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Counting scallops and managing the fishery in Port Phillip Bay, south-east Australia

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Abstract

Annual yield from the scallop fishery in Port Phillip Bay, Victoria, south-east Australia, has ranged from 2000 tonnes to 0. Even in less extreme circumstances, the yield may vary almost 20-fold between years. In view of such variability, managers face difficulty in predicting the success of the fishery and in setting appropriate catch limits each year.

Since 1982 divers have carried out an annual survey to provide quantitative estimates of the number of scallops potentially available to the fishery. The success of the fishery is not only dependent on the number of scallops in the bay each year. Annual differences in scallop growth and survival, in the length of the fishing season and in the number of boats taking part in the fishery also have an effect. Despite the influences of these other factors, abundance estimates from the dive survey do correlate significantly with the outcome of the fishery. The survey has therefore proved to be a useful management tool in forming an assessment of how successful the fishery is likely to be and in setting catch limits for the coming season. Experience in Port Phillip Bay shows that, in at least some circumstances, divers may be used to obtain truly quantitative estimates of scallop abundance for whole stocks, an undertaking that has previously been considered as impracticable. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Scallops; Abundance estimates; Fisheries management

1. Introduction

Port Phillip Bay supports a fishery for the scallop *Pecten fumatus* Reeve (=*Notovola meridionalis* (Tate) and *Pecten alba* (Tate)). The fishery is extremely variable. Since the fishery started in 1963 the annual meat yield (of the edible portion, adductor muscle plus gonad) has ranged from 0 to 2000 tonnes. Even in less extreme circumstances, yield may vary almost 20-fold between years. A problem facing managers, given such variability, is how to predict the likely success of the fishery and set appropriate catch limits. For scallop fishers, such variability makes it difficult to estimate their likely income from the fishery. For those who are also engaged in other fisheries, this variability also makes it difficult to decide each year whether to take part in the scallop fishery in the bay or whether it might be more profitable to engage in some other fishery.

Each year since 1982 a dive survey to provide quantitative estimates of scallop abundance in Port Phillip Bay has been carried out. These estimates are used to predict the success of the fishery and in setting

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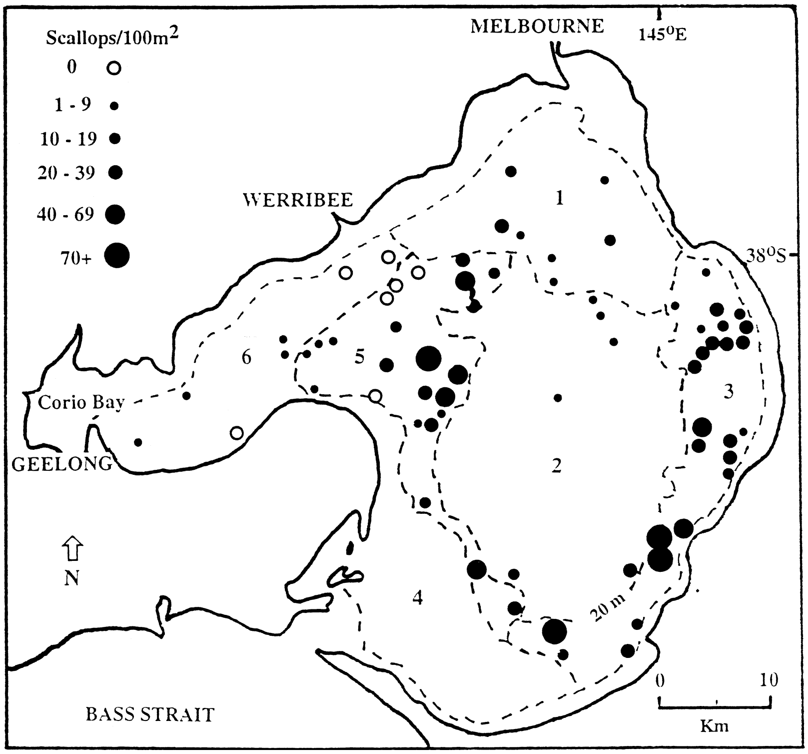

Fig. 1. Port Phillip Bay showing strata defined for the annual dive survey (1–6) and the scallop abundance at stations sampled in February 1996.

catch limits. In this paper a general description of Port Phillip Bay and the scallop fishery is given, the dive survey is described and the success of the survey is assessed.

2. Port Phillip Bay

Port Phillip Bay (Fig. 1) is a largely enclosed marine bay in Victoria, south-east Australia. The surface area is approximately 1950 km^2. There are some small areas of reef but otherwise the bottom is of sand and mud. The central portion of the bay is 20–24 m deep but about half of the bay is less than 14 m deep. The seafloor slopes gently from the west and more steeply from the east towards the centre of the bay. Contact with Bass Strait is through a single, narrow opening. Water temperature ranges (approximately) from 8°C to 26°C annually and salinity from 26°/oo to 39°/oo. Melbourne, Victoria's largest city (population 3.5 million), is situated in the north of the bay. Suburbs extend along the eastern and north-western shores. A sewage farm at Werribee, on the west coast, discharges treated effluent to the bay. The area south of Werribee is mainly rural but Geelong, Victoria's second largest city (population 175 000), is situated on Corio Bay.

3. The scallop fishery in Port Phillip Bay

The fishery in Port Phillip Bay began in 1963. Yield from the fishery increased to almost 2000 tonnes meat weight by 1966 but subsequently declined with only 18 tonnes being produced in 1970 (Young and Martin, 1989; Coleman et al., 1996). Since 1970 yield has fluctuated widely, from 1655 tonnes in 1985 to nothing in 1989 and 1990 when there were too few scallops to support a fishery (Coleman et al., 1996).

Scallops are fished using the self-tipping dredge, developed in Australia in the early 1960s (Hughes, 1973; McLoughlin et al., 1991). The dredge is rigid, rectangular in shape with a maximum allowable width of 4.4 m and is covered in 70×45 mm weldmesh. The mouth of the dredge is approximately 45 cm in height. The dredge rests on a metal frame at the stern of the vessel with its mouth facing downwards towards a sorting tray. A cable runs from two towing points at the front of the dredge to a winch. Shooting, hauling and tipping the contents of the dredge onto the sorting tray are all controlled by one person operating the winch.

Eighty four boats are licensed to fish in the bay. Fishing is permitted from Monday to Thursday inclusive between 5 a.m. and 5 p.m. On board the fishing vessels scallops are packed into lidded metal crates which are sent to an on-shore processor where the scallops are split and the meat removed. Depending on the size of the scallops the number to a crate ranges from about 1800 to 2600. The edible yield (of adductor muscle+gonad) varies throughout the fishing season and from year to year but generally ranges from 12 to 26 kg per crate (Fig. 2).

The fishing season lies within the period April–December (autumn, winter, spring and early summer in the southern hemisphere). The actual timing and duration of the season varies from year to year, depending on the condition and abundance of the scallops. Because it is a roe-on fishery, fishing is generally concentrated in the period July–October (winter–early spring) when the gonad is most fully developed and condition and meat yield are the highest (Fig. 2).

A daily catch limit, as number of crates per boat per day, is set. Each boat is given the same limit. To maximise yield from the fishery catch limits are generally set higher during July–October, when scallops are in peak condition, than that at the beginning and the end of the season. Size is used as a general guide in assessing commercial conditions. While there is no legal minimum size limit in the bay, it is expected that the majority of scallops in a fished population will be 68–70 mm or more in shell height (the distance perpendicular from the hinge to the margin of the flat valve). A more important criterion in assessing commercial condition and preventing over-exploitation of small scallops, or scallops in poor condition, is that fishing is not permitted if the average number of meats per kilogram exceeds 120. During the fishing season on-board monitoring of the catch is undertaken (by fisheries enforcement officers). If more than 20% of dredged scallops are discarded, in order to maintain meat weights of 120 or less to the kilo, the fishery can be closed (in which case further monitoring is undertaken to determine whether the size and the condition improve).

Thirty years of scalloping have changed the structure of the population in the bay. Potentially *Pecten fumatus* has a lifespan of 16 years, and up to 7 year-

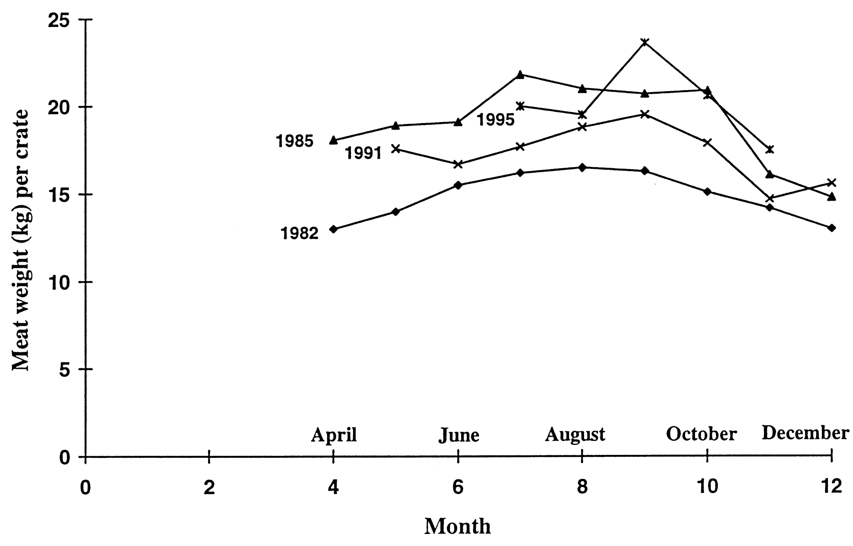

Fig. 2. Mean monthly weight per crate (adductor muscle+gonad) for scallops from various fishing seasons in Port Phillip Bay.

classes were recognised in Port Phillip Bay in the 1960s (Fairbridge, 1953; Gwyther and McShane, 1988). Studies in the 1980s showed that the population in the bay is now primarily composed of only one or two year groups. Scallops spawn during late winter and early spring and settle round October–December. The growth of *P. fumatus* is rapid in comparison with that of the other temperate pectinid species and the commercial size is reached within 16–18 months of settlement (Sause et al., 1987a, b). Each year the fishery is largely dependent on the 1+ year class of scallops entering the fishery for the first time, 2+ scallops remaining from the previous year make a smaller contribution (the significance of which will vary according to the success with which 1+ scallops are recruited to the fishery) and few scallops survive into their third year (Gwyther and McShane, 1988).

4. The dive survey

Before 1982 estimates of scallop abundance in Port Phillip Bay were made from dredge surveys using a commercial scallop dredge and tows of a standard duration. In 1982 abundance estimates were made using independent dredge and diver surveys (McShane and O'Connor, 1982; McShane, 1982). The number of harvestable scallops estimated from the dredge survey was double that estimated from the dive survey. In extrapolating from dredge samples to total harvestable scallops, assumptions concerning the catching efficiency of the dredge and the total area sampled were made. Both dredge efficiency and the area actually sampled in a standard tow may vary considerably from site to site and with different fishing conditions, leading to inaccuracies in abundance estimates (McShane, 1982; Orensanz et al., 1991). No assumptions concerning catch efficiency and the total area sampled were necessary for the dive survey, which was therefore assumed to give a more accurate and unbiased estimate of the population. Dive surveys have continued since 1982.

The dive survey is carried out between January and March each year using a stratified random sampling scheme. For the survey the bay is divided into six strata (Fig. 1). These strata were initially defined (using catch statistics) in relation to scallop abundance in the bay, with most scallops consistently being found in the areas covered by stratum 3 in the east and stratum 5 in the west of the bay. The boundary of stratum 2 is provided by the 20 m deep contour. Water depth in the remaining strata is 5–20 m. Stratum 4 is usually not sampled. Much of this area contains shallow water and sandbanks and is not fished.

In the laboratory random numbers are used to generate pairs of grid co-ordinates. The positions thus selected are plotted on a chart of Port Phillip Bay until the required number have been allocated to each stratum. In the field, sampling stations were located by radar in the early years of the survey and more recently by global positioning system. Seventy sites are sampled, the majority being allocated to strata 3 and 5 (Table 1). It takes about 15 days for a team of five divers to sample all the sites and the number of samples is based on the time and resources available rather than on any truly statistical criterion. At each site 100 m^{-2} are sampled. Two ropes 50 m in length are placed on the sea bed, one on each side of the sample vessel. A diver swims along each rope pushing

Table 1
Estimated abundance of scallops potentially available to the fishery in Port Phillip Bay, February 1996

Stratum	No. of sample sites	No. of scallops collected	Mean no. of scallops per square metre	Estimated abundance of scallops in millions (±95% confidence interval)
1	7	66	0.09	25.8 (±17.1)
2	6	69	0.12	67.4 (±61.6)
3	25	704	0.28	72.5 (±23.9)
5	25	674	0.27	64.2 (±38.4)
6	7	6	0.01	1.9 (±1.9)
Bay-wide	70	1519	0.15	231.8 (±189.2)

Estimated abundance is calculated as the mean number of scallops per square metre multiplied by the total area of the stratum.

a 1 m long bar held at right angles to the rope and collecting all the scallops in the path of the bar. Scallops down to 15 mm or less in shell height may be collected but only scallops greater than 40 mm shell height are considered as potentially available to the fishery in the coming season.

The results from the survey are used to estimate the abundance of scallops potentially available to the fishery (Table 1). They may also be used to determine the relative proportions of 1+ scallops (40–70 mm in shell height) and 2+ and older scallops (>70 mm shell height) (Sause et al., 1987a; Gwyther and McShane, 1985). Older catch records show that scallops were most abundantly collected from those areas covered by strata 3 and 5. This pattern does not appear to have altered during the life of the survey. Since 1982 strata 3 and 5 have consistently had the highest population densities (as number of scallops per square metre) and commercial catches continue to be greatest from these areas of the bay. Within strata scallops tend to be clumped into patches of different population densities and sizes (Fig. 1) but small-scale patchiness has not been investigated.

After the dive survey, further monitoring is carried out in association with the industry. Commercial boats are used to collect monthly or fortnightly scallop samples. When these samples indicate that scallops are in sufficiently good condition, the fishery is opened.

As scallop abundance becomes reduced during the fishing season, the time to fill a crate with scallops increases, it becomes difficult to reach even moderate daily catch limits and fishing becomes uneconomical. This point is reached when the population is reduced to about 40–70 million scallops (calculated from estimates of initial scallop abundance, of the number of scallops taken by the fishery and of natural mortality) (Gwyther et al., 1991). In setting total catch limits for the season the aim is to leave a residual population of around 70 million. This level of stock will not support a fishery in the following season, but is assumed to leave sufficient breeding stock to ensure future recruitment to the fishery. In some years the recruitment had failed and the fishery has been poor or non-existent. Whether such failures indicate that 70 million is insufficient to ensure good recruitment or result from environmental conditions which are unsuitable for reproduction and spat settlement is not known; but between 1989 and 1991 the estimated scallop population went from 20 million (the lowest ever recorded) to 390 million, which shows that a depleted population may rapidly recover if the conditions are right.

5. Comparison of dive survey estimates with scallop fishery statistics

There is a positive correlation between the abundance of scallops estimated from the dive fishery and the yield from the fishery. Fishers' comments on the success of the season also tend to be more favourable in those years when estimates of abundance are highest (Table 2). However, 1992 and 1993 were exceptional years. Estimates of abundance in those years greatly exceeded those of any other year yet, by comparison with other years, yield from the fishery was very low in proportion to abundance. Fishers' also commented that these were poor years. The discrepancy between yield and abundance was due to exceptionally high mortality in the populations in those years.

Presenting the data as a scatter plot of yield against the estimated number of scallops (Fig. 3) shows the anomalous situation in 1992 and 1993. Results from most years cluster together and show that yield increases as the estimated number of scallops increases, but results from 1992 and 1993 clearly do not fit this general pattern. Results from 1985 also appear to be anomalous with yield being exceptionally high in relation to estimated abundance.

To assess the success of the dive survey in predicting the success of the fishery, and therefore its use as a management tool, regressions and correlations between the survey estimates and fishery statistics were investigated. During initial analyses time series analysis was carried out. Analyses were undertaken to determine whether there was any correlation between the abundance of scallops in one year and abundance one and two years later (since it is 1–2 years after settlement that the scallops enter the fishery). No correlations were found. A range of environmental studies have been undertaken in Port Phillip Bay. Using data from these studies attempts were made to correlate scallop abundance with environmental variables (water temperature,

Table 2
Estimated abundance of scallops, yield from the fishery and opinions on the fishery in Port Phillip Bay (numbers in brackets are 95% confidence limits)

Year	Estimated number of scallops available to the fishery (millions) (±95% confidence limit)	Yield (tonnes meat weight—adductor muscle+gonad)	Fishers' comments on the season
1982	489 (±363)	894	Very good
1983	195 (±95)	440	Fairly poor
1984	312 (±101)	868	Good
1985	321 (±108)	1672	Very good
1986	135 (±24)	160	Poor
1987	268 (±123)	645	Good
1988	92 (±26)	35	Very poor
1989	20 (±11)	0	(No fishing)
1990	51 (±39)	0	(No fishing)
1991	390 (±225)	529	Good
1992	2654 (±1164)	189	Poor (very high mortality)
1993	1200 (±495)	312	Poor (very high mortality)
1994	212 (±132)	133	Poor
1995	330 (±318)	368	Poor
1996	232 (±189)	75	Poor

salinity, dissolved oxygen, phosphate, ammonium, chlorophyll *a*, *b* and *c*, total nitrogen, silica, zinc, arsenic, nickel and mercury) within each year and at time lags of one and two years. No correlations were found. While it is to be expected that environmental conditions do influence scallop abundance, the lack of correlation may reflect the complexity of the relationship. Abundance could be affected by environmental factors influencing reproduction in the adult population, influencing larval survival during the planktonic phase, and influencing the success of settlement and further growth. Alternatively, lack of correlation could reflect the fact that the fishery and environmental data were collected over different temporal and spatial scales and without any reference to each other.

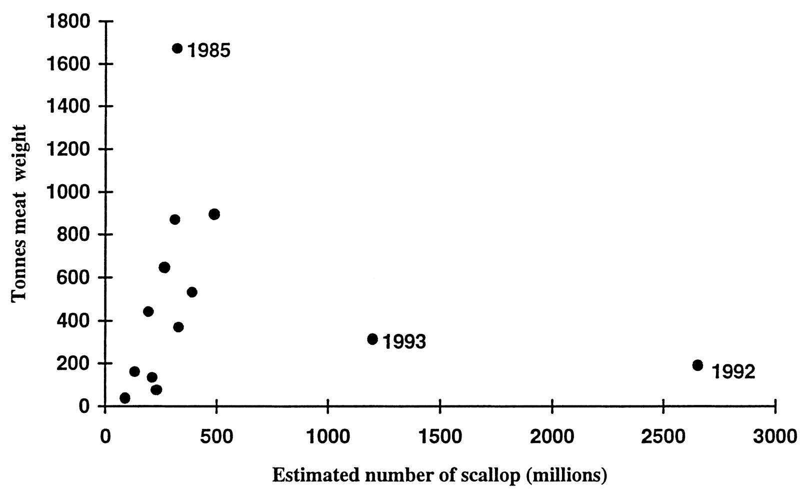

Fig. 3. Estimated number of scallops and yield from the fishery in Port Phillip Bay from 1982 to 1996. Meat weight is the weight of the adductor muscle+gonad.

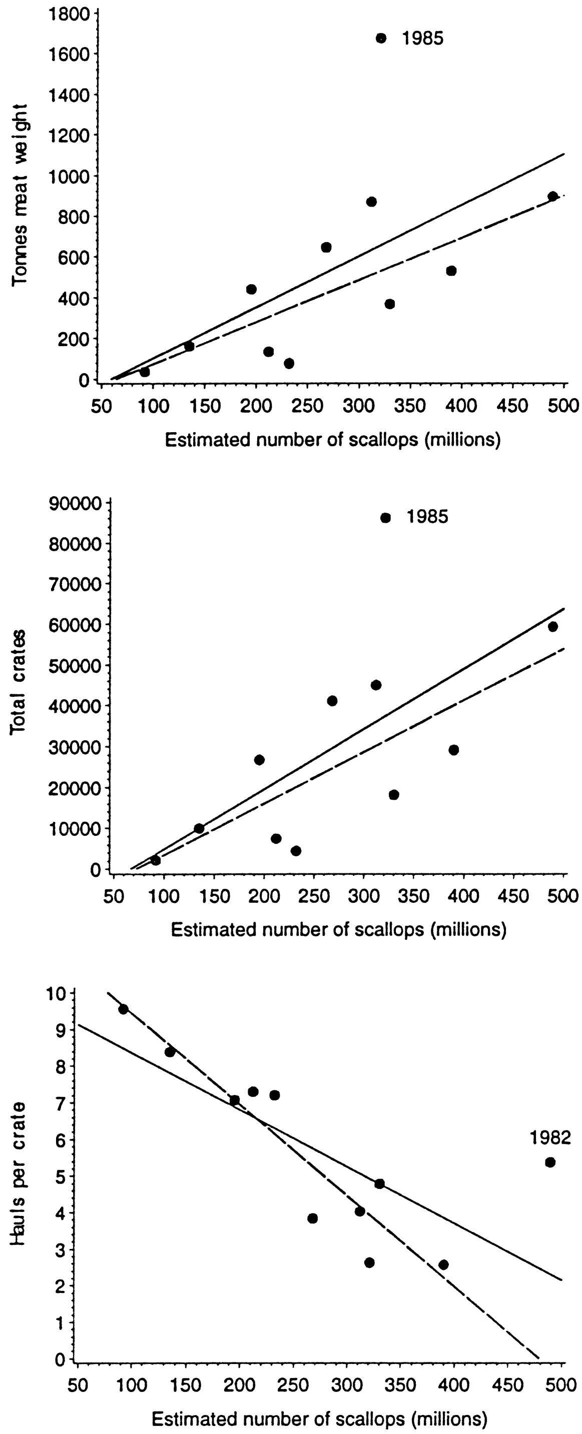

Fig. 4. Correlations between fisheries statistics and dive survey estimates of scallop abundance. Meat weight is the weight of adductor muscle+gonad. Solid lines are regressions calculated using all data, broken lines are regressions calculated with the data from labelled years omitted. Regressions are: tonnes=−148.6+2.5 (no. of scallops), r^2=0.35, p=0.06 (all data); tonnes=−133.1+2.1 (no. of scallops), r^2=0.60, p=0.01 (excluding data from 1985); crates=−9948+147.4(no. of scallops), r^2=0.41, p=0.03 (all data); crates=−9937+127.4(no. of scallops), r^2=0.60, p=0.01 (excluding data from 1985); hauls/crate=9.92−0.016(no. of scallops), r^2=0.57, p=0.01 (all data); hauls/crate=11.94−0.025(no. of scallops), r^2=0.88, p=0.0001 (excluding data from 1982).

Because time series analysis and correlations with environmental data did not yield positive results, a more simplistic approach was taken. Linear regressions and correlations between the survey estimates and fishery statistics for each year since 1982 were investigated (Tables 3 and 4; Figs. 4 and 5). The fishery statistics used were totals (for kg, crates and hours fished) or averages (for hauls per crate and crates and kg per hour) obtained over the whole season. Monthly results were not used because they are influenced by monthly catch limits. Results for 1992 and 1993 were omitted from the calculations because conditions in these years were so obviously exceptional. Results from 1989 and 1990 when there was no fishery were also omitted. In several cases correlations were highly influenced by one data point (i.e. the results from one year) and whether or not this point was included made the difference between significance or non-significance at the 5% level. Where regressions were calculated the residuals were examined. In no case did these show patterns that could indicate that the assumptions underlying the regression model were invalid.

The correlations investigated were of three kinds. Bay-wide fishery statistics were correlated with bay-wide abundance estimates; bay-wide fishery statistics were correlated with abundance estimates from within individual strata; and fishery statistics and abundance estimates obtained from within individual strata were correlated. Results from strata 1, 2 and 6, which make a relatively small contribution to the fishery and are allocated few sample stations in the dive survey, were combined for analysis.

The correlation between estimate of scallop abundance and yield from the fishery (Table 3 and Fig. 4) is highly influenced by the results for 1985, when the yield was extremely high in relation to the estimated abundance. The correlation is not significant at the 5%

Table 3
Correlations between estimates from dive survey results and annual fisheries statistics

Fishery statistics estimates	Yield	Total crates	Hauls per crate	Total hours	Crates per hour	Kg per hour
Total no. of scallops	$r=0.59$, $p=0.06$ ($r=0.77$, $p=0.01$)[a]	$r=0.64$, $p=0.03$	$r=-0.75$, $p=0.01$	$r=0.65$, $p=0.03$	$r=0.65$, $p=0.03$	$r=0.59$, $p=0.06$ ($r=0.87$, $p=0.001$)[b]
No. of scallops in stratum 3	$r=0.55$, $p=0.08$ ($r=0.75$, $p=0.01$)[a]	$r=0.61$, $p=0.04$	$r=-0.71$, $p=0.01$	$r=0.61$, $p=0.05$	$r=0.66$, $p=0.03$	$r=0.55$, $p=0.08$ ($r=0.82$, $p=0.004$)[b]
No. of scallops in stratum 5	$r=0.61$, $p=0.05$	$r=0.64$, $p=0.03$	$r=-0.78$, $p=0.004$	$r=0.52$, $p=0.10$ ($r=0.79$, $p=0.01$)[c]	$r=0.80$, $p=0.003$	$r=0.77$, $p=0.01$
No. of scallops in strata 3 and 5	$r=0.60$, $p=0.05$	$r=0.62$, $p=0.06$ ($r=0.81$, $p=0.009$)[c]	$r=-0.78$, $p=0.005$	$r=0.60$, $p=0.05$	$r=0.74$, $p=0.01$	$r=0.67$, $p=0.02$
No. of scallops in strata 1, 2 and 6	NS	NS	$r=-0.48$, $p=0.13$ ($r=-0.65$, $p=0.04$)[a]	NS	$r=-0.32$, $p=0.33$ ($r=-0.59$, $p=0.07$)[a]	$r=-0.32$, $p=0.34$ ($r=-0.61$, $p=0.06$)[a]

Where correlations are highly influenced by data from one year, values of r (Pearson correlation coefficient) and p (probability) calculated minus those data are shown in the brackets. Yield was measured as tonnes meat weight (adductor muscle+gonad). Yield, total crates and total hours are bay-wide totals for the season; hauls per crate, crates and Kg per hour are bay-wide averages for the season. NS, correlation not significant ($p>0.1$) and not highly influenced by one data point.
[a]Year omitted 1985.
[b]Year omitted 1982.
[c]Year omitted 1991.

Table 4
Correlations between estimates from dive survey results and annual fisheries statistics from strata 3 and 5 individually and from the remaining strata combined

Fishery statistics estimates	Yield per stratum	Total crates per stratum	Hauls per crate per stratum	Total hours per stratum	Crates per hour per stratum	Kg per hour per stratum
No. of scallops in stratum 3	NS	$r=0.46$, $p=0.15$ ($r=0.65$, $p=0.04$)[c]	$r=-0.63$, $p=0.04$	$r=0.53$, $p=0.09$ ($r=0.70$, $p=0.03$)[b]	$r=0.61$, $p=0.04$	$r=0.26$, $p=0.44$ ($r=0.82$, $p=0.004$)[a]
No. of scallops in stratum 5	$r=0.66$, $p=0.02$	$r=0.62$, $p=0.04$	$r=-0.86$, $p=0.001$	$r=0.47$, $p=0.14$ ($r=0.81$, $p=0.004$)[b]	r=0.90 p=0.0001	r=0.88 p=0.0004
No. of scallops in strata 1, 2 and 6	NS	NS	$r=-0.45$, $p=0.15$ ($r=0.63$, $p=0.05$)[c]	NS	NS	$r=0.34$, $p=0.30$ ($r=0.62$, $p=0.05$)[c]

Where correlations are highly influenced by data from one year, values of r (Pearson correlation coefficient) and p (probability) calculated minus those data are shown in the brackets. Yield was measured as tonnes meat weight (adductor muscle+gonad). Yield, total crates and total hours are totals per stratum for the season; hauls per crate, crates and Kg per hour are averages per stratum for the season. NS, correlation not significant ($p>0.1$) and not highly influenced by one data point.
[a]Year omitted 1982.
[b]Year omitted 1991.
[c]Year omitted 1985.

level when all the years' data are considered but becomes so if data from 1985 are excluded. Correlation between yield and numbers of scallops in stratum 3 is also highly influenced by the results for 1985, but estimates of abundance in stratum 5 and in strata 3 and 5 combined correlated significantly with the yield at the 5% level without the need to omit data from 1985.

The total number of crates collected correlates significantly with the estimated total abundance at the 5% level when all the years' are included (Table 3) but is still highly influenced by the results for 1985 (Fig. 4) when the number of crates collected was high in relation to the estimated scallop abundance. The total number of crates collected is also correlated with the abundance of scallops in strata 3 and 5, singly and in combination. The correlation for strata 3 and 5 combined is highly influenced by the results for 1991 when the number of crates collected from stratum 5 was low in relation to the abundance estimate for that stratum.

The number of dredge hauls required to fill a crate is significantly correlated with the abundance at the 5% level with all the data included (Table 3) but is nevertheless highly influenced by the data for 1982. In that year the number of hauls required to fill a crate was high in relation to the abundance estimate (Fig. 4). The number of hauls per crate is also correlated with the abundance of scallops in strata 3 and 5, singly and in combination. There was also some correlation with abundance estimates from strata 1, 2 and 6 (combined).

The total number of hours fished was positively correlated with the abundance estimates (Table 3 and Fig. 5). For the bay as a whole no year's data particularly influenced the correlation, but the correlation between total hours fished and the number of scallops in stratum 5 was particularly influenced by the data for 1991 when hours fished was small in relation to the abundance estimates.

The number of crates and kg collected per hour (themselves highly correlated, r=0.97, p=0.0001)

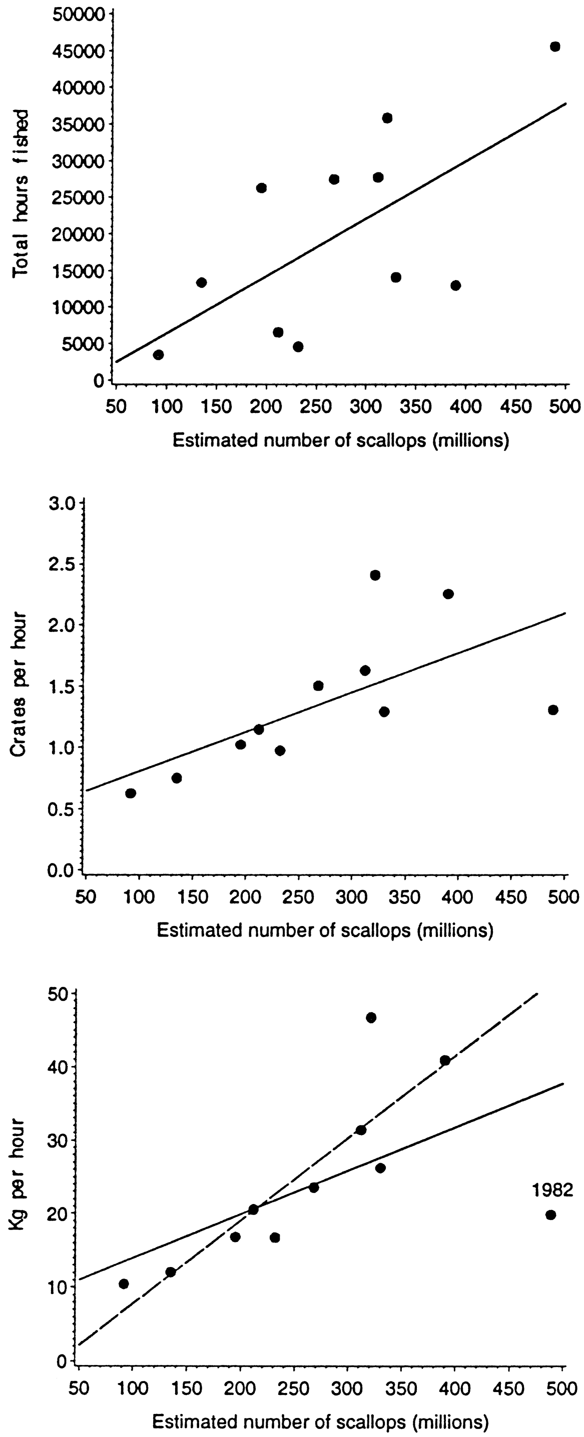

Fig. 5. Correlations between fisheries statistics and dive survey estimates of scallop abundance. Solid lines are regressions calculated using all data, broken lines are regressions calculated with data from labelled years omitted. Regressions are: total hours fished=−1481+78.5(no. of scallops), r^2=0.43, p=0.03; crates per hour=0.48+0.003(no. of scallops), r^2=0.42, p=0.03; kg per hour=8.01+0.06(no. of scallops), r^2=0.35, p=0.06(all data); kg per hour=−3.46+0.11(no. of scallops), r^2=0.76, p=0.001 (excluding data from 1982).

were both correlated with the abundance estimates from the dive survey (Table 3 and Fig. 5) although various of the correlations were highly influenced by the results from 1982 (when kg/h was very low in relation to the abundance estimate for stratum 3) or 1985 (when kg/h and crates/h were both low in relation to the abundance estimates for strata 1, 2 and 6 combined).

Correlations between the survey estimates and the fisheries statistics from within individual strata (Table 4) mirror those shown using the bay-wide fisheries statistics. In general correlations exist although the results may be highly influenced by the data from a single year. More significant correlations were obtained within stratum 5 than within stratum 3 and correlation coefficients are generally higher in stratum 5 than in stratum 3. Correlations between survey and fisheries results within strata 1, 2 and 6 combined are poor.

6. Discussion

Each year since 1982 a dive survey to provide a quantitative estimate of the abundance of scallops in Port Phillip Bay has been carried out. The results of the survey are used to predict the likely success of the fishery. Initially fishers were sceptical that the survey would be able to predict the outcome of the fishery, but now accept that it gives a good general indication of the fishery to the extent that they are enquiring about each year's results even before the survey is finished. More objectively, the statistical correlations that exist between survey results and the outcome of the fishery indicate that the survey is a useful tool and is providing data of relevance to managing the fishery.

In correlating survey estimates with fisheries statistics, data for the years 1992 and 1993 have been omitted. This seems justified on the basis that these were obviously quite extraordinary years. Abundance estimates were far higher than those for any other year, yet the fishery was poor because of extremely high mortality in the scallop population. Data for 1985 are also somewhat anomalous in that the yield from the fishery was high in relation to the abundance estimates. In some instances data from 1985 have a particularly strong influence on correlations and make the difference between significance or non-significance at the 5% level. Similarly, data from 1982 and 1991 also appeared to be highly influential for some correlations. If correlations at the 10% probability level are regarded as significant, which might be considered reasonable given the relatively coarse nature of fisheries data, then more correlations become significant without the need to remove the effects of individual, but highly influential, years.

It might be argued that correlations between survey estimates and results from the fishery are part of a self-fulfilling prophecy. If the estimates of scallop abundance are low, low catch limits are set so the yield from the fishery and the total hours fished are low and vice versa. However, this is not the case. Throughout the fishing season meetings are held between managers and industry representatives to discuss the conduct of the fishery. At any time during the season catch limits can be altered if the actual results of fishing are greatly at variance with the predictions made on the basis of the survey. What is taken by the fishery is therefore a direct reflection of what is available; and correlations between survey estimates and fishery statistics reflect the accuracy of the survey, not some artificial constraint placed on the industry on the basis of the survey results.

In calculating regressions relating survey estimates and fisheries statistics r^2 values were less than 0.65, indicating that although correlations exist the regression models have little predictive power (Prairie, 1996). Lack of predictive power does not invalidate the use of the survey as a management tool since the results have so far been applied only in a general sense. That is, based on abundance estimates, each season is predicted as likely to be relatively good or bad; having an abundance estimate and an estimate of the number of scallops per crate it is possible to estimate the number of crates likely to be taken during the season, and depending on whether this estimate is relatively high or low crate limits are likely to be set higher or lower; and, depending on whether the abundance estimate suggests the season will be long or short, the desirability of opening or closing the season early or late will be considered. There is no suggestion that for a given estimate of the scallop abundance the actual yield from the fishery, or the length of the season can be precisely predicted or crate limits precisely set. Nevertheless, the relationships between abundance estimates and outcomes from the fishery demonstrated here do mean that it is possible to make some, albeit very broad, quantitative estimates regarding the likely outcome of the fishery each year.

The inability to make precise predictions arises because the success of the fishery does not depend solely on the number of scallops present in the bay. Other factors which influence the observed relationships between the survey estimates and the outcome of the fishery are incorrect reporting of catches and yield per crate by fishers and processors (not discussed further), imprecision in survey estimates, the influence of environmental conditions on the fishery (not at present understood), and socio-economic factors.

The precision of the survey estimate varies considerably from year to year. Since 1982 the standard errors for bay-wide estimates of the scallop abundance have ranged from 9% to 48% of the mean. Within individual strata the standard error of the mean has shown similar levels of variation. Generally, the most precise estimates are those for strata 3 and 5. Although the standard error for these strata has been as low as 3% it is usually in the range 15–30% of the mean.

The precision of the estimate could be increased by increasing the sample size, and it is relatively easy to determine the number of samples required to give a specified level of accuracy (Vézina, 1988). However, large increases in sampling effort are likely to result in only modest increases in precision and are not practicable. For example, a doubling of the number of samples taken in stratum 3 in 1996 would have only decreased the standard error from 16% to 11% of the mean and doubling the number of samples in stratum 5 would have reduced the standard error from 29% to 20%.

As an alternative to increasing sample size, some reallocation of sampling effort to strata using an optimal allocation strategy might also give slightly more precise results. But given that a very large increase in sampling effort is needed to make any appreciable increase in precision, reallocating the current number of samples is unlikely to have much effect. In particular there is little correlation between fisheries statistics and abundance estimates from strata 1, 2 and 6 and so it could be argued that it is better to reallocate these stations to strata 3 and 5. But considering the small gains likely to be made, it is probably just as reasonable to allocate a few stations to these strata to gain some idea of scallop abundance in these areas. Similarly, although estimates of abundance from within strata 3 and 5 correlated with the total yield from the fishery, there would probably be little point in allocating all of the samples to just one of these strata and attempting to use a slightly more precise estimate from a considerably smaller area of the bay to assess the fishery. Apart from any statistical considerations, the industry feels comfortable with a sampling scheme in which all fishable areas of the bay are sampled. It would seem unwise to reallocate samples, and risk losing industry confidence, when the statistical gains would be slight.

A reallocation of stratum boundaries might also be considered as a means of improving precision. Stratum boundaries were initially drawn up with respect to the known distribution and the abundance of scallops in the bay, and these do not seem to have changed much over the years. Nevertheless, there is one aspect in which the stratum boundaries do need to be treated with some caution. Relatively few scallops are found in the central portion of the bay. This area is represented by stratum 2 and its boundary is the 20 m deep contour. It does seem to be the case that if stations in stratum 2 are very close to the boundaries of strata 3 and 5 they are likely to have particularly high numbers of scallops, presumably because the distribution of scallops is not precisely governed by the 20 m deep contour. Because stratum 2 has a large area and only a few stations, one or two stations with high number of scallops can lead to a very high estimate of the scallop abundance (calculated as the mean number of scallops per square metre sampled multiplied by the total area of the stratum). There is, therefore, a case for redefining stratum 2 so that the areas immediately adjacent to strata 3 and 5 are included in those strata, or for ensuring that none of the stations allocated to stratum 2 lie close to the boundaries with strata 3 and 5. In practice, the latter solution has been followed on the assumption that it is better to make conservative estimates rather than to give overly optimistic estimates of abundance.

The success of the fishery depends on scallop growth, size and condition as well as on the number of scallops in the bay. During January and February, when the dive survey is conducted, the majority of scallops are too small and in too poor a condition to be fished. Growth continues and condition improves as the weather becomes cooler. The fishery is a roe-on fishery and scallop condition is at its peak within the period July–October when the gonad is most fully developed. Large inter-annual variations occur in growth rate and in scallop condition, and these are reflected in annual variations in weight per crate (Fig. 2). These variations also influence the way the fishery operates and may help to explain some of the discrepancies encountered in correlating abundance estimates with statistics from the fishery.

In 1985 the yield from the fishery was exceptionally high in relation to the estimate of the abundance. The exceptional yield from the fishery in 1985 resulted from a combination of factors. The estimated number of scallops available to the fishery (321 million) was relatively high; the hours spent fishing were the second highest on record; the number of crates of scallops collected was the highest on record; and the condition of scallops, measured as meat weight per crate, was relatively high throughout the fishing season. The relatively good condition shown by scallops throughout the season may have resulted in lower than usual mortality, which would also contribute towards the higher than expected yield in 1985.

Data for 1982 show that the number of dredge hauls required to fill a crate of scallops was high in relation to the abundance estimate. During that year the condition of scallops remained poor throughout the fishing season. Probably dredge hauls were well sorted and only the larger and heavier scallops were kept in order to maximise the weight per crate. Because of the relatively high level of sorting and discarding, the number of hauls to fill a crate was higher than that which might otherwise be expected based solely on numbers.

The estimated number of scallops in 1995 was higher than that in 1984, 1985 and 1987, yet the total yield from the fishery was smaller than that in any of these years. During 1995 scallops throughout large areas of the bay remained small and in poor condition and these areas remained closed to the fishery. The survey estimate for 1995 did not therefore truly reflect the abundance of scallops actually available to the fishery during the fishing season.

Social and economic considerations also play some part in the management of the fishery. The ways in which such considerations influence management of the fishery have not been studied in any detail, but two examples show how yield from the fishery may be affected by the decisions made on a socio-economic basis.

Since the value of the catch is dependent upon weight, it makes sense to concentrate fishing in those periods when the scallop condition is at its peak. This is achieved by setting higher catch limits during months of peak condition than that at the start and the end of the season when the condition is poorer. Logically fishing could be confined solely to the period of high condition and there has been a tendency in more recent years to start the fishery later. However, in some years factors such as the need for scallop fishers to have a cash flow from the fishery early in the season have been a consideration. The season has opened early to accommodate this need even though a later opening may have resulted in a higher yield, and a higher value overall, to the fishers.

The final outcome of the fishery each year may also be influenced by the number of boats fishing. Eighty four boats are licensed to fish the bay and catch limits are set on the assumption that all will do so. However, many fishers have licences for other fisheries. They may not take scallops from the bay if they can obtain a better income from some other fishery, and will use the results of the dive survey, plus subsequent monitoring, in assessing the scallop fishery in relation to other fisheries in which they are involved. If fewer than 84 boats fish the bay the potential yield from the fishery may be reduced. Fewer boats may lead to an increase in the length of the season. This may have little effect on the total number of scallops collected; but a few extra weeks fishing at the end of the season, when the scallop condition is reduced, may still result in a lower tonnage of scallops than if all the boats are fishing when the condition is at its peak. Increasing the catch limit if fewer than 84 boats are fishing is not an option for increasing yield. An increase may alter the profitability of the bay scallop fishery in relation to other fisheries and so lead to more boats taking part in the fishery, thus requiring a subsequent decrease in the limit.

While the dive survey has been carried out since 1982 and has, subjectively, been considered useful by both managers and industry, it has not previously been objectively investigated. The present statistical analysis has shown that significant correlations exist between estimates of scallop abundance and yield from the fishery and has emphasised the usefulness of the survey as a management tool. Although regressions relating scallop abundance to various aspects of the fishery have little predictive power, the recognition that this is so has led to the consideration of factors other than scallop abundance that may be influencing the outcome of the fishery. These factors are of two kinds, environmental and socio-economic. Data of both kinds are currently inadequate for modelling purposes, but could be collected and used to construct models with greater predictive power than those based only on scallop abundance. Finally, the study has demonstrated the feasibility of dive surveys. Although estimates of scallop abundance have been previously obtained by diving, Orensanz et al. (1991) considered that diving is useful only on a small-scale experimental basis and is not practicable for estimating the size of whole populations, fishing grounds or stocks. Experience in Port Phillip Bay shows that where scallops occur in relatively shallow water whole stocks can be surveyed and estimates of abundance obtained by diving can provide a useful tool in managing and in indicating the success of the fishery.

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References

Coleman, N., Walker, T.I., Peters, B., 1996. Scallop 1995, Victorian Fisheries Assessment Report. Compiled by Scallop Stock Assessment Group. Victorian Fisheries Research Institute, Queenscliff, Vic. 3225, Australia.

Fairbridge, W.S., 1953. A population study of the Tasmanian "commercial" scallop, *Notovola meridionalis* (Tate) (Lamellibranchiata, Pectinidae). Aust. J. Mar. Freshwater Res. 4, 1–41.

Gwyther, D., Cropp, D.A., Joll, L.M., Dredge, M., 1991. Australia. In: Shumway, S.E. (Ed.), Scallops: Biology, Ecology and Aquaculture, Elsevier, Amsterdam, pp. 835–851.

Gwyther, D., McShane, P.E., 1985. Port Phillip Bay scallop population assessment and catch forecast for the 1985 season. Mar. Sci. Lab. Tech. Rep. 40, Department of Conservation, Forests and Lands, Vic., Australia.

Gwyther, D., McShane, P.E., 1988. 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. Fish. Res. 6, 347–361.

Hughes, W.D., 1973. Operational tests of Victorian scallop boats. Aust. Fish. 32(5), 14–16.

McLoughlin, R.J., Young, P.C., Martin, R.B., Parslow, W., 1991. The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. Fish. Res. 11, 1–24.

McShane, P.E., 1982. A comparison of dredge and dive surveys of scallop populations in Port Phillip Bay, Victoria. Mar. Sci. Lab. Tech. Rep. 10, Department of Conservation, Forests and Lands, Vic., Australia.

McShane, P.E., O'Connor, M.S., 1982. A dredge tow estimate of scallop distribution, abundance and size composition in Port Phillip Bay, Victoria, January 1982. Mar. Sci. Lab. Tech. Rep. 9, Department of Conservation, Forests and Lands, Vic., Australia.

Orensanz, J.M., Parma, A.A., Iribarne, O.O., 1991. Population dynamics and management of natural stocks. In: Shumway, S.E. (Ed.), Scallops: Biology, Ecology and Aquaculture, Elsevier, Amsterdam, pp. 625–713.

Prairie, Y.T., 1996. Evaluating the predictive power of regression models. Can. J. Fish. Aquat. Sci. 53, 490–492.

Sause, B.L., Gwyther, D., Burgess, D., 1987a. Larval settlement, juvenile growth and the potential use of spatfall indices to predict recruitment of the scallop *Pecten alba* Tate in Port Phillip Bay, Victoria, Australia. Fish. Res. 6, 81–92.

Sause, B.L., Gwyther, D., Hanna, P.J., O'Connor, N., 1987b. Evidence for winter–spring spawning of the scallop *Pecten alba* Tate in Port Phillip Bay, Victoria. Aust. J. Mar. Freshwater Res. 38, 329–337.

Vézina, A.F., 1988. Sampling variance and the design of quantitative surveys of the marine benthos. Mar. Biol. 97, 151–155.

Young, P.C., Martin, R.B., 1989. The scallop fisheries of Australia and their management. Rev. Aquat. Sci. 1(4), 615–638.