulatus, Electroma georgiana and a number of venerid species. Their relative settlement densities in collectors immersed for 2 months (Fig. 3) showed that E. georgiana was the dominant species at St. Leonards (Fig. 3 a), while E. georgiana and M. edulis were dominant at Dromana (Fig. 3 b), especially from November 1983 to February 1984.

Results from the rotational collector sampling system (Figs. 4 a & b) show that spat which had settled in collectors within 1 month could not be reliably identified as scallop spat. After 2 months, scallop spat could be identified and had settled in greater numbers in collectors immersed for 2 months than in those immersed for 3 months. Each year at both sites spatfall started during October and was complete by the end of December. Although the timing and duration of settlement were similar each year, the settlement density varied both between stations in 1983 and 1985 and between each of the three years studied (Fig 4 a & b). When spat were first observed in collectors, divers searched the seabed nearby for newly settled scallop spat. Collection and laboratory examination of various potential substrates (algae, shell, stones and hydroid) revealed scallops of 2-4 mm attached by single byssus thread to several species of filamentous algae and detached (but semi-buried) fronds of sea grass (Fig. 5).

Juvenile growth

Cage-held and commercial samples

Table I shows the mean size (± standard deviation) of the cage-held scallops and juveniles taken from the commercial scallop catch. At Dromana Bay, scallops grew from a mean shell length of 14 mm in January to 63 mm in December. A similar but slightly slower growth rate was observed for the population at St. Leonards which grew from 15 mm to 59 mm shell length during the same period. The length-frequency distributions of the cage-held scallops at Dromana are shown in Fig. 6 a, with the monthly length-frequency distribution of the commercial scallop catch and of the non-exploited pre-recruitment year class (sorted separately) for 1984 and 1985 (Fig. 6b and c). The same pattern of progression of modal sizes of the pre-recruit group from around 20 mm in April to 60 mm in November/December is apparent for the 2 years (Fig. 6b and c). The size frequency distribution of the commercial catch is strongly uni-modal, increasing from approximately 68 to 78 mm in both years. Student t-test analysis of the sizes of scallops grown in cages at St. Leonards and Dromana Bay and those of the pre-recruitment population for 1984 appear in Fig. 7. No significant difference was shown at .05 level for January samples and when comparing the St. Leonards cage population in December and the pre-recruitment population during November.

Tagging

Of the 270 scallops (mean length 27; range 16–41 mm) tagged and released on to the seabed in April 1984, 80 (mean length 48; range 37-62 mm) were recovered in July, 12 (54 mm; range 47-66 mm) in September, 3 (68 mm; 63-72 mm) in December 1984, 11 (74 mm; range 64-80 mm) in May 1985, and 13 (78 mm; range 71-87 mm) in October 1985, 25 months after settlement and 18 months after tagging.

DISCUSSION

Because planktonic and settling stages of bivalves are more vulnerable than juveniles to a wide range of physical, environmental and biological factors, recruitment should be more predictable from the numbers of spat that settle than from the numbers of eggs or larvae. Consequently, our study was designed to examine whether settlement and recruitment might be related, rather than to determine the causes of fluctuations so characteristic of recruitment into scallop populations. Our results confirmed early indications (Gwyther et al. 1985) that recruitment during one year can be related to and can be predicted from, the density of settlement during the preceding years.

Duration and intensity of settlement

In Port Phillip Bay, scallop settlement occurred during a short period in late spring to early summer (October - December). A single seasonal settlement period from November to April has been reported for *Chlamys tehuelchus* in Argentina (Ruzzante and Zaixso 1985) and from July to August for *Chlamys opercularis* and *Pecten maximus* in the North Irish Sea (Brand et al. 1980). In contrast, *Pecten fumata (Reeve)* in Tasmanian waters has two settlement periods, one in spring and the other during summer (Hortle 1983). During each of the 3 years of our study, numbers of *P. alba* were consistently highest in collectors retrieved during December, although the numbers of spat per collector varied markedly between the 3 years. This difference in the density of settlement and the short duration of settlement enabled us to correlate settlement and recruitment more easily than if settlement were more protracted or intermittent.

Settlement at different depths

Results from our study in waters 13 m deep showed that settlement in midwater collectors was greater than in those nearer the seabed. In water of similar depth (14 m), settlement of C. opercularis and P. maximus was greatest at midwater (Brand et al 1980). In deeper waters, settlement of Placopecten magellanicus increased with depth but then decreased just above the seabed (Naidu and Scaplen 1976). In waters 15–40 m deep, the greater numbers of spat of Chlamys. islandica were collected closest to the seabed and brown algae growing on collectors was thought to have either inhibited spat settlement or smothered spat which had already settled (Wallace 1981/82). Brand et al. (1980) found fewer spat in surface collectors and suggested that this could have been caused either by fouling by algae or by the effects of wave action and turbulence. Naidu and Scaplen (1975) suggested that fewer P. magellanicus settled in collectors placed closer to the seabed because of greater siltation; this could have been a factor in our study. However, the behaviour and position of the larvae in the water column may influence the success of collectors at different depths but information on the effect of these factors is sparse.

Collector immersion period

Collectors immersed for 2 months consistently contained more spat than those immersed for 3 months, even when collectors were initially immersed at the same time. The decrease in numbers of spat the longer the immersion time may have been caused by predation by small fish and crabs or by spat escaping through the mesh bag. Paul et al. (1981) observed a decrease in numbers of spat (*C. opercularis* and *P. maximus*) with time but could not correlate the decrease with the presence of predators; he attributed the decrease to natural mortality or to spat escaping when the collectors were agitated during poor weather conditions.

Timing of the annual spatfall

Studies of the breeding cycle of adult scallops in Port Phillip Bay have shown that spawning takes place primarily during spring (Sause et al. unpublished data). The short period of settlement observed during our present study probably resulted from the spring spawning. A direct relationship between adult spawning and spat settlement in collectors has been found by Naidu and Scaplen (1976) and Ruzzante and Zaixso (1985) but not by and Brand et al. (1980) who found that more spat of *P. maximus* and *C. opercularis* appeared after minor or partial spawning periods.

Growth of juvenile scallops

P. alba seemed to grow faster, at least initially, in cages than under natural conditions but the main difference between *P. alba* and other pectinid species is that under natural conditions it seems to grow the fastest. P. alba in Port Phillip Bay reaches 60 mm or more within 12 months of settling during October - December. C. islandica reaches a size of 7 mm after one years growth under natural conditions (Wallace 1981/1982) although they grew slower than those suspended in cages (Wallace and Reinsnes 1985). Chlamys varia reaches a size of 20 mm within 12 months (Conan and Shafee 1978). P. maximus reaches a size of 50-55 mm within 2 years (Mason 1957) but in cages, reaches only 40 mm in 16 months (Paul et al. 1981). C. opercularis reaches 20 mm under natural conditions and 30 mm in cages within 12 months (Paul et al. 1981).

Settlement and recruitment

In January, when P. alba are 60 mm and 1+ years old, they are easily distinguishable by size from the 2+ year old or older scallops remaining after the end of each fishing season. Results from the annual surveys of scallop abundance (McShane and Gwyther 1984, Gwyther and McShane 1985, Gwyther and Burgess 1986) show that in recent years, the commercial fishery in Port Phillip Bay has relied primarily on the newly recruited 1+ year old scallops with few of the residual stock remaining at the start of the season. Because each commercial fishing season starts in April, scallops are recruited and fished when they are 16-17 months old and therefore settlement one year can be related to recruitment abundance in the following year.

So far, settlement indices for 3 years with the corresponding estimates of recruitment abundance for 2 years are available (Gwyther and McShane 1985, Gwyther and Burgess 1986). Spatfall indices of 700 per collector (east) and 450 per collector (west) in the summer of 1983/84 corresponded to recruitment estimates of 108 million and 90 million for the eastern and western sectors of the bay respectively. In the summer of 1984/85 settlement was much lower at 100 per collector in both areas and recruitment this year was very poor: 30 million in the eastern and 18 million in the western sectors of the bay. The high settlement observed in the 1985/86 summer therefore suggests that a higher recruitment might be expected for the 1987 season.

Several years' data are required before we can be confident that the predictions are reliable. However, the discrete seasonality of settlement and the rapid growth rate to recruitment size are factors which, in conjunction with the ability to obtain estimates of recruitment abundance in Port Phillip Bay, present possibilities for the use of a predictive component in the management of this valuable but widely fluctuating scallop fishery.

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TABLE I

Size of juvenile scallops held in midwater cages and of those from commercial catches. N = number sampled; x = mean; s.d. = standard deviation

Month (1984)	Mean size (mm) and standard deviation ($\bar{x}$ s.d.) for scallops from											
	Midwater cage growth								Seabed growth			
	Dromana				St. Leonards				Commercial catch			
	x	s.d.	Mode	N	x	s.d.	Mode	N	x	s.d.	Mode	N
Jan	14	3	14	236	15	3	15	207	14[1]	5	12,13	75
Apr	43	3	43	168	39	4	40	207	34	7	26,36,37	49
Oct	55	5	56,58	168	51	5	53	205	58	3	61	74
Dec	63	5	63	163	59	5	61	202	60[2]	5	61	193

1. Scallops collected by divers during annual survey.

2. November sample.

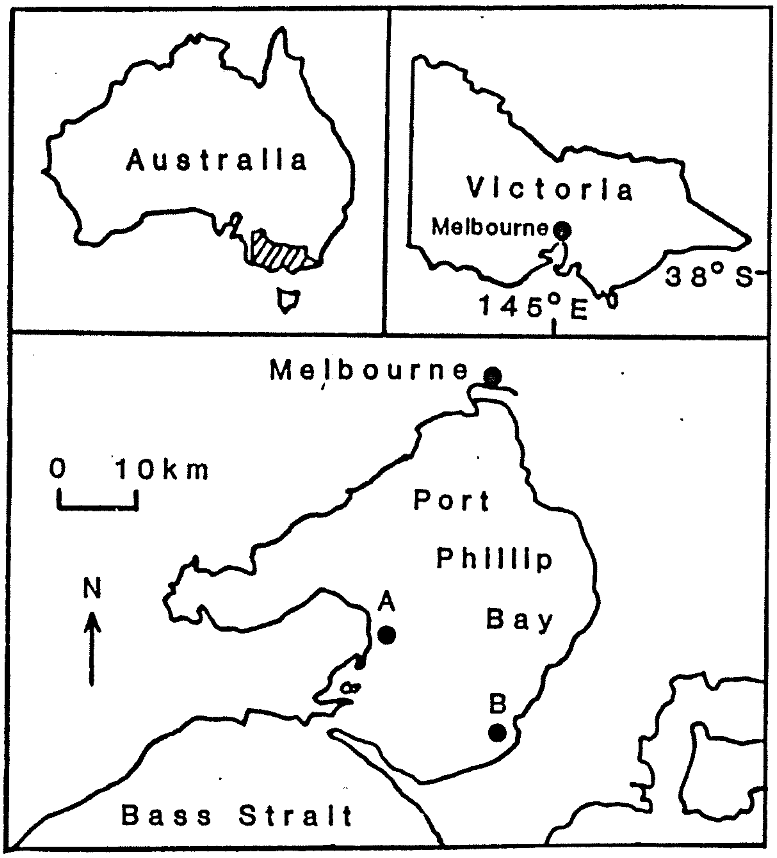


Fig. 1. Study sites (A and B) in Port Phillip Bay.

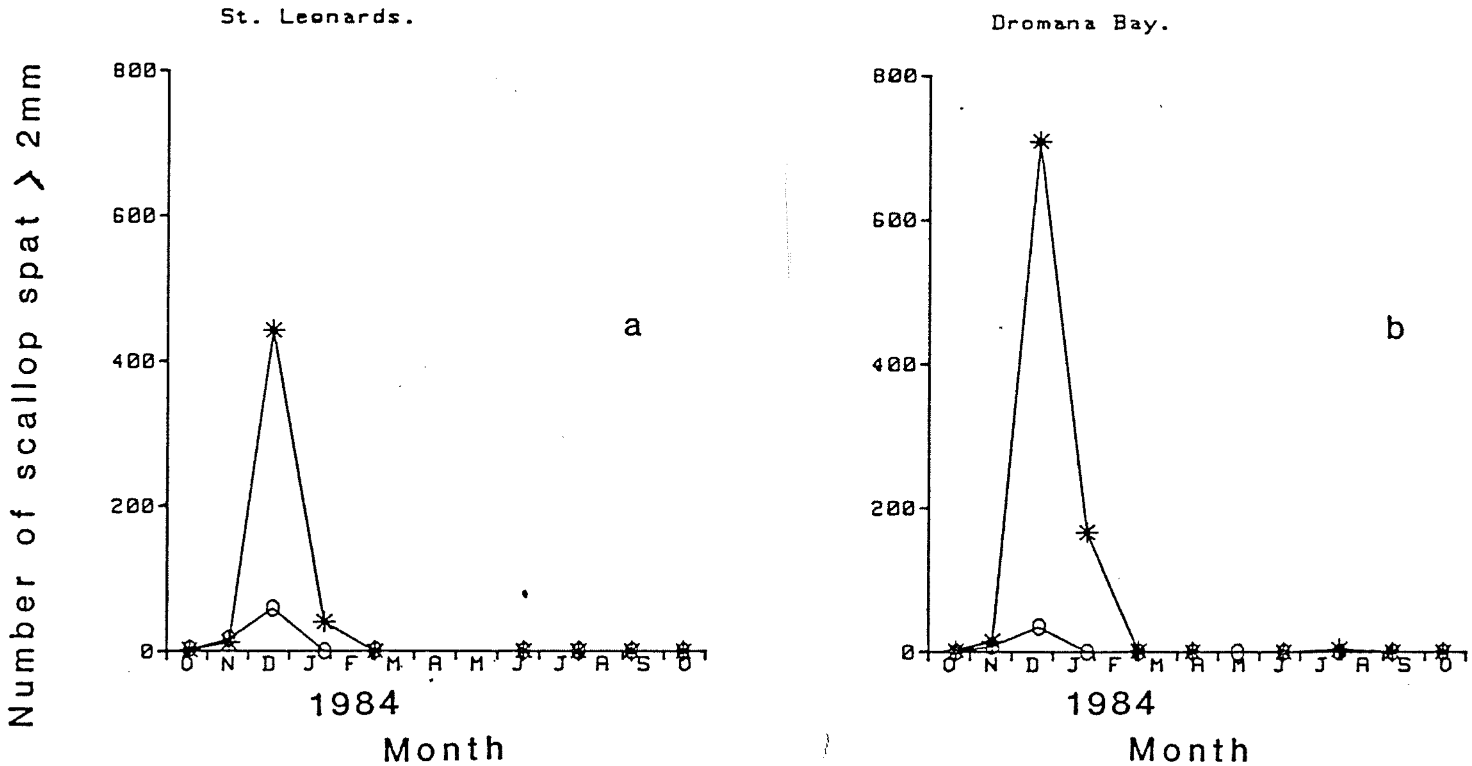


Fig. 2. The number of scallop spat >2 mm in collectors placed at (*) midwater and (O) near the seabed at (a) St. Leonards and (b) Dromana Bay.

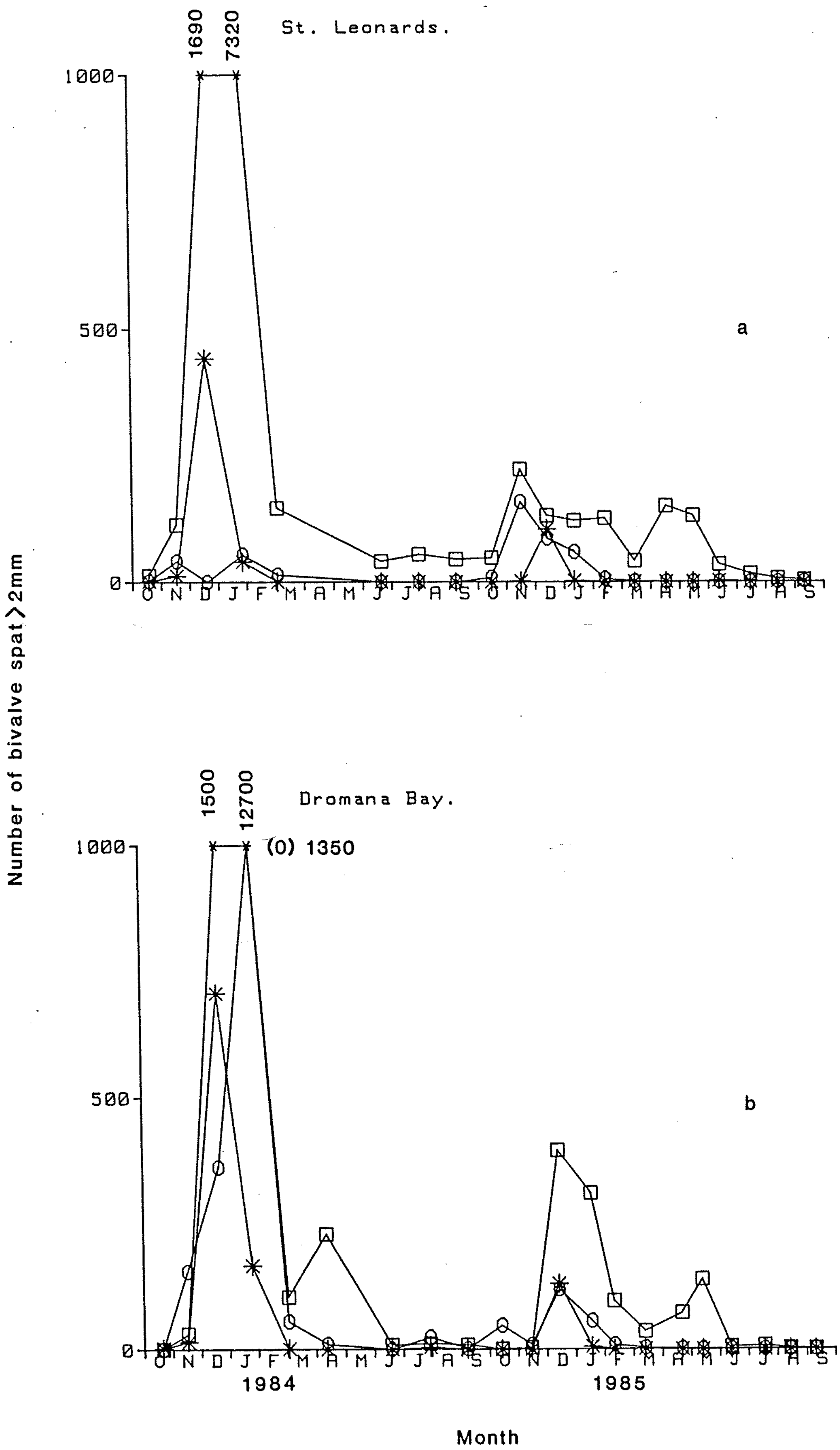


Fig. 3. The number of ([]) E. georgina, (o) M. edulis and (*) P. alba in collectors immersed for 2 months at (a) St. Leonards and (b) Dromana Bay.

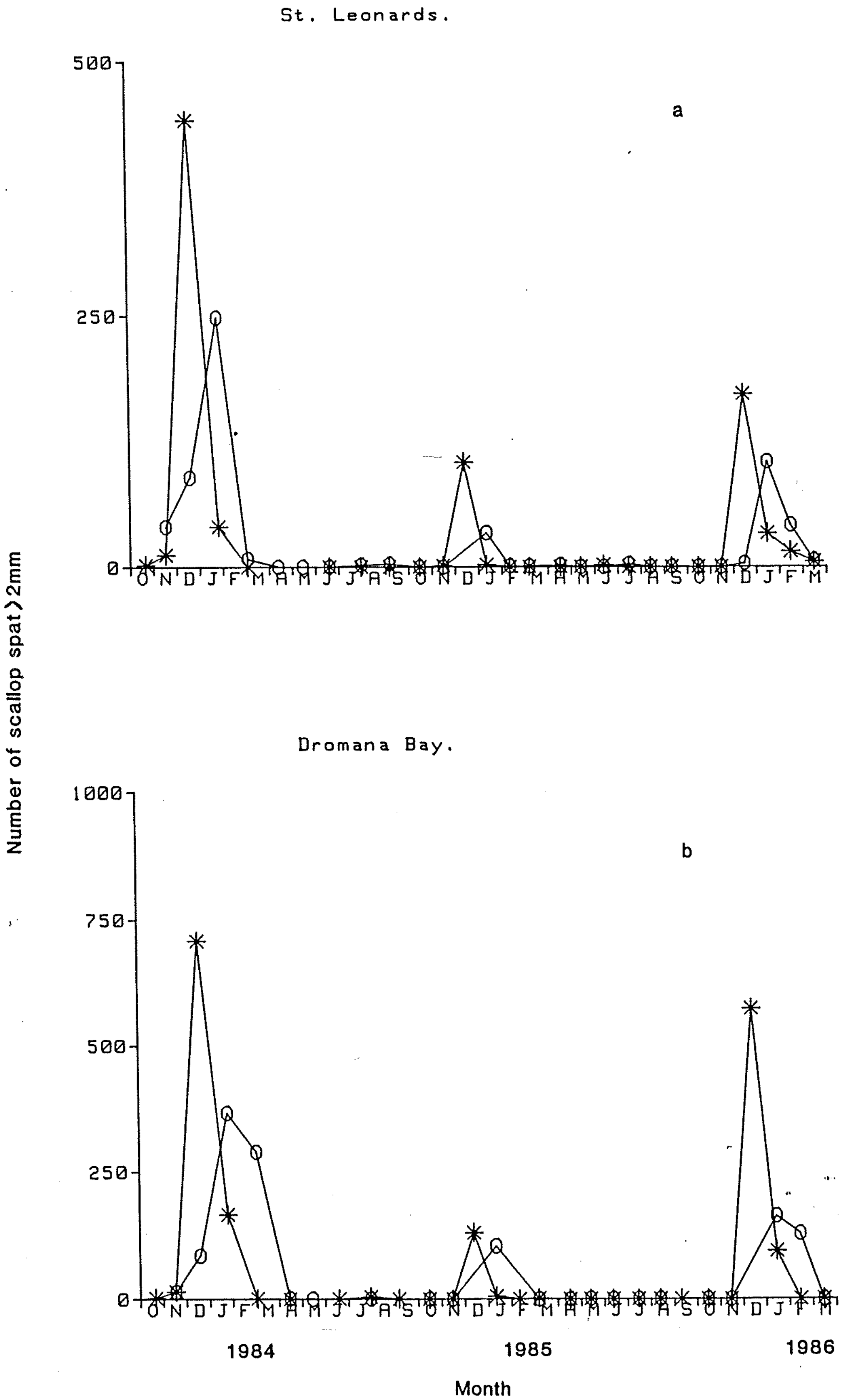


Fig. 4. The number of scallop spat >2 mm in collectors immersed for (*) two months and (O) three months at (a) St. Leonards and (b) Dromana Bay.

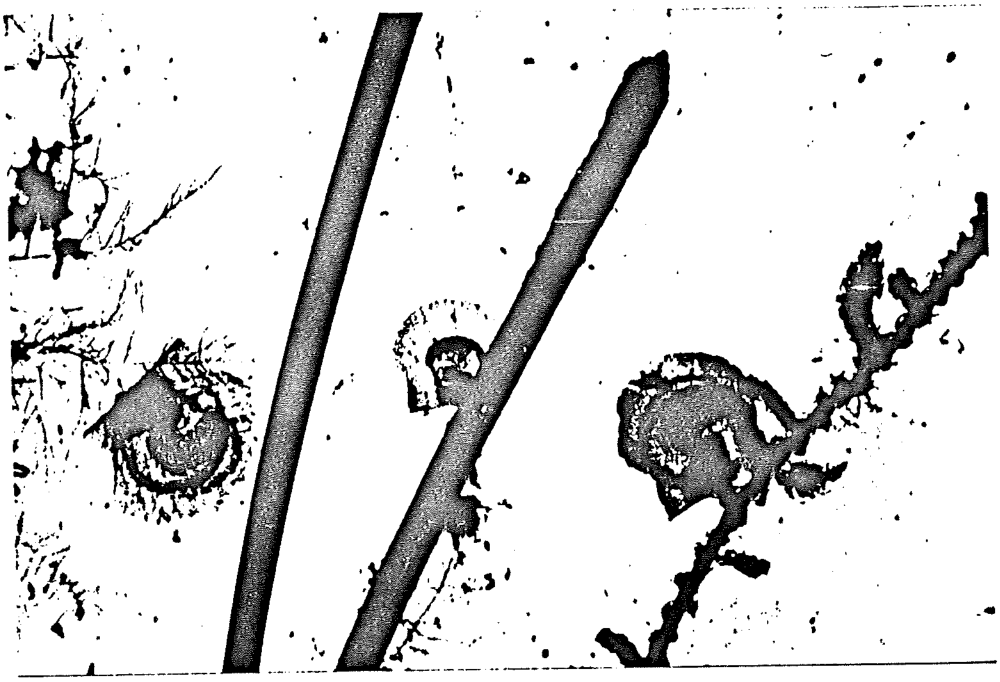


Fig. 5. Scallop spat attached by byssus to seagrass and filamentous algae. Bar = 4 mm. (Photo. A. Stephens).

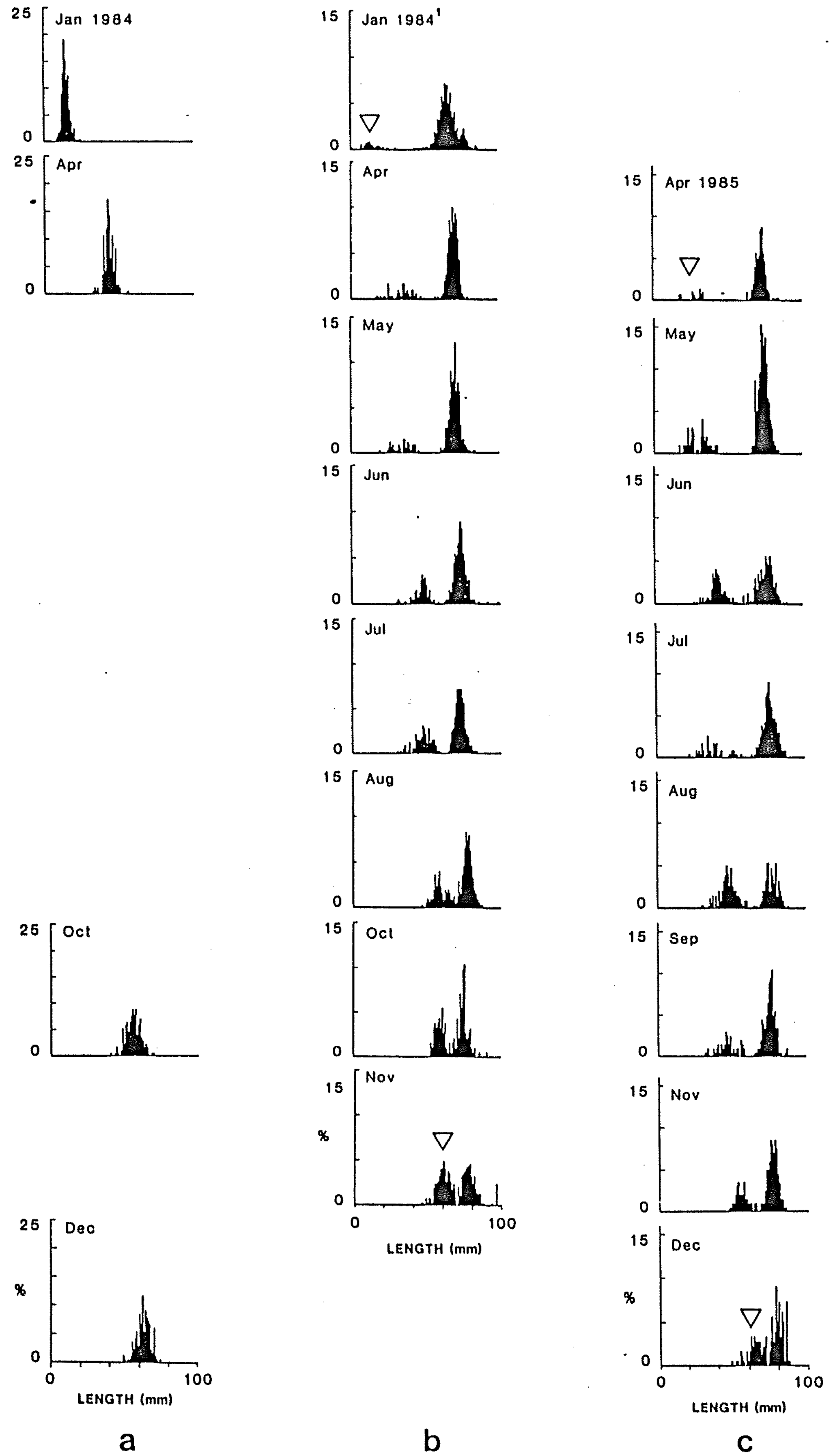
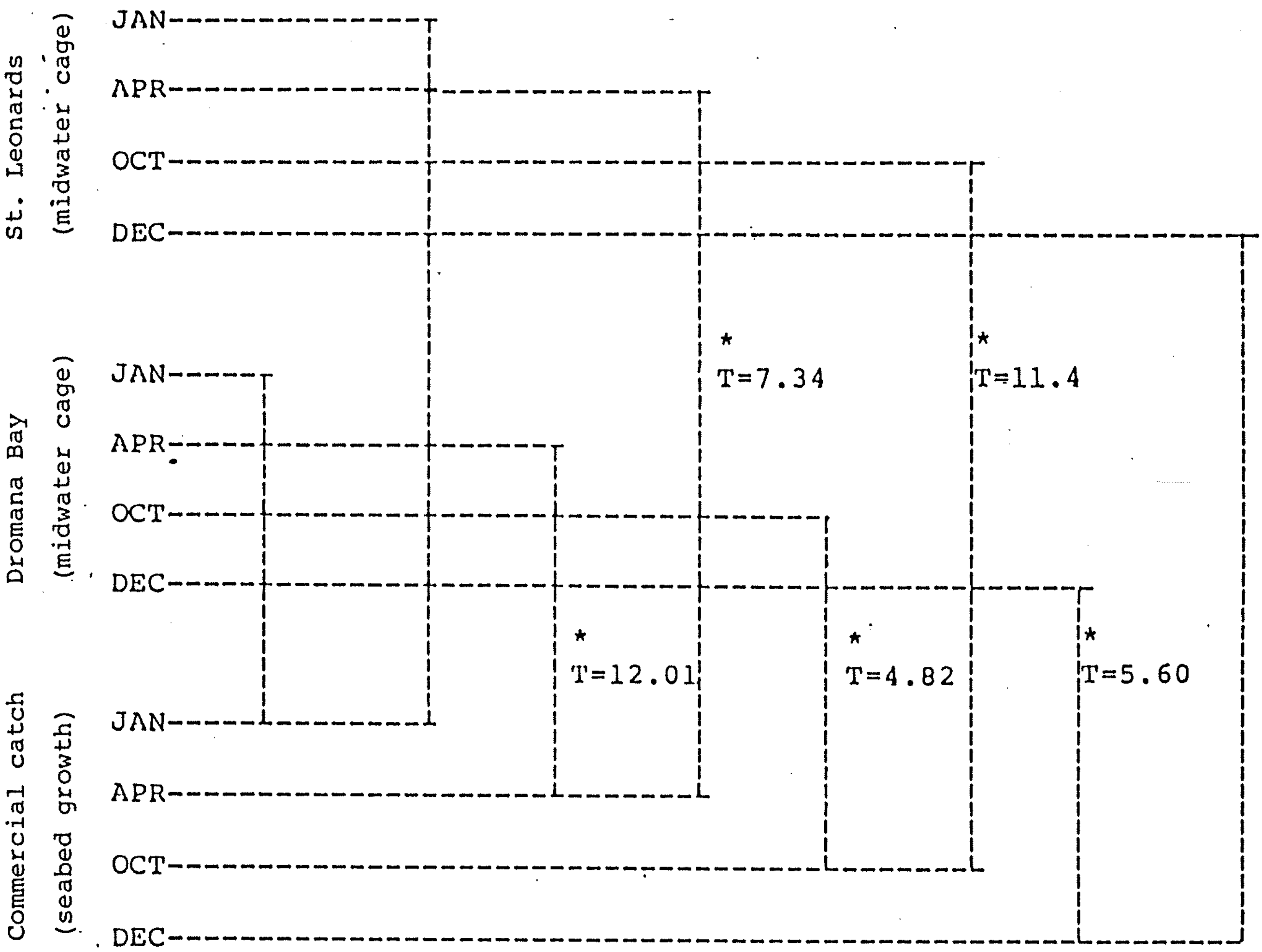


Fig. 6. Size frequency of scallops (a) grown in cages (midwater) at Dromana Bay, (b) collected from commercial dredge samples during 1984 and (c) during 1985.



* Significant difference

Fig 7. Student t-test analysis of the size frequency of scallops grown in midwater cages at St. Leonards and Dromana Bay and of juvenile scallops from commercial catches (seabed growth).

APPENDIX 3

Gwyther, D. and McShane, P.E. Growth rate and natural mortality of the scallop *Pecten alba* (Tate) in Port Phillip Bay, Australia and evidence for changes in growth rate after a 20 year period. (submitted to 'Fisheries Research'.

Growth rate and natural mortality of the scallop *Pecten alba* Tate in Port Phillip Bay, Australia, and evidence for changes in growth rate after a 20 year period

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Abstract

The instantaneous coefficient of natural mortality of the scallop *Pecten alba* Tate in Port Phillip Bay (38°S, 145°E) in south-eastern Australia was estimated from tag-recapture experiments as 0.52 year^{-1}. Values for the parameters k and l_{oo} of the von Bertalanffy growth curve were 1.6 and 86 mm respectively. Our results indicate that the growth rate of *P. alba* has increased substantially since the species was first commercially exploited 20 years ago. The scallops now attain a shell height of 70 mm more than 1 year sooner. We suggest that the increase in growth rate is related to the effects of 20 years of commercial exploitation by scallop dredgers.

Introduction

Exploitation of the scallop, *Pecten alba* Tate in Port Phillip Bay (38°S, and by 1967, 150 vessels using self-tipping dredge gear were fishing in the bay, and record catches of 300,000 bags (approximately 4900 t flesh) were landed that year. A drastic decline to 16,000 bags in 1969 led to limited-entry licensing, restrictions on dredge width and reductions in permitted daily fishing hours. After this initial decline in catch rates, recruitment has continued to fluctuate and landings were good (> 150,000 bags) in 1973, 1981 and 1985. Current management of this fishery provides for variation in recruitment abundance, and daily quotas are set each year after total abundance of scallop populations in the bay have been estimated (McShane 1982, 1983; McShane and Gwyther 1984, Gwyther and McShane 1985, Gwyther and Burgess 1986). While these estimates of total abundance are necessary in the setting of realistic quotas, information on rates of growth and natural mortality are also required for more detailed estimation of yields available each year. In this paper we present estimates of the growth rates and natural mortalities of P. alba in two unfished areas of Port Phillip Bay, and compare them with those of 20 years ago.

Samples of P. alba obtained from Port Phillip Bay since 1982 have not shown shell rings that could be regarded as annual. During the 1960s P. alba did show shell rings, and Sanders (unpublished data, Fisheries and Wildlife Service, Victoria) used them to determine age composition of P. alba in Port Phillip Bay. Fairbridge (1953) also validated the annual nature of rings for the related or synonynous Pecten (= Notovola) meridionalis in Tasmania. We used data from tag-recapture methods to determine growth rates of scallops in Port Phillip Bay.

For most exploited scallop species, the presence of annual growth checks or annuli on the shells has enabled rates of growth and total mortality to be determined from catch curves. This has been successfully applied to Pecten maximus (Gibson 1956, Mason 1957, Dupouy et al 1983), Chlamys opercularis (Broom and Mason 1978, Taylor and Venn, 1978) Chalmys varia (Conan and Shafee 1978), Placopecten magellanicus (Stevenson and Dickie 1954, Merrill et al 1966) and for Patinopecten caurinus (Haynes and Hitz, 1971).

Natural mortality is more difficult to estimate except in unfished populations (Baird 1966, Gruffydd 1974a) and in some analyses, has to be assumed (Mason et al 1979). Dickie (1955) and Merrill and Posgay (1964) estimated natural mortality from the number of dead, intact shells or "clappers" in catches. They reasoned that if natural mortality rate is constant, the number of scallops dying and adding to the clapper population should equal the number being removed by decomposition of hinge ligaments. This method was not considered appropriate for scallops in Port Phillip Bay because of the high probability of hinges breaking during emptying of dredges. Instead we estimated natural mortality from the results of our tag-recapture experiments.

Method

Site description

Port Phillip Bay (Fig. 1) is an embayment that drains a largely urbanised catchment whose population, including that of the State capital, Melbourne, is about three million. Sea temperatures range from about 9°C in winter to about 22°C in summer. Two sites, measuring 50 m x 20 m, on the seabed off

St Leonards and off Dromana (Fig. 1) were marked with stakes placed at 5 m intervals along the perimeter. The sites, at a depth of approximately 13 m, were within the two main scallop grounds in Port Phillip Bay (McShane 1982) but were sufficiently peripheral to escape interference by the dredge fishery. Large surface buoys warned fishing vessels of the underwater obstructions and allowed experiments to be conducted in the absence of fishing.

Tagging procedure

During September and October 1983, about 1000 scallops from within and around each marked site were collected by divers and tagged with numbered plastic discs tied to holes drilled in one wing of the upper flat valve. Divers then replaced the scallops at an average density of 1 per m^2 within 1 hour of collection. The shell length (hinge to distal point on edge of flat shell) of most of the scallops tagged was 50-85 mm; only about 5% were smaller than 50 mm. After 4 weeks, divers removed any dead tagged scallops, recording these as tagging mortality.

Natural mortality

At 2 or 3 monthly intervals during the next 12 months divers collected both live and dead tagged scallops along four transects (50 m long, 1 m wide) within or near each market site. Two transects were within the marked site, the other two were within 5 m and 5-10 m of the marked site. Each transect was subdivided into three sections of 16 m^2, 16 m^2 and 18 m^2 so that variances of density could be estimated. Scallops collected were not returned to the seabed because of potential interference to growth and mortality, and calculation of natural mortality was corrected accordingly.

After 12 months, teams of two or four divers recovered as many of the tagged scallops as they could by collecting both live scallops and "clappers" during systematic searches. To account for scallops which might have escaped from the marked site, divers systematically searched the following areas and transects (Fig. 2a)

1. An 800 m^2 area within the marked site (stippled in Fig. 2a).
2. An area extending 5 m beyond the perimeter of the marked site (stippled in Fig. 2a).
3. Eight transects, 45 m long x 1 m wide, running perpendicularly to the boundary of the marked site and covering the distance between 5 m and 50 m from the site (Fig. 2a).

Because of the extent of the area to be sampled, it was not feasible to cover it all. For the areas not searched, the number of scallops was determined by extrapolation from densities observed in the corresponding sections.

In another experiment started in October 1984, a different type of tag consisting of stainless steel wire and moulded marker was used to reduce tag loss and interference with valve movements. The tags were applied to the scallop shell in the same way as those of the first experiment. Divers placed 1100 tagged scallops at each of the two marked sites.

Periodic sampling of densities and final collection of scallops within and outside the sites was conducted as before but areas searched by divers was extended to include: (1) the entire area of the marked site, by sampling of transects parallel and perpendicular to the long axis of the site; (2) the area 5 m beyond the perimeter of the site; (3) two areas outside the marked site, one circular of radius 10 m, the other semicircular of radius 25 m (Fig. 2b). The divers used a rope fixed at one end and progressively increased its length by 1 m after completion of each search. By this method, 15% of the outer area was searched and it had to be assumed that numbers of scallops per m^2 in the area sampled were representative of the entire outer area. Because empty tagged scallop shells could have become buried and therefore overlooked during the search, surface sediment in a further four transects of 20 m x 1 m within the marked site at Dromana was sifted.

In the absence of emigration from the sampled area, the instantaneous rate of natural mortality, ($\underline{M}$ year^{-1}) was determined from the expression

$$N_{t+1} = \left[(((N_t e^{-t_1 M} - S_1) e^{-t_2 M} - S_2) e^{-t_3 M} - S_3) e^{-t_4 M}\right] \qquad (1)$$

where N_{t+1} is the number surviving after 1 year

N_t is the original number tagged

$S_{1,2,3,}$ is the number removed by interim sampling

$t_{1,2,3,4}$ is the inter-sampling period

Growth

Fabens (1965) used von Bertalanffy's (1938) growth equation in a form suitable for results from tagging experiments in which length at tagging, length at recovery and time intervals are known. The size at recapture, l_{t+i} depends on the size at tagging, l_t, the time interval i, the asymptotic length l_{∞} and the instantaneous rate of growth k as follows:

$$l_{t+i} = l_t + (l_{\infty} - l_t)(1 - e^{-ki}) \qquad (2)$$

We used Fabens' computer program to calculate least square estimates of k and l_{∞}, standard errors, and standardised residuals.

Results from a separate but simultaneously conducted tagging experiment to determine growth rates of juvenile scallops (Sause et al Marine Science Laboratories unpublished data) were included in the analysis of growth at the Dromana site thereby increasing the number of records for scallops < 50 mm long at tagging.

Between 1964 and 1967, tagging studies of scallops in Port Phillip Bay were first carried out (Sanders unpublished data, Fisheries and Wildlife Service, Victoria) using tags similar to those we used for our first experiment. Sanders tagged and recovered scallops from the catches of the commercial scallop fleet operating in Port Phillip Bay at that time. He recovered 261 tagged scallops after time intervals ranging from 50 to 900 days and we analysed his data with our methods.

Results

Natural mortality

Initial tagging mortality was low. Four weeks after tagged scallops had been placed at the two marked sites in October 1983, divers found only 13 dead tagged shells at one site and 16 at the other. Tagging was therefore discounted as a significant cause of mortality. Tag loss was evident in the first experiment, because a number of shells were recovered with holes drilled. This problem did not occur when the stainless steel wire tags were used. Although the individual growth records of scallops with tags missing were lost, the hole drilled in the shell ensured that such scallops were identifiable as part of the experiment and the calculations of natural mortality were not affected.

The results of the four experiments to determine natural mortality are shown in Tables 1 and 2. In three of the four experiments, more than one-half the original scallops could not be accounted for at the end of the experiment. However, at the end of the second experiment at Dromana, a much higher proportion of tagged scallops was recovered. Sifting of four transects at the marked site at Dromana after the second experiment yielded a total of nine empty tagged shells in the four transects. Assuming this density to be representative of the area which was not sampled sufficiently thoroughly to recover any buried dead shells, we estimate the number of tagged shells which remained buried within the site to be 110 $\pm$ 10, leaving 198 or 18% of the original tagged scallops still missing. From the second experiment at Dromana, the instantaneous rate of natural mortality, $\underline{M}$ was then calculated from equation (1) to be 0.52 (equivalent to 40%) year^{-1}.

Table 2 shows estimates of the numbers of tagged scallops surviving within and at distances beyond the marked site at successive sampling periods. These estimates have high standard deviations, possibly because of the small sample sizes. Emigration beyond the marked site was evident in all four experiments but appeared to occur sooner and possibly to a greater extent at St Leonards than at Dromana. Because of the high proportion of tagged scallops lost during three of the four experiments, little could be concluded regarding seasonal variation in mortality rates. In the second experiment at Dromana, where there was less unexplained loss of scallops, mortality was highest during summer, or the first 140 days from October.

Growth

Values estimated for the parameters of the von Bertalanffy growth curve (Table 3) show that the growth rate (k) and asymptotic (l_{∞}) size calculated for the 1964 and 1984 sets of data were substantially different; values of k being 2-3 times higher now than 20 years ago. The growth curves for tagged scallops released at St Leonards and Dromana were also significantly different ($p < 0.01$), but the difference was minor compared with the change during the 20 years (Figs. 3a and b).

To determine whether the difference between the values of k and l_{∞} for different years could have been, in part, caused by a higher proportion of small and young scallops being used in our experiments, we analysed separately a sub-set of 30 juvenile scallops (30-50 mm size at tagging) from Sanders' data (Table 3). Values estimated from these data were consistent with his combined 1964-67 data and were much different from those determined from the juveniles tagged in 1984. Comparisons between k and l_{∞} values are often confounded by the highly correlated nature of the two variables (Table 3). The result for the data from Dromana, however, indicates that these variables are less correlated and their absolute values are correspondingly more precise.

Discussion

The significance of our findings is that the size or age at which yield is optimum cannot be assumed to remain constant over long periods. Our results show that the growth rate of P. alba has increased substantially during the last 20 years, and natural mortality has been consistently high since 1982.

When fisheries stocks are being assessed, values for the growth parameters k and loo for a population at a particular location are assumed to remain unchanged. Instances of substantial departures from this assumption are few, but scallops in Port Phillip Bay now attain a shell height of 70 mm (current harvestable size) more than 1 year sooner than when stocks were first exploited 20 years ago. Williams and Dredge (1981) showed a small but significant change in asymptotic size with year for Amusium japonicum balloti. Gruffydd (1974b) showed that P. maximus attained greatest mean length in areas where population density was lowest; this suggests density-dependent growth. Mason (1983) gives further evidence for this when he compared of growth of P. maximus in the Clyde Sea between 1965 and 1975. During the 1960`s, when beds of P. maximus were heavily smothered by queens (C. opercularis) the growth rate of P. maximus was low. During the early 1970`s, when the density of C. opercularis declined drastically, the growth rate of scallops was greater after this reduction, suggesting that their earlier growth was retarded by the queens competing for food and space.

However, there have been many reported instances of variations in growth parameters for particular species inhabiting different localaties. These differences have been variously attributed to depth, hence temperature and food availability (Mason 1957; MacDonald and Thompson 1985) degree of exposure (Gibson 1956; Baird 1966), tidal currents, (Fairbridge 1953) turbulence and phytoplankton concentration (Haynes and Hitz 1971) and sediment type (Gruffydd 1974b). In most of the above cases, increased growth was observed where condition provided for increased food supply. If differences in growth between locations can be accounted for in this way, it follows that differences over time could also occur if, during the intervening period, there are changes in environmental conditions.

We believe that the increase in mean growth rate of P. alba in Port Phillip Bay may be related to density dependent effects resulting from the removal by exploitation of old, large scallops and other benthic filter feeding organisms which may have been incidently destroyed in the heavily dredged areas. But nutrient input, principally from sewage effluent and urban run-off may also have increased significantly with the spread of Melbourne's suburbs since 1964 and led to more food being available.

With such an increase in length-at-age of P. alba in Port Phillip Bay during the last 20 years we would expect that the age composition of the population would also have changed markedly during the same period. Sanders (unpublished data, Fisheries and Wildlife Service, Victoria) recognised up to seven age classes in the P. alba population of Port Phillip Bay during the 1960s. A reduction in the number of older age classes following exploitation is normal but at present the shells of P. alba no longer show growth checks comparable with Sanders' earlier observations. Since at least 1983, the exploited stock each year has been mainly the newly recruited, 1+ aged, scallops with few surviving into their third year (McShane and Gwyther 1984, Gwyther and McShane 1985, Gwyther and Burgess 1986). The majority of scallops would therefore not be expected to show more than one growth check. However, a single annual growth check is not readily apparent on shells of P. alba currently sampled in Port Phillip Bay. The rapid growth rate and short life span of P. alba in Port Phillip Bay is more comparable with that of the tropical species A. japonicum balloti (Williams and Dredge, 1981) than with the closely related P. meridionalis (Fairbridge, 1953) and other temperate species such as P. maximus (Mason 1957) and P. magellanicus (Stevenson and Dickie, 1954) each of which reportedly lives 11 or more years.

For any exploited fish stock, a knowledge of rates of growth and natural mortality is essential if management aims are to optimise production from the natural growth and decay of populations or cohorts. We have used our results to develop a yield model for this fishery (Gwyther and Burgess 1986). Using Alverson and Carney's (1975) tables, and our values of M and k for P. alba in Port Phillip Bay, we calculate that cohorts would now maximise their yield at 1.5 years. This is consistent with current practice of exploiting the 1-2 year old scallops, a practice which clearly would have been quite inappropriate had it been applied earlier in the development of this fishery.

The success of our experiments to determine rates of natural mortality depended upon our being able to recover, or account for, most of the tagged scallops 1 year after their release. That such success was achieved in only one of four trials demonstrates the difficulties in conducting controlled experiments in the wild. The large numbers of scallops missing may have resulted from ineffective sampling of the extensive area beyond the marked site but other possibilities can also be proposed. Scallops could have migrated beyond the sampled area, could have been removed by predators or could have died and their shells could then have become covered by sediments. Shells covered by sediment are difficult to find, and under-sampling of "clappers" was shown to be important but we considered it unjustifiable to assume that the large numbers of scallops missing from three of the trials could be accounted for in this way. It is difficult to assess the effects of fish predators as they would leave little or no trace of shells. One problem occurring in both experiments at the St Leonards site was periodic accumulation of drift-weed smothering the bottom, causing obvious, anoxic conditions. Although high mortality was expected, we did not find large numbers of "clappers" after these episodes.

Gibson (1956), Mason (1957) and Baird (1966) found no evidence of migratory capability of P. maximus and similar conclusions have been drawn for N. meridionalis (Olsen 1955) and P. magellanicus (Dickie 1955; Posgay 1981). Posgay (1981) concluded that any distance or direction that P. magellanicus moved was a consequence of current only. Swimming is reported to be stimulated mainly by predators, such as starfish, for both P. maximus (Thomas and Gruffydd 1971) and for A. irradians (Peterson et al 1982). One predator, the starfish Coscinasterias calamaria was observed at both marked sites in Port Phillip Bay. This starfish was also observed to ellicit the escape response in P. alba which otherwise, particularly larger scallops, remained recessed in the seabed, even when approached by divers. We consider that escape movements directed by local water currents probably contributed most to the loss of scallops in three of the four trials.

Any assumptions about the fate of scallops unaccounted for in our experiments would confer an element of uncertainty to estimates of M. Therefore most credence was attributed to the estimate from the experiment in which 82% of the scallops were accounted for after 1 year. Independent estimates of natural mortality were also available from successive surveys of scallop abundance in Port Phillip Bay (Gwyther and McShane 1985). Knowing the abundance (recruits plus residual stock) at the beginning of each year, the abundance of residual stock remaining one year later and the number removed by fishing allowed us to estimate natural mortality by difference. These estimates ranged from 38% to 50% annually between 1982 and 1984, although by this method errors in the determination of abundances and any under-reporting of catch would give rise to corresponding errors in the estimation of natural mortality. These estimates would also have included a component of incidental mortality due to fishing. In the soft substratum of the Port Phillip Bay scallop beds, burial of scallops rather than shell breakage may be a more significant cause of incidental mortality. Krantz (1974) demonstrated experimentally that Aequipecten irradians had a very limited ability to escape once buried by 1 cm of sand and this is probably true for most pectinid species. Nevertheless natural mortality estimated from survey data is comparable with the estimate we obtained during the present experiments. Natural mortality of P. alba in Port Phillip Bay is consistently high, even when the incidental effects of fishing are discounted, and appears to have been consistently high since 1982.

Acknowledgements

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TABLE 1. Decline in numbers ±1 standard deviation of tagged *P. alba* after 12 months of being placed within 1000 m^2 experimental sites in Port Phillip Bay, Australia.

NUMBER OF TAGGED *P. ALBA*	DROMANA 1983-84	DROMANA 1984-85	ST LEONARDS 1983-84	ST LEONARDS 1984-85
Initially in marked site	969	1100	1030	1100
Alive after 12 months				
i in site	62	244	37	48
ii 0-5 m from site	24	64	13	41
iii 5-40 m from site	53±60	240±80	0	290±100
Total	139±60	548±80	50	379±100
Dead after 12 months				
i in site	9	18	15	15
ii 0-5 m from site	0	21	7	4
iii 5-40 m from site	0	30±10	0	0
Total	9	69±10	22	19
Removed by interim sampling				
i alive	164	159	131	99
ii dead	40	16	52	7
Missing	617	308	775	596

TABLE 2. Estimates of numbers of tagged scallops (±1 standard deviation) surviving within the marked site and at distances up to 5 m and 10 m beyond the site boundary at intervals after tagging. (*final sampling; see Table 1).

Experiment	Time (days) from tagging	Estimates of numbers of surviving tagged scallops: In marked site	0 – 5 m beyond site	5 – 10 m beyond site	Total	No. live scallops removed	No. "clappers" removed
	0	1000					
Dromana	68	440±390	150±100	0	590±490	62	3
October 1983-84	186	260±130	60±30	40±30	360±190	39	21
	247	100±20	80±50	30±30	210±100	24	8
	281	140±20	50±30	40±10	230±60	39	8
	360*	62	24		139±60		
	0	1100					
Dromana	51	620±50	200±30	0	820±180	97	5
October 1984-85	140	290±70	120±130	130±130	540±330	34	3
	233	250±10	80±140	70±110	400±260	28	8
	362*	244	64		548±80		
	0	1000					
St Leonards	66	490±30	200±80	150±30	840±140	79	9
October 1983-84	187	130±60	30±0	20±0	180±60	15	11
	248	90±10	50±20	30±10	170±30	18	9
	282	60±40	40±10	20±0	120±50	19	23
	361*	37	13		50±0		
	0	1100					
St Leonards	58	390±70	80±140	0	470±210	60	3
October 1984-85	143	120±60	80±140	330±340	530±540	19	3
	236	160±20	120±120	70±70	350±210	20	1
	373*	48	41		419±116		

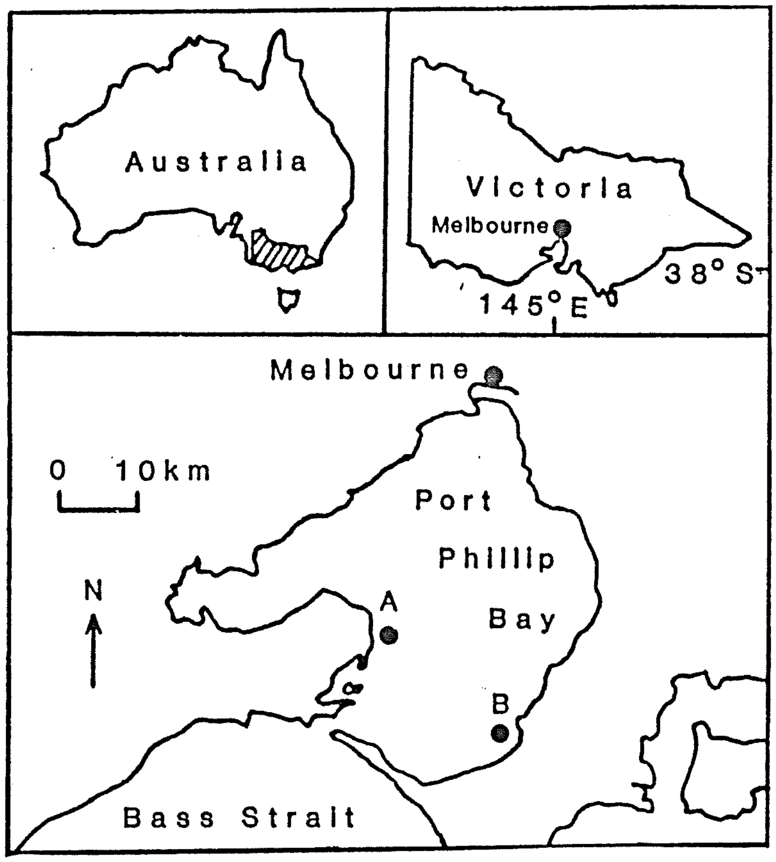
TABLE 3. Comparison of estimates of growth parameters, k and l_{∞}, for P. Alba in Port Phillip Bay between the periods 1964-67 and 1983-85.

Source of data	k	Standard error	l_{∞}	Standard error	n	Coefficient of correlation between k and l_{∞}
Dromana 1983-85	1.56	0.03	85.0	0.3	624	0.64
St Leonards 1983-85	1.45	0.09	88.7	0.8	366	0.92
Juvenile, Dromana (Sause et al unpublished data 1984-85)	1.43	0.05	87.7	0.9	172	0.89
All data 1983-85	1.57	0.03	85.9	0.3	990	0.72
1964-67 (Sanders unpublished data)	0.59	0.03	92.5	0.6	261	0.81
1964-67 Juvenile data (Sanders unpublished data)	0.73	0.10	87.7	3.3	30	0.95

Figure 1. Study sites at (A) St Leonards and (B) Dromana Bay in Port Phillip Bay.

Figure 2. Plan of the marked site and areas sampled (stippled) within and outside the marked site for both study areas in 1984 (upper) and 1985 (lower). Total area of site (A) = 1000 m^2; area 5 m beyond boundary of site (B) = 180 m^2; area 5-50 m beyond site (C) = 14075 m^2; area 5-40 m beyond site (D) = 8670 m^2; outer areas sampled (E) = 314 m^2, (F) = 980 m^2.

Figure 3. Calculated length at age for (a) 1983-85 data and (b) 1964-67 data, $\pm$ 95% confidence limits on line of best fit. Upper and lower confidence limits shown for St. Leonards and Dromana data respectively.


Australia
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Melbourne
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145° E
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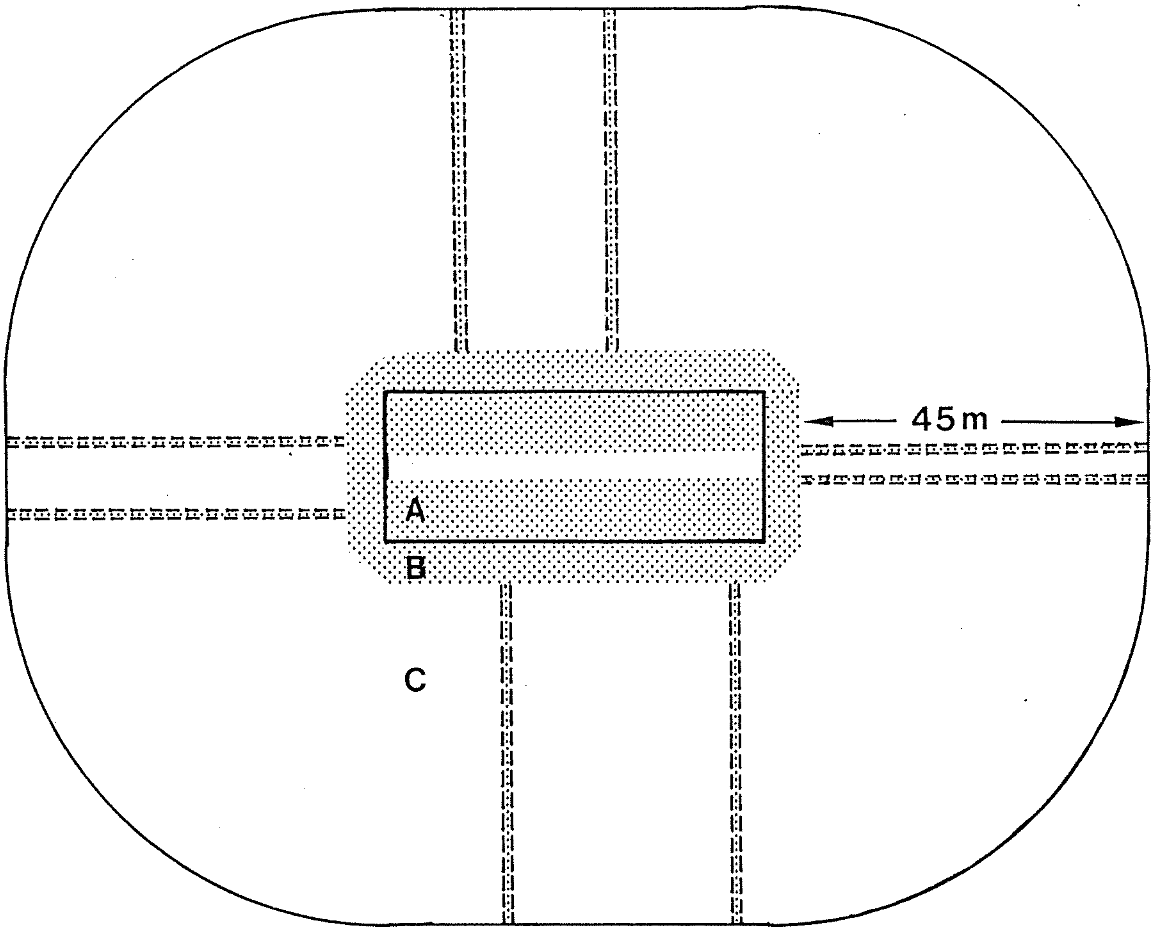
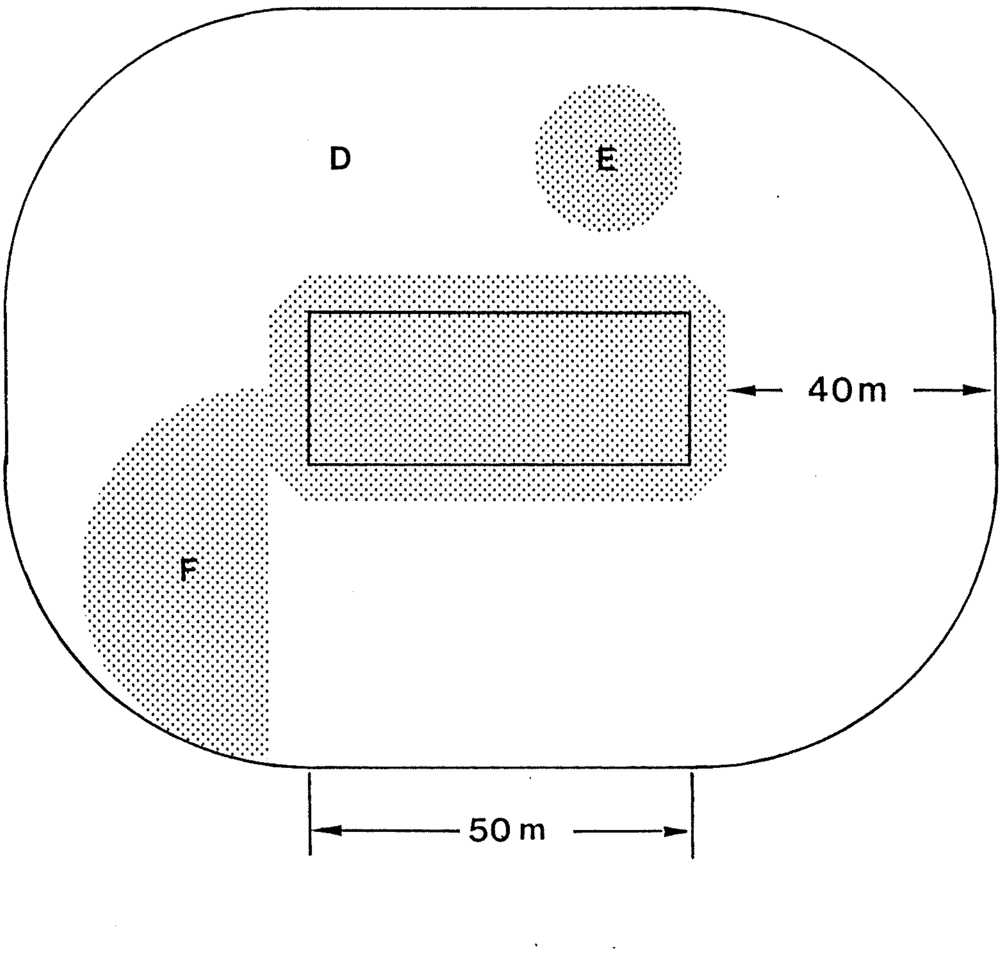
Phillip
Bay
N
A
B
Bass Strait

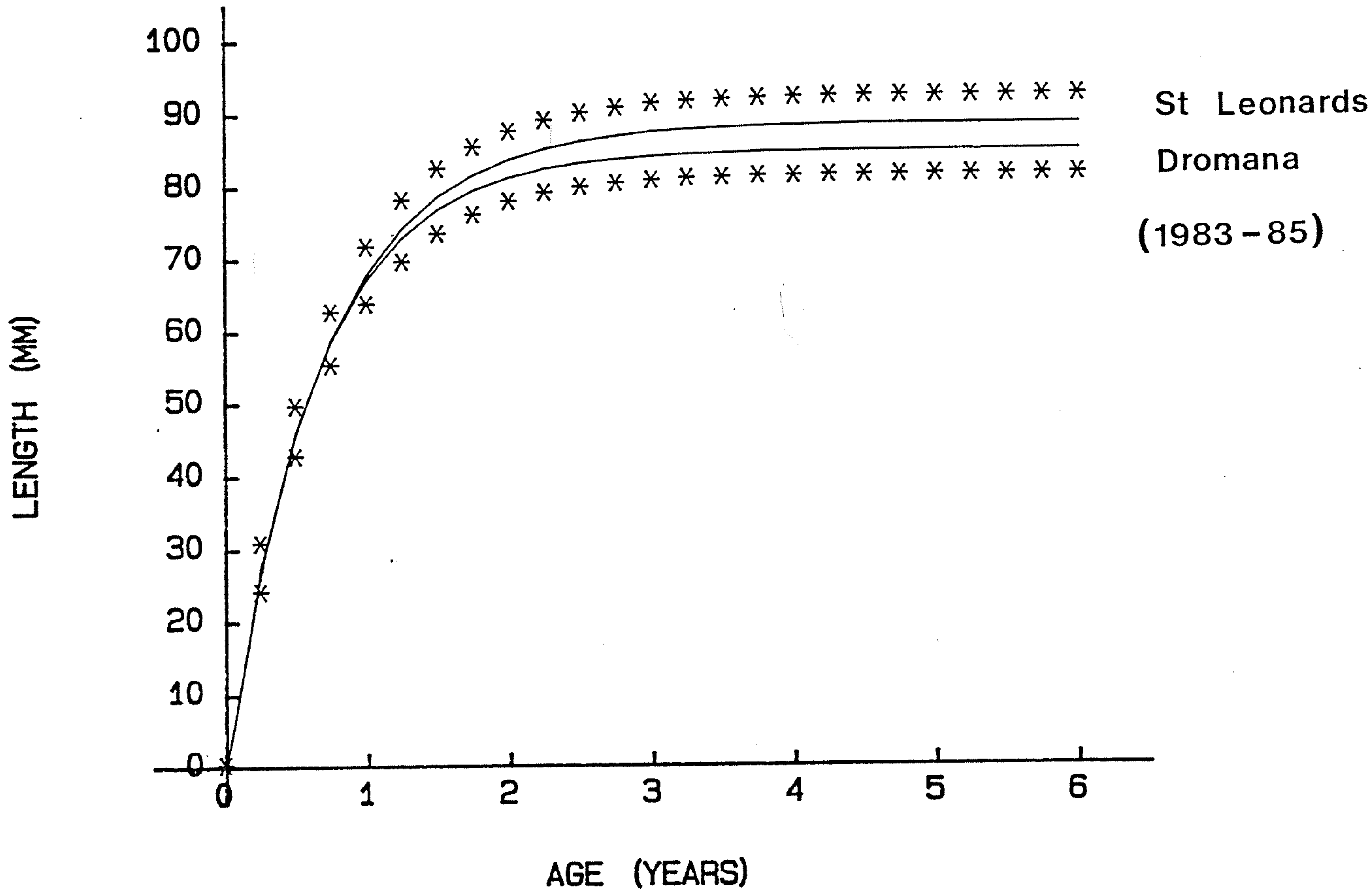
Fig. 2

a



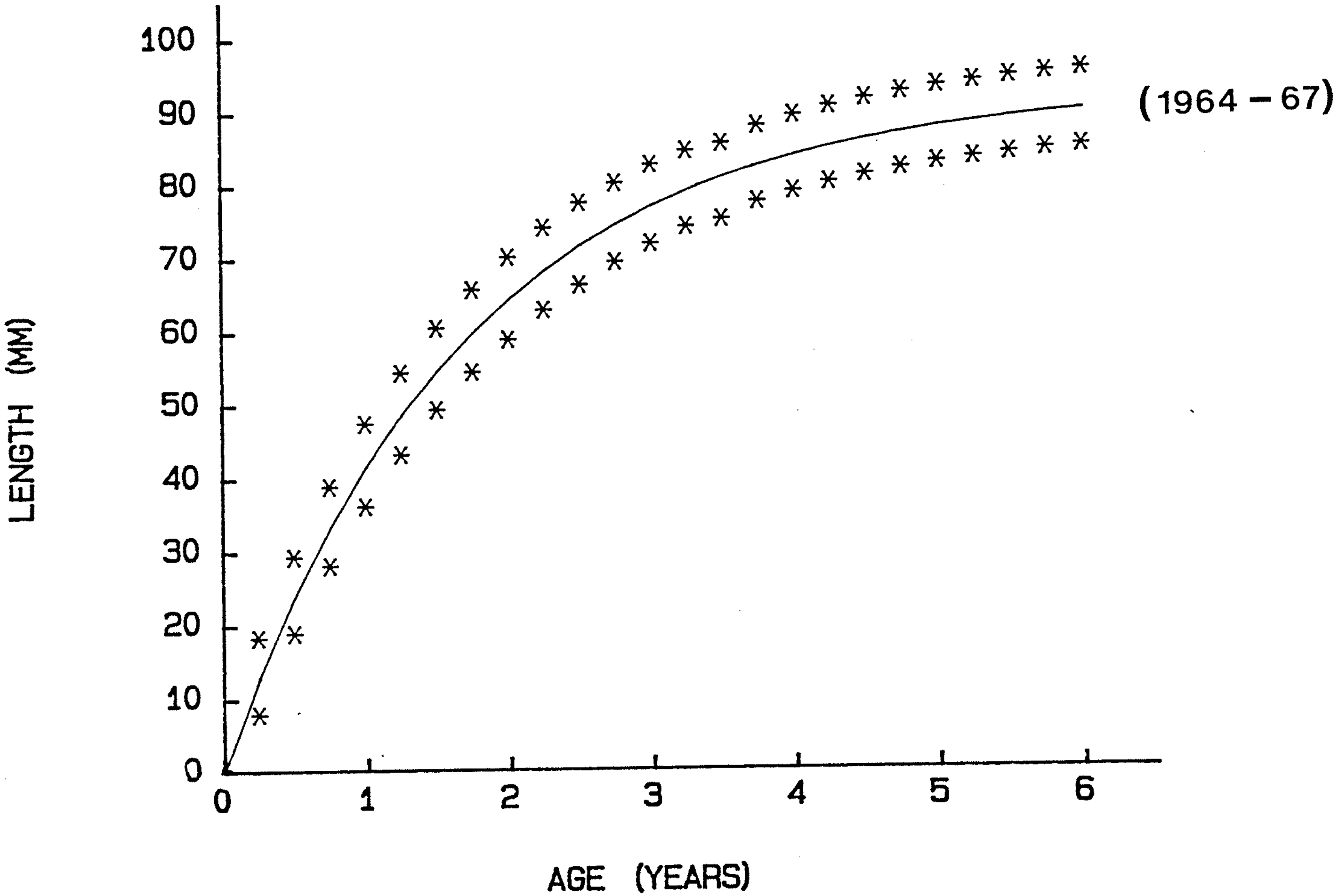
b





100
90
80
70
60
50
40
30
20
10
0
LENGTH (MM)
0
1
2
3
4
5
6
AGE (YEARS)
St Leonards
Dromana
(1983-85)

Fig. 3b



LENGTH (MM)
100
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40
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10
0
0
1
2
3
4
5
6
AGE (YEARS)
(1964 – 67)

APPENDIX 4

Gwyther, D. and Burgess, D.C. (1986). Abundance of scallops in Port Phillip Bay and predictions of yields for the 1986 season. Mar. Sci. Lab. Tech. Rep. No. 59. Department of Conservation, Forests and Lands, Victoria, Australia.

Department of
Conservation
Forests & Lands
Fisheries and Wildlife Service

ABUNDANCE OF SCALLOPS IN PORT PHILLIP BAY AND PREDICTIONS OF YIELDS FOR THE 1986 SEASON

by
D. Gwyther and D.C. Burgess

Technical Report No. 59

August 1986

MARINE SCIENCE LABORATORIES

ABUNDANCE OF SCALLOPS IN PORT PHILLIP BAY

AND PREDICTIONS OF YIELDS FOR THE 1986 SEASON

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ABSTRACT

Gwyther, D. and Burgess, D.C. (1986). Abundance of Scallops in Port Phillip Bay and predictions of yields for the 1986 season. Mar. Sci. Lab. Tech. Rep. 59. 18 pp.

The total number of scallops estimated to be in the strata sampled by SCUBA divers during a survey in Port Phillip Bay was 135 ± 24 million. This is compared to the 1985 estimate and a substantial decrease in population has resulted from poor recruitment this year. For the 1986 season, we predict that catch rates in the two most productive strata will be much lower (2.1 and 1.6 bags/h) than the catch rates of 4.8 and 4.0 bags/h during 1985.

The population comprised recruits 1+ years of age and residual scallops 2+ years of age in similar numbers. Early indications are that settlement this year is greater than that of 1984/85. Improved catches are forecast for 1987.

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Queenscliff, Victoria 3225, Australia.

INTRODUCTION

The results of previous surveys (McShane 1982, 1983, McShane and Gwyther 1984, Gwyther and McShane, 1985) indicate high year to year variability in scallop abundance this variability necessitated annual adaptation of management policies governing scallop fishing in the bay. The previous surveys have revealed a decline in the relative abundance of fully recruited (2+ years) scallops. In fact, during 1984, the fishery depended on newly recruited (1+ years) scallops because fewer older scallops were present in Port Phillip Bay and during 1985 it was a large recuitment of scallops 1+ years of age which supported the industry.

In this report we assess the scallop abundance and size composition of the scallop population in Port Phillip Bay before the opening of the 1986 scallop fishing season. We estimate recruitment strength (numbers of 1+ scallops) and predict the mean catch rates of scallops in the bay for 1986. We assess the yields available from the existing stock under various strategies for bag limits. These assessments and estimates incorporate results now available (though as yet unpublished) from the research program on growth rates, mortality rates and seasonal changes in flesh weight.

MATERIALS AND METHODS

POPULATION STRUCTURE

During the 1985 scallop season in Port Phillip Bay, as in previous years, monthly on-board observations of population size frequency were made, primarily to monitor the appearance and growth of the 0+ (newly settled) cohort during the year. Though quantitatively unrepresented in catches for most of the season, this cohort normally becomes increasingly evident in the later months of the year. Appearance of this cohort in catches in October-November provides a useful early indication of its likely strength (as 1+ year old) for the following season and its size composition with respect to the older year class or classes present. This is vital information to have prior to the January assessment of absolute abundance of these year classes.

POPULATION ABUNDANCE

During January 1986, SCUBA divers collected samples of scallops from 62 sites in Port Phillip Bay (Figure 1). The samples were collected, according to a stratified random sampling strategy (McShane 1983), from six strata whose boundaries were defined as for the previous study (Gwyther and McShane 1985). Because, in the past few scallops have been found in Strata 2 and 4, neither was sampled during our survey in January 1986.

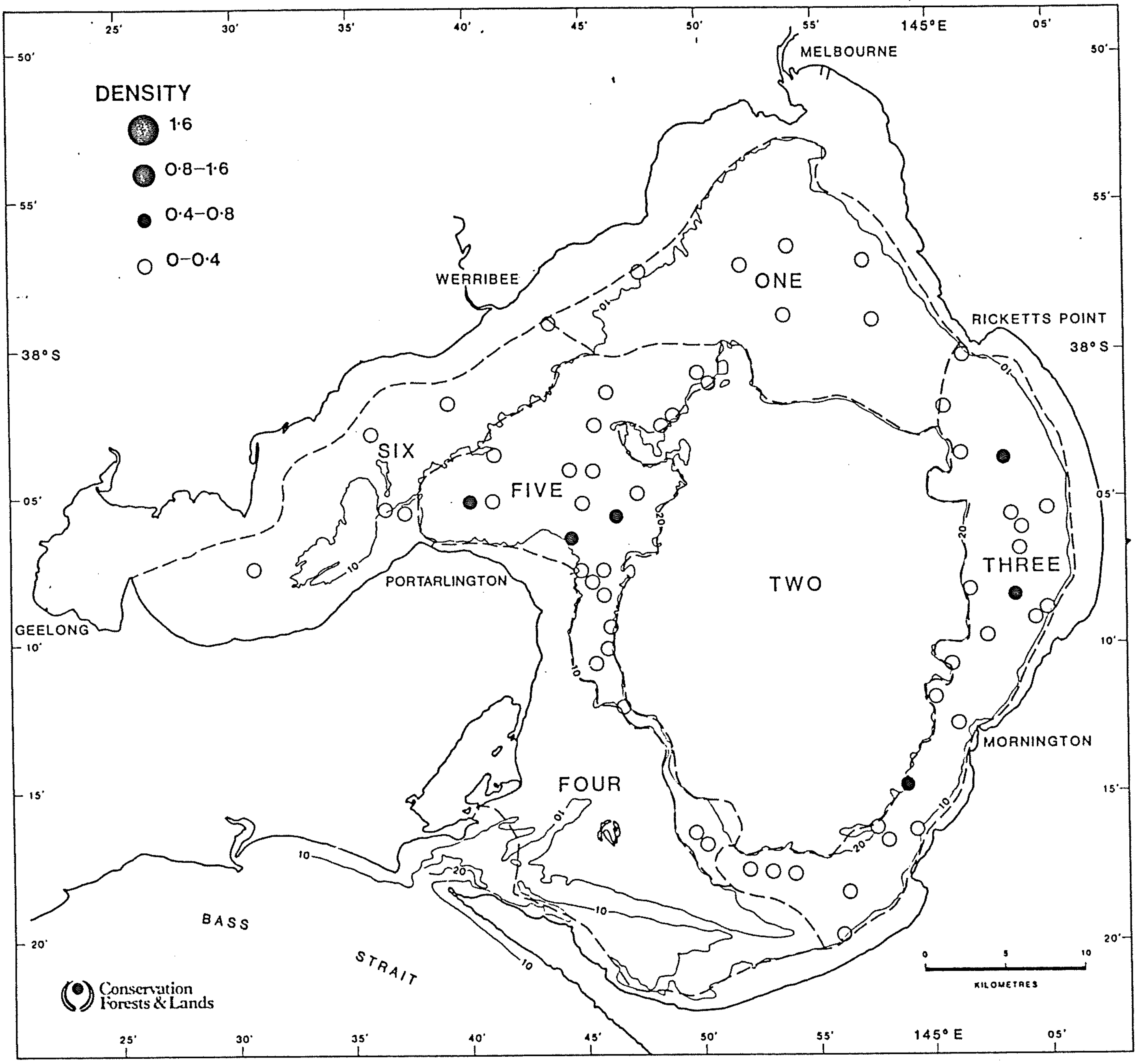

Figure 1. Densities of scallops at sample sites in Port Phillip Bay, January 1986. Density = scallops m^{-2}.

Abundance and size frequency of scallops were calculated according to the method described in McShane (1983) and standard deviations according to McShane and Gwyther (1984).

ESTIMATION OF MEAN CATCH RATE AND YIELD

Mean catch rate for 1986 was calculated by multiplying the abundance estimates for 1986 by catchability. Catchability was calculated by dividing the recorded average catch rate (scallops per hour) for the east and west sectors of the bay during the 1985 season by the abundance estimates for 1985 (Gwyther and McShane 1985).

For the first time, the results of this year's survey have been combined with research results (as yet unpublished) on rates of growth, rates of natural mortality and seasonal changes in condition to provide a model of expected yields under different fishing strategies. The management options included variations in daily bag limits, the timing of imposition or alteration of bag limits and the expected number of vessels fishing.

RESULTS

POPULATION STRUCTURE

Figure 2 shows the length frequency composition of scallops sampled throughout 1983, 1984 and 1985. The pattern that has emerged over the past 3 years is that commercial catches consist predominantly of the 1+ year old cohort with the obvious progression of the 0+ cohort to partial recruitment by November or December when they become 1+ year old.

The length-frequencies of the scallop population in Strata 3 and 5 are shown in Figure 3. Because scallops were sampled by divers, the results show more accurately the relative proportion of 1+ year old (recruit class, < 70 mm) and residual stock (> 70 mm). The modal size of the 1+ year old scallops is around 64 mm and for the residual 2+ year old scallops, 80 mm. Evidently there is a higher proportion of newly recruited scallops in Stratum 3 and a higher proportion of residual stock in Stratum 5. Less than 30 scallops were sampled in Strata 1 and 6 and therefore, length frequency distributions are not shown in Figure 3.

POPULATION ABUNDANCE

A total area of 6,200 m^2 was sampled and yielded 1210 scallops. As in past surveys, scallops were most dense in Strata 3 and 5 where mean densities were 0.231 $\pm$ 0.15 and 0.238 $\pm$ 0.19 scallops per square metre respectively (Table 1). These densities are considerably lower than those reported a year ago

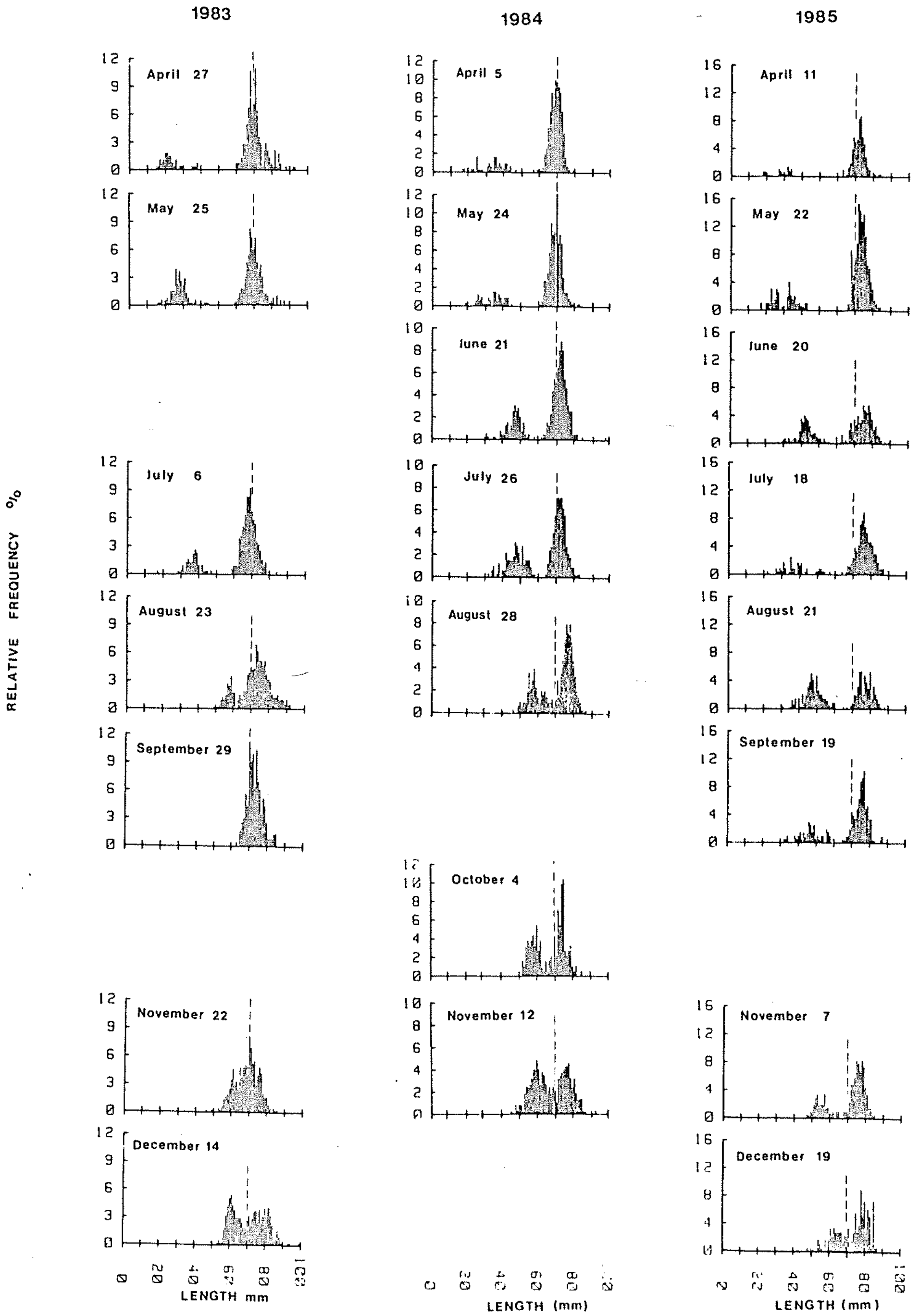

Figure 2. Length frequency distributions of commercial and pre-recruit (0+) class scallops sampled from dredgers in Port Phillip Bay during 1983, 1984 and 1985.

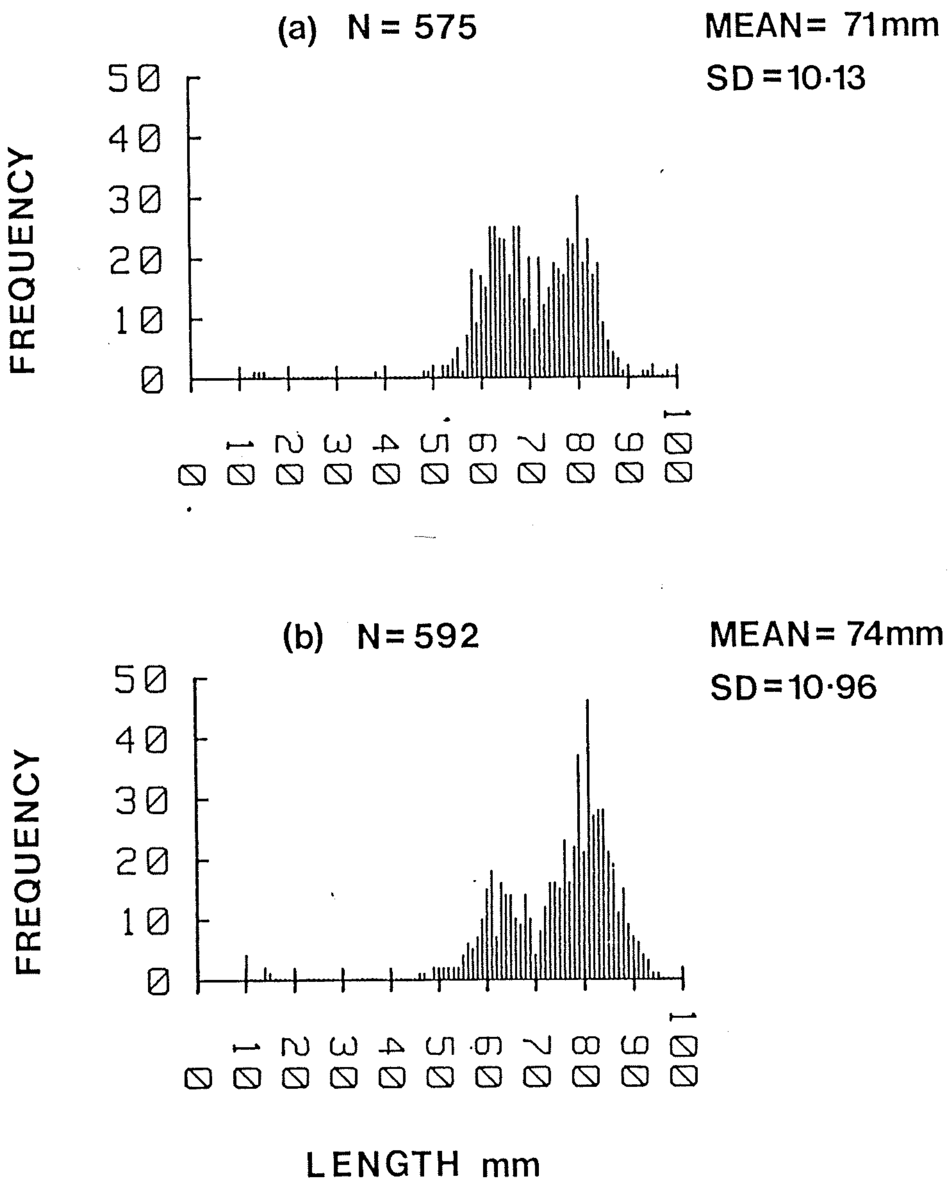

Figure 3. Length frequency distribution of scallops in stratum 3 (above) and stratum 5 (below) in January 1986.

Table 1. Estimates of abundance and of mean population density of scallops after stratified random sampling in Port Phillip Bay in January 1986.

Stratum	Stratum Area ($m^2 x 10^6$)	Number of Sites Sampled	Mean Scallop Density (Scallops/m^2) $\pm$ S.D.	Millions of Scallops in Stratum (X 10^6)
1	273.8	6	0.047 $\pm$ 0.03	12.9
3	257.4	25	0.231 $\pm$ 0.15	59.5
5	238.2	25	0.238 $\pm$ 0.19	56.7
6	223.4	6	0.025 $\pm$ 0.03	5.6
	992.8	62		134.6 $\pm$ 23.8

(Gwyther and McShane 1985) and reflect the poorer recruitment of scallops of the 1+ age class.

The total number of scallops in the strata sampled in Port Phillip Bay was estimated to be 135 ± 24 millions (Table 1) - a decrease from last year's estimate. Allowing for the un-sampled Strata 2 and 4, which in previous years have contributed 20-30 million scallops, the figure is probably nearer 150 to 160 million scallops or about half that for January 1985.

This decline in numbers of scallop is due primarily to the recruitment of 1+ scallops in 1986 being lower than that for 1985 (Table 2).

In Stratum 3 the recruitment was only 29 million in 1986, compared with 108 million in 1985. The residual stock in 1986 (> 70 mm) is similar to that estimated at the equivalent time in 1985. In the more heavily fished Stratum 3, the level of residual stock (i.e. that remaining after fishing each season) has been constant at 20-30 millions, particularly since 1983.

PREDICTED AND ACTUAL CATCH RATES

In January 1985 the predicted mean catch rate in Strata 3 and 5 was 4.5 and 3.9 bags per hour respectively (Gwyther and McShane 1985). Because 1985 catch returns have not been analysed, the catch and mean catch rates from strata are not available. An estimate of the mean catch rate from each stratum was calculated from a random selection of records from 10 vessels (Figure 4). The estimate for May in Stratum 3 appears anomalous, probably because this was calculated from the return of 10 vessels rather than all 84. Nevertheless, Figure 4 amply demonstrates the decline in catch rates as the season progressed and shows that the predicted mean catch rate for the 1985 season was realistic.

Table 3 shows the expected mean catch rate based on catchability for 1985 and the abundance estimates for 1986. Much lower mean catch rates of 2.1 and 1.6 bags per hour (= 1.8 and 1.4 crates per hour) in Stratum 3 and Stratum 5 respectively are forecast.

Table 2. Comparison of population structure of Port Phillip Bay scallops sampled during January 1982, 1983, 1984 and 1985 Data are millions of scallops estimated for each stratum.

Cohort	Length class Stratum 5 (length in mm)	Millions of scallops in Stratum 3					Millions of scallops in Stratum 5				
		1982	1983	1984	1985	1986	1982	1983	1984	1985	1986
0+	< 40	5.9	0.9	9.9	0.1	0.4	4.9	3.9	10.3	2.4	.4
1+	40 - 70	78.5	22.7	88.6	108.4	29.0	62.7	77.6	92.0	87.1	17.6
2+	> 70	162.6	22.8	27.5	22.8	30.1	86.6	20.4	15.7	51.0	38.7
TOTAL		247.0	46.4	126.0	131.3	59.5	154.3	101.9	118.0	140.5	56.7

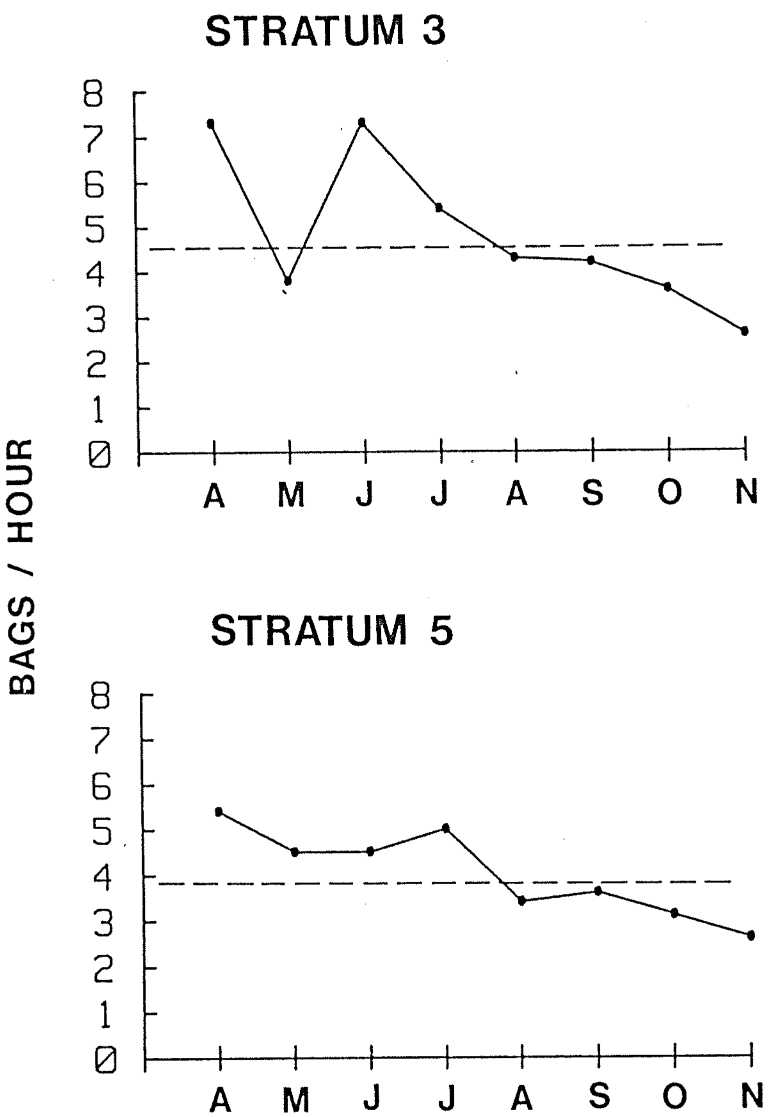

Figure 4. Decline in monthly average catch rates (bags/h) during the 1985 season compared with the predicted average (dotted line).

Table 3. Dredge efficiency and catchability for 1985 season and predicted catch rate for 1986 season (1 crate = 1.2 bags).

		Stratum 3	Stratum 5
1985 Abundance estimate (millions)		131	138
Density in 1985 (scallops/m)		0.51	0.59
Mean catch rate (Bags/h)	*1	4.8	4.0
No. scallops caught/h	*2	4800	4000
Area covered (m^2/h)	*3	18530	18530
No. scallops in path of dredge (density x area covered)		9500	10900
Dredge efficiency %		50	37
Catchability (proportion of total caught /h)		0.36×10^{-4}	0.29×10^{-4}
1986 Abundance estimate (millions)		59	56
Predicted mean catch rate Bags/h for 1986	*4	2.1	1.6

*1 .. An arithmetic mean of monthly catch returns from 10 vessels, randomly selected. This may differ from the average since total monthly catch and effort for each stratum was not known.

*2 .. Assumes 1000 scallops per bag.

*3 .. 1 hour fishing = 40 minutes dredging at 5 knots. Dredge width 3m.

*4 – Assumes the number of vessels and catchability are similar to those of 1985 levels.

YIELD ESTIMATES

We have developed a mathematical model for calculating yields available from the scallop stock under different conditions of bag limits, time of opening of the season and seasonal alterations of bag limits. The development and operation of this model will form the subject of a separate report. The basis of the model is the application of the von Bertalanffy growth parameters (K,Loo), the exponential rate of natural mortality (M) and parameters for the conversion of length to weight (Ln A, B) incorporating seasonal variation (unpublished data) to the estimates of abundance and of mean size[1]. A projection of the monthly change in biomass of scallops is presented (Table 4 a & b). It can be seen that peak biomass occurs during the period June to October. Two management alternatives are then compared;

a) 50 vessels on limit of 10 bags (= 8.5 crates) per day, April - June and November. 75 vessels on limit of 15 (= 12.75 crates) bags July - October.

b) 70 vessels on limit of 7 bags (= 6 crates) per day, April - June, October and November, 85 vessels on limit of 11.8 bags (= 10 crates), July to September.

The parameters used in the model and the results obtained are given in Tables 4 a & b. Option (a) presents a normal fishing strategy where those operators who can choose between Bass Strait and Port Phillip Bay grounds would be expected to respond to the daily bag limits as shown: 50 vessels on a limit of 10 bags. 75 vessels on a limit of 15 bags. It can be seen from Table 4a that the number of scallops remaining would be reduced to the very low level of 11 million by October. Because of the present closures of the traditional Bass Strait grounds, option (b) allows for a greater number of vessels fishing in the bay but imposes a lower daily bag limit. The result of this (Table 4b) is similar, with low scallop stocks remaining at the end of the year.

DISCUSSION

The number of scallops present in Port Phillip Bay is estimated as about half of that which was estimated to be present one year ago. Therefore a much poorer season is forecast. The population comprises 1+ recruits and residual 2+ scallops in almost equal numbers although a higher proportion of residual stock exists on the west side of the bay.

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1. The mean shell length is used as the initial point for the calculation of monthly growth in length and conversion to weight. A slight but consistent under estimation of values of biomass is likely, because population mean weight would occur at a shell length greater than the mean.

Table 4a. Estimation of yield available and scallops remaining under strategy A: 50 vessels on 10 bags/day (April - June): 75 vessels on 15 bags/day.

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Scallop shell length mm	73	75	76	77	78	79	80	81	81	82	82	83
Dry Meat Weight (g)	2.00	2.08	2.38	2.41	2.53	3.24	3.11	3.72	3.75	3.58	3.44	2.74
Numbers(m=.033/month (millions)	150	144	138	133	128	123	118	113	109	105	101	97
Monthly Biomass	300	300	330	320	323	398	367	422	409	375	346	265
Daily Bag Limit				10	10	10	15	15	15	15	10	0
Expected No. Vessels				50	50	50	75	75	75	75	50	0
Scallops Taken (million)				9	9	9	20.25	20.25	20.25	20.25	9	0
Biomass Taken				21.7	22.8	29.2	63.0	75.3	76.0	72.5	31.0	0.0
Scallops Remaining at end of month	144	138	133	119	106	93	70	48	26	6	0	0
Biomass Remaining	288	289	317	287	268	302	218	178	99	21	0	0

PARAMETERS												
days fished/month	18											
M	0.04											
k	1.565											
Linf	85.86											
t0	-1.21											
Number per Bag	1000											
ln(A)	-11.92	-13.02	-11.43	-11.03	-10.93	-12.20	-15.34	-13.00	-14.60	-13.13	-16.10	-12.33
B	2.94	3.19	2.84	2.74	2.72	3.06	3.76	3.26	3.62	3.27	3.93	3.02

Table 4b. Estimation of yield available and scallops remaining under strategy B: 70 vessels, 7 bags/day (April - June); 85 vessels, 11.8 bags/day (July - October).

Scallop shell length mm	JAN. 73	FEB. 75	MAR. 76	APR. 77	MAY 78	JUN. 79	JUL. 80	AUG. 81	SEP. 81	OCT. 82	NOV. 82	DEC. 83
Dry Meat Weight (g)	2.00	2.08	2.38	2.41	2.53	3.24	3.11	3.72	3.75	3.58	3.44	2.74
Numbers(m=.033/month (millions)	150	144	138	133	128	123	118	113	109	105	101	97
Monthly Biomass	300	300	330	320	323	398	367	422	409	375	346	265
Daily Bag Limit				7	7	7	11.8	11.8	11.8	11.8	7	0
Expected No. Vessels				70	70	70	85	85	85	85	70	0
Scallops Taken (million)				8.82	8.82	8.82	18.05	18.05	18.05	18.05	8.82	0
Biomass Taken				21.2	22.3	28.6	56.2	67.2	67.8	64.6	30.4	0.0
Scallops Remaining at end of month	144	138	133	119	106	94	73	52	33	14	5	5
Biomass Remaining	288	289	317	287	269	303	226	195	124	51	18	14

PARAMETERS												
days fished/month	18											
M	0.04											
k	1.565											
Linf	85.86											
t0	-1.21											
Number per Bag	1000											
ln(A)	-11.92	-13.02	-11.43	-11.03	-10.93	-12.20	-15.34	-13.00	-14.60	-13.13	-16.10	-12.33
B	2.94	3.19	2.84	2.74	2.72	3.06	3.76	3.26	3.62	3.27	3.93	3.02

A poor recruitment for the 1986 season was predicted on the basis of indices of spatfall in collectors, (Gwyther and McShane 1985, Gwyther et al. 1985). The high recruitment in 1985 resulted from a spatfall index of 700 per collector during the summer of 1983/84 and the low recruitment this year was predicted with spatfall indices of only 100 per collector in December 1984. During the summer of 1985/86, higher spatfall of about 200 (west) and 600 (east) per collector was again observed (Sause et al, unpublished data). An improvement in recruitment for 1987 therefore seems likely though observations during the coming season will be needed to confirm this.

The catchability coefficients estimated from the 1985 survey and catch return data are very similar to those estimated from the equivalent data for 1983 and 1984 (McShane and Gwyther 1984, Gwyther and McShane, 1985). Values for Stratum 3 have ranged from 0.34×10^{-4} to 0.39×10^{-4} and those for Sector 5 have ranged from 0.24×10^{-4} to 0.29×10^{-4}. It appears that dredge retention is consistently higher in Stratum 3, although more yearly comparisons are required to know if this difference is significant.

In setting daily quotas management is faced with the conflicting objectives of making the catching season last as long as possible while at the same time maximising the share of the catch taken during the months of best yield. This year, results obtained from the model which predicts the yields available from the stock under different quota strategies provide management with the opportunity to explore many options. One option, a strategy of a 10 bag limit rising to 15 during the winter months would reduce the population to a very low figure and therefore would not be achievable, even with only 50 vessels fishing on the 10-bag limit. Consequently a lower daily quota needs to be set (eg Table 4b) if the existing stock is to support the fishery for the greater part of the year. Judgement as to what constitutes an acceptable residual number of scallops after the fishing season is subjective. In practice residual numbers of scallops have been fairly constant at 40 - 70 millions for the past 4 years (Table 2). As the population is reduced to these levels by the end of each fishing season, catch rates decline and it is common for vessels to return to port with less than the daily quota. Therefore any strategy which reduces the stock below these levels is likely to result in quotas being unobtainable. Even with the second option (Table 4 b), the model predicts that the numbers of scallops will decline below 40 million in September and it therefore seems unlikely that the season will last until November.

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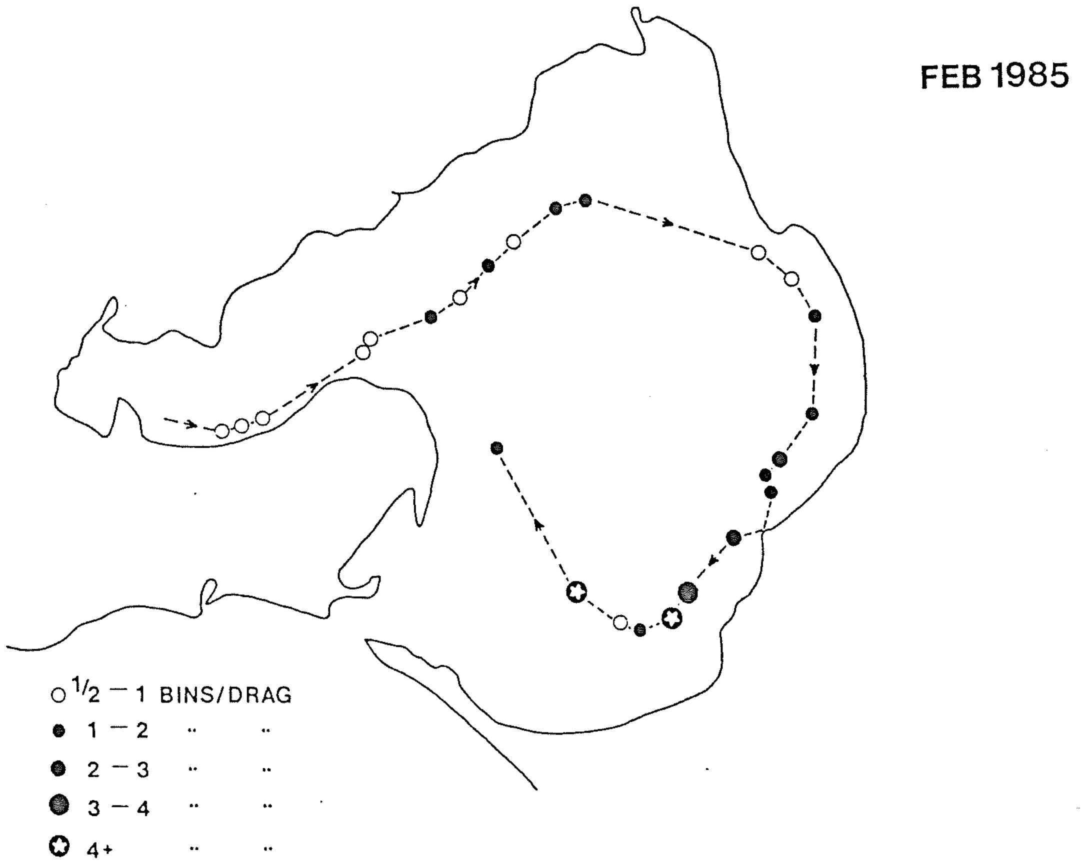
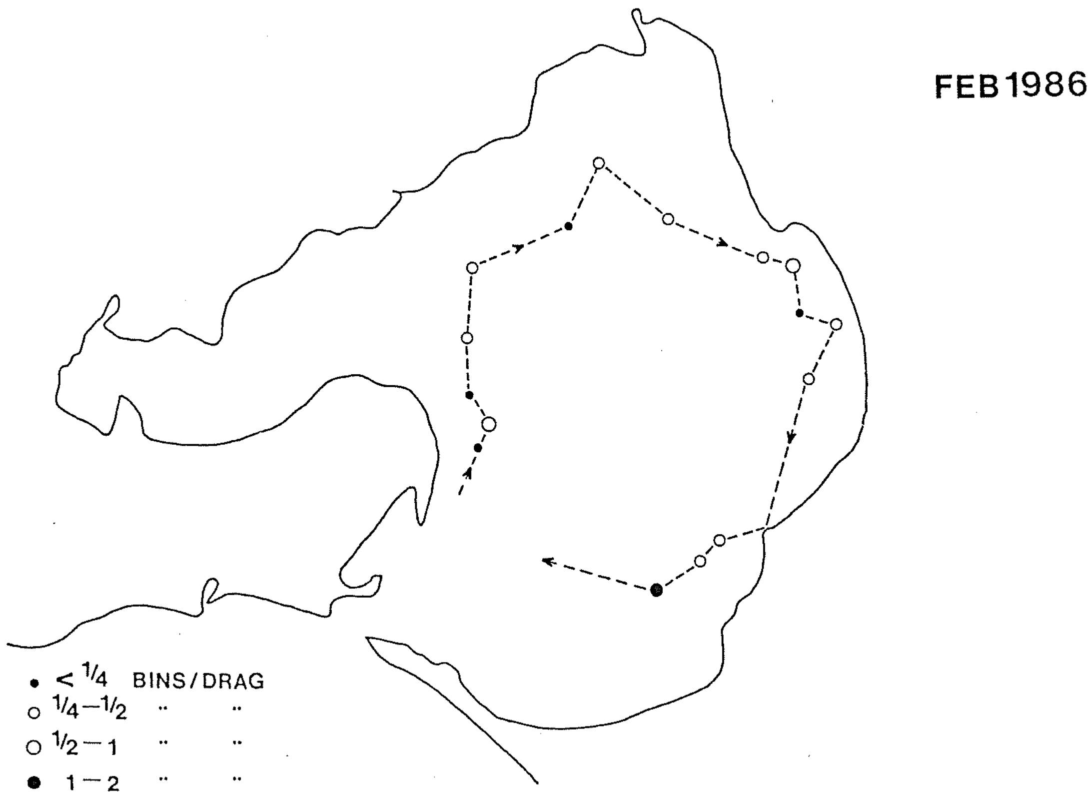
APPENDIX 1. COMMERCIAL DREDGE OBSERVATIONS

In February 1985, a commercial scallop vessel (F.V. St. Andrew) was chartered so that a number of scallop fishermen could observe dredge catch rateswithin the main scallop grounds.

In February 1986, a similar operation was conducted, using the same vessel and following a similar course through the main scallop beds. Appendix Figure 1 compares the catch rates (bins per two) observed for the 2 years. Tows were of 5 minutes duration. Fishermen are aware that catches from a single tow may be quite different from catches made by the whole fleet on any particular ground. Nevertheless, the results clearly demonstrate the reduced stock abundance this year when compared with the situation in 1985. Only one tow resulted in a catch greater than one bin of scallops.





Appendix Figure 1. Catch rates (bins/tow) observed on F.V. St. Andrew in February 1986. One bin contains approximately 600 scallops.