

## 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

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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<sup>-1</sup>. Values for the parameters  $k$  and  $l_{\infty}$  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 length of 70 mm more than 1 year sooner. We suggest that the increase in growth rate is related to density-dependence effects resulting from 20 years of commercial exploitation by scallop dredgers.

### INTRODUCTION

Exploitation of the scallop, *Pecten alba* Tate in Port Phillip Bay (38°S, 145°E) began in 1963 and by 1967, 150 vessels using self-tipping dredge gear were fishing in the bay, and record catches 4900 t (adductor muscle with gonad) were landed that year. A drastic decline to 960 t 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 (> 1800 t) 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 real-

istic 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.

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. However, 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, (M. Sanders, Fisheries and Wildlife Service, Victoria, unpublished data, 1967), which were 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 synonymous *Pecten* (= *Notovola*) *meridionalis* (Tate) in Tasmania. We used data from tag-recapture methods to determine growth rates of scallops in Port Phillip Bay.

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 × 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.

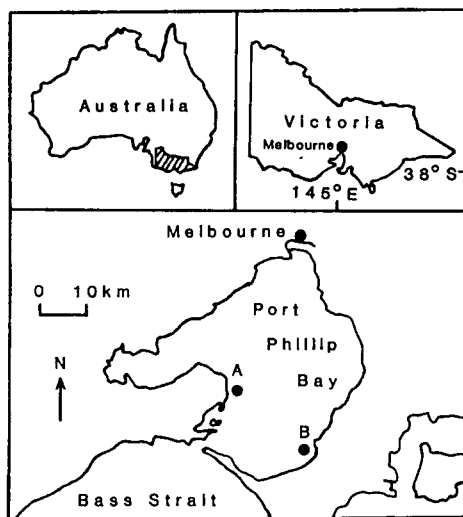


Fig. 1. Study sites at (A) St Leonards and (B) Dromana Bay in Port Phillip Bay.

### *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  $1 \text{ m}^{-2}$  within 1 h 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 4 randomly located transects (50-m long, 1-m wide) within or near each marked site. Two transects were within the marked site, the other 2 were within 5 and 5–10 m of the marked site. Each transect was subdivided into three sections of 16, 16 and 18  $\text{m}^2$  so as to increase sample size and to obtain variances of estimates of average density. 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 2 or 4 divers recovered as many of the tagged scallops as they could by collecting both live scallops and “clappers” during systematic searches. Virtually the entire area of the marked site was searched

including an area extending 5 m beyond the perimeter (stippled in Fig. 2a). To account for scallops which might have escaped beyond this sampled area, divers systematically searched 8 transects, 45 m long  $\times$  1 m wide, running perpendicularly to the boundary of the marked site and covering the distance between 5 and 50 m from the site. Two transects were located on each boundary (Fig. 2a), the points of origin chosen at random. In this extended area, the number of scallops was determined by extrapolation from densities observed in the transects.

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

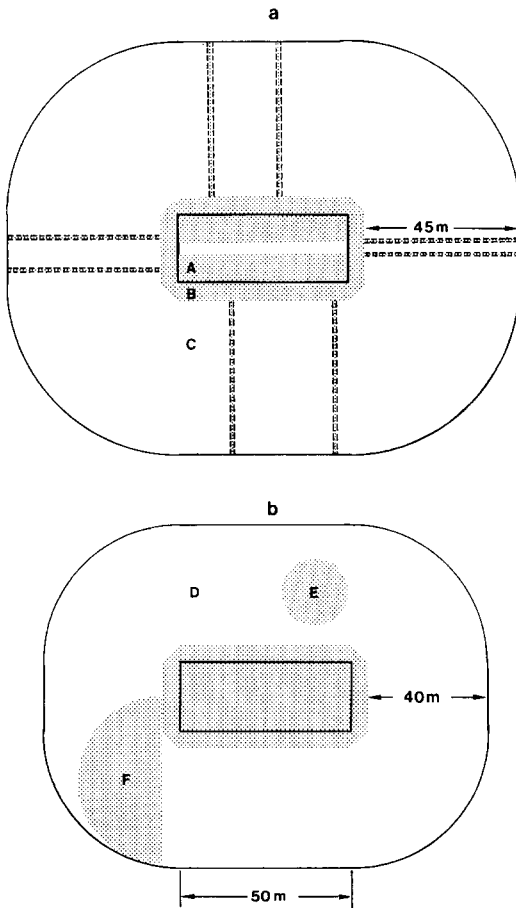


Fig. 2. Plan of the marked site and areas sampled (stippled) within and outside the marked site for both study areas in 1984 (upper) and 1985 (lower). Total area of site (A) = 1000 m<sup>2</sup>; area 5 m beyond boundary of site (B) = 180 m<sup>2</sup>; area 5-50 m beyond site (C) = 14075 m<sup>2</sup>;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

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 2 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 were 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 randomly-located 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, which compared with only 4% of the same area sampled by the first method, using the 8 randomly-located transects. However, it had to be assumed that numbers of scallops per m<sup>2</sup> 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 4 transects of 20 m × 1 m within the marked site at Dromana was sifted.

The calculation of natural mortality rate had to take into account the number of scallops removed during interim sampling as well as the final number surviving. Hence, in the absence of emigration from the sampled area, the instantaneous rate of natural mortality, ( $M \text{ year}^{-1}$ ) was determined from the equation

$$N_{t+1} = (((N_t e^{-t_1 M} - S_1) e^{-t_2 M} - S_2) e^{-t_3 M} - S_3) e^{-t_4 M} \quad (1)$$

solving for  $M$  by Newton Raphson iteration and 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  $l_{00}$  and the growth constant of von Bertalanffy,  $k$  as follows:

$$l_{t+i} = l_t + (l_{00} - l_t) (1 - e^{-ki}) \quad (2)$$

We used Fabens' computer program to calculate least square estimates of  $k$  and  $l_{00}$  standard errors, and standardised residuals.

Results from a separate but simultaneously conducted tagging experiment

to determine growth rates of juvenile scallops (Sause et al., 1987) 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 (M. Sanders, unpublished data, Fisheries and Wildlife Service, Victoria, 1967) 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 2 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 (40–50 in total) of shells were recovered with holes drilled.

TABLE I

Decline in numbers  $\pm 1$  standard deviation of tagged *P. alba* after 12 months of being placed within 1000 m<sup>2</sup> experimental sites in Port Phillip Bay, Australia

Number of tagged <i>P. alba</i>	Dromana		St Leonards	
	1983–84	1984–85	1983–84	1984–85
Initially in marked site	969	1100	1030	1100
Alive after 12 months				
in site	62	244	37	48
0–5 m from site	24	64	13	41
5–40 m from site	53 $\pm$ 60	240 $\pm$ 80	0	290 $\pm$ 100
Total	139 $\pm$ 60	548 $\pm$ 80	50	379 $\pm$ 100
Dead after 12 months				
in site	9	18	15	15
0–5 m from site	0	21	7	4
5–40 m from site	0	30 $\pm$ 10	0	0
Total	9	69 $\pm$ 10	22	19
Removed by interim sampling				
alive	164	159	131	99
dead	40	16	52	7
Missing	617	308	775	596

TABLE II

Estimates of numbers of tagged scallops ( $\pm 1$  standard deviation) surviving within the marked site and at distances up to 5 and 10 m beyond the site boundary at intervals after tagging

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

<sup>1</sup>Final sampling; see Table I.

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 calculation of natural mortality were not affected.

The results of the 4 experiments to determine natural mortality are shown in Tables I and II. In 3 of the 4 experiments, more than one-half of the original scallops could not be accounted for at the end of the experiment and calculations of natural mortality were not made for these cases. However, at the end of the second experiment at Dromana, a much higher proportion of tagged scallops was recovered. Sifting of 4 transects at the marked site at Dromana after the second experiment yielded a total of 9 empty tagged shells in the 4 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,  $M$  was then calculated from eqn. (1) to be 0.52 (equivalent to 40%) year<sup>-1</sup>.

Table II 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 4 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 3 of the 4 experiments, little could be concluded regarding seasonal variation in

TABLE III

Comparison of estimates of growth parameters,  $k$  and  $l_{00}$ , for *P. alba* in Port Phillip Bay between the periods 1964-67 and 1983-85

Source of data	$k$	Standard error	$l_{00}$	Standard error	$n$	Coefficient of correlation between $k$ and $l_{00}$
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., 1987) <sup>1</sup>	1.43	0.05	87.7	0.9	172	-0.89
All data (1983-85) pooled	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
Sub-set of 1964-67 data analysing juveniles only	0.73	0.10	87.7	3.3	30	-0.95

<sup>1</sup>Included in Dromana 1983-85 analysis.



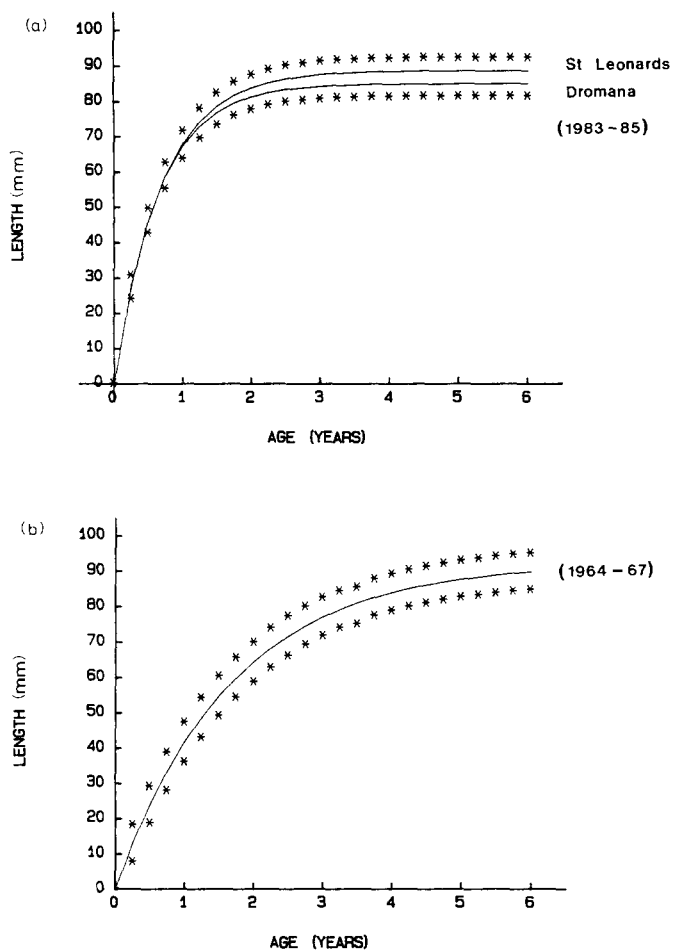


Fig. 3. Calculated length at age (from Table III) for (a) 1983-85 data and (b) 1964-67 data,  $\pm 95\%$  confidence limits on line of best fit. Upper and lower confidence limits shown for St Leonards and Dromana data, respectively.

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 III) show that the growth constant ( $k$ ) and asymptotic size ( $l_{00}$ ) calculated for the 1964 and 1984 sets of data were different. Values of  $k$  are between 2 and 3 times higher now than 20 years ago, while values of  $l_{00}$  have

decreased from 92.5 mm to 85.9 mm over the same period. However, comparisons between  $k$  and  $l_{00}$  values are often confounded by the highly correlated nature of the 2 variables (Table III), and for this reason we compared curves using an  $F$ -test to test the hypothesis that  $k$  and  $l_{00}$  were the same at both sites and for both 1964 and 1984 sets of data. The growth curves for tagged scallops released at St Leonards and Dromana in 1983 (Fig. 3a) were significantly different ( $P < 0.01$ ). The difference between the two growth curves was small, its significance being attributable to the large sample size and we pooled data for the 1983–85 period in order to compare them with the 1964–67 data. The difference was substantial (Fig. 3a and b). Scallops now reach a size of 70 mm in 1 year compared with 2–3 years in the 1960s.

To determine whether the difference in growth over this period 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 III). Values estimated from these data were consistent with his combined 1964–67 data and were dissimilar to those determined from the juveniles tagged in 1984.

## 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  $l_{00}$  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* (Habe). Gruffydd (1974b) showed that *Pecten maximus* (L.) 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 the growth the *P. maximus* in the Clyde Sea between 1965 and 1975. During the 1960s, when beds of *P. maximus* were heavily smothered by queens (*Chlamys opercularis*) the growth rate of *P. maximus* was low. During the early 1970s, 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 localities. 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.

It is conceivable that the lower  $k$  value from the earlier data is the consequence of the scallops having been released onto the fishing grounds rather than onto the undredged experimental sites, as in our recent studies. However, independent observations of the progression of modal sizes of juveniles taken by the commercial fishery (Sause et al., 1987) confirm that there is no evidence of retardation of the growth of scallops in fished areas.

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 incidentally 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.

If changes in length-at-age of *P. alba* have occurred 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. Based on shell annuli (M. Sanders, Fisheries and Wildlife Services, Victoria, unpublished data, 1967) up to 7 age classes in the *P. alba* population of Port Phillip Bay during the 1960s were recognised. At that time and until 1978, a minimum legal length of 80 mm was in force and Sanders (1970) considered that this length was reached at an age of 2.5–3.5 years. Our analysis of his tagging data confirms that at that time, the exploited stock (shell length > 80 mm) would have been the 3+ and older age groups.

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. The minimum size regulation was abolished in 1978 and since at least 1983, the exploited stock each year has been mainly the newly-recruited, 1+ aged, scallops of size range 70–80 mm, with few surviving into their third year (McShane and Gwyther, 1984; Gwyther and McShane, 1985; Gwyther and Burgess, 1986; Sause et al., 1987). The majority of scallops would therefore not be expected to show more than one growth check although even this is not readily apparent on shells of *P. alba* currently sampled in Port Phillip Bay.

Abolition of size restrictions has inevitably resulted in exploitation of younger age classes. What has also occurred in Port Phillip Bay is that the exploited

1+ -year-old scallops now attain a size of 70–80 mm, a size which 20 years ago was not reached until the age of 2.5–3.5 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 1 of 4 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. The sampling of this area did present some problems; the low density of scallops and lack of reference points for divers working underwater made random searching of a larger number of sites impractical. Methods were therefore chosen so as to sample as much of the outer area as possible, having first searched the entire area of the marked site, and an area 5 m beyond the boundary of the marked site.

Other possibilities for loss of scallops can also be proposed. Scallops could have migrated more than 50 m beyond the sampled area, could have been removed by predators or could have died and their shells could then have become covered by sediments. The latter two possibilities would be part of natural mortality. 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 *Notovola meridionalis* (Olsen, 1955) and *Placopecten magellanicus* (Gmelin) (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 *Argopecten irradians* (L.) (Peterson et al., 1982). One predator, the starfish *Coscinasterias cala-*

*maria*, was observed at both marked sites in Port Phillip Bay. This starfish was also observed to elicit 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 3 of the 4 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 1 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 *A. 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.

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