FINAL REPORT - FIRTA PROJECT 82/37

TITLE:

Investigation of growth, feeding and mortality of Victorian abalone.

INVESTIGATORS:

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OVERVIEW OF OBJECTIVES AND RESULTS:

The major focus of this project has been to measure the growth, mortality and recruitment of *Haliotis rubra* on reefs in Port Philip Bay, so as to determine the factors controlling abalone production. Preliminary laboratory work on growth on various algal foods has also been done. The work was concentrated at two reefs: Point Cook, which is highly productive, and Table Rock Point, where production is low. The results on growth rates have been presented at the February 1986 AMSA conference, and the first section of this report is to be submitted to Australian Fisheries. Another section of the work was presented by A. Leorke to the 1985 Australian Society for Fish Biology conference, and will also be submitted to Australian Fisheries. Further papers for scientific periodicals are in preparation.

Growth was measured in two ways: by individually marking animals, and by following cohorts of animals over time. Growth was much faster in spring and summer than in autumn or winter, and was more rapid at Point Cook than at Table Rock Point. Juveniles especially vary greatly in how fast they grow, but this is not due to inherent differences between individuals. We estimate it takes six years for *Haliotis rubra* to reach harvestable size on these reefs.

Large scale recruitment of juveniles appears to have occured only in two years between 1981 and 1986 at one of three sites in Port Phillip Bay. Only very small numbers of juveniles were found in other years and other sites. However, because of variable growth rates these irregular bursts of larval recruitment may each sustain harvests over several years.

Mortality of 20 - 60mm juveniles was estimated as about 50% per year, using cohort analysis, while the mortality of abalone over 40mm long was estimated as 67% per year using a mark recapture method. Such high mortality rates, and the slow growth to harvestable size, indicate that only a small percentage of the juveniles which settle will reach harvestable size. Small changes in mortality rates would alter the yield of abalone from a reef dramatically

The irregular recruitment, slow and variable growth and high mortality observed may all be the result of the fact that *Haliotis rubra* depends on a supply of drifting algae as food, which will fluctuate greatly over time and space. Our laboratory experiments suggest that certain red algae are the best food for growth. As these are most abundant in spring and summer, and food supply varies between places on the reef, variations in feeding may well explain the variability in growth rates of individual animals, and the differences between seasons and sites. Overseas work on other abalone species suggests that food supplies may also affect reproduction and therefore presumably recruitment. Prince (personal communication) has some evidence that recruitment depends on local reproductive stocks. It seems possible that assessments of food supply on reefs would allow predictions of the production from those reefs, and it may be possible to manipulate food and thus production on some reefs.

GROWTH OF MARKED ABALONE:

Abalone were marked at the study site, either by painting numbers on their shells using tinted epoxy, or using 5mm long numbered tags glued to the shell. We have found that collection and marking induces *Haliotis rubra* to migrate immediately after release, which might lead to higher mortality or lower growth. Beinssen and Powell (1979) also suggested tagged animals may migrate immediately after marking. To avoid this problem and to check for any short term tagging mortality or tag loss, abalone were placed on rocks in cages after tagging. A few days later the rocks were moved to the return site with the abalone attached. Subsequently abalone were measured without removing them from the substratum, to minimise disturbance. We are therefore confident that the growth rates measured represent natural growth rates. Measurement error was estimated by measuring a number of animals twice on the same day at various times. The average measurement error was 0.5mm, and analyses showed that these errors did not depend on the size of the animal, on whether both measurements were made by the same or by different divers, or on who measured the animals.

Initially about 600 *H. rubra* between 20mm and 120mm were tagged at each site. Tagged animals were remeasured and further animals tagged at approximately three month intervals, so as to investigate seasonal changes in growth. Diving schedules had to be worked around the weather, as both sites are exposed to swells and bad visibility after strong winds.

Walford plots for the data for each season and site fitted von Bertalanffy growth, but the data were very variable, especially for the smaller abalone. Significant differences in the growth parameter (K) were found between seasons, with growth fastest in spring and summer (September to March); and between sites in the same season, with growth faster at Point Cook than at Table Rock Point. A number of small juveniles (5-14mm) were marked *in situ* at Point Cook with tinted dots of epoxy in early 1984 after a large scale recruitment in September 1983, and measured every 2-3 weeks. The data were in close agreement with the Walford plot for summer growth of larger tagged animals.

The estimates of maximum length (L_∞) also varied between seasons, which indicates that the seasonal growth model developed by Shepherd and Hearn (1983) is not applicable. Shepherd and Hearn also noted that their data did not strictly fit the model. A model which allows for seasonal changes in both rates of growth and the size at which growth stops was applied, and gave a good fit to the data. The average constants K and L_∞ were estimated as 0.33 , and 115.8 at Point Cook, and 0.29 and 118.0 at Table Rock Point. These results are similar to the growth rates reported elsewhere, for example by Shepherd and Hearn (1983) in South Australia, although maximum sizes are lower. Growth to harvestable size would take about six years at both sites.

Sainbury (1980) has shown that growth increment data may produce biased estimates of the growth constants if individual abalone grow at different rates. To determine whether the large variations in growth we observed were a result of differences between individuals, the data for individuals measured over several seasons was examined. The residuals from the seasonal Walford plots were analysed using a repeated measures ANOVA. There were no consistent differences in growth between individuals; each individual varies in growth over time as much as different animals vary. This suggest that local environmental factors such as food control growth rates.

GROWTH OF COHORTS:

A series of 20 permanent $4m^2$ quadrats, randomly placed at the study sites, was established in June 1983. These were searched at approximately three month intervals until October 1985. All abalone within these quadrats were measured *in situ*, and the overturned boulders were replaced to minimise disturbance. Very few rocks in these areas could not be overturned, and we are confident that animals over 15mm were found consistently and efficiently. The numbers of abalone in each size range varied markedly between quadrats, presumably as a result of differences in the sizes of rocks.

After a large scale settlement at Point Cook in late September 1983, $0.25m^2$ quadrats were searched for abalone <40mm long, at approximately one month intervals, to follow the growth of the September cohort and of juveniles which appeared in January and February 1984. Each survey comprised twenty randomly placed quadrats in an area of small rocks encrusted with crustose corralines, as all tiny juveniles (<7mm) were found on corralines. These surveys were made underwater by an experienced diver (A. Leorke). The anaesthetic technique described by Prince and Ford (1985) coould not be used as it involves very extensive disturbance to the substratum, and requires a boat overhead, which was impractical at our sites.

Size frequency histograms were constructed and analysed using normal probability plots, to determine the mean size of cohorts at each sampling date. The mean sizes of the cohorts measured in both series of quadrat surveys are shown in Figure 2 of the first section of this report, with 2 SD error bars to show the range of sizes in each cohort. The growth of these cohorts is consistent with the results obtained from marked abalone.

RECRUITMENT:

The size frequency distributions used to measure growth can be used to estimate the relative strength of recruitment in each year at the two sites. Large numbers of new recruits were seen only at Point Cook, after settlements in September 1983 and January 1984. A cohort of larger juveniles at Point Cook in 1983 is estimated, on the basis of growth data, to have settled in late 1981. However small numbers of <20mm juveniles were found at the end of summer in other years (1982/3,1984/5) at Point Cook, and from 1980-1985 at Table Rock Point. Casual observations of Kirks Point, another site on the west side of Port Phillip Bay, suggest that no major recruitment occured there between 1981 and 1985.

Large scale recruitment therefore appears to be very irregular in Port Phillip Bay. We have evidence of only two major years of recruitment at Point Cook, and none at two other sites between 1981 and 1986. "Trickle" recruitment occurs at other times and places.

Our study and other studies from Tasmania and South Australia have found settlement appears to occur mainly in spring or summer. Therefore surveys of the numbers of small recruits in March or April each year, perhaps using Prince and Ford's (1985) technique, could be used to determine which reefs receive large scale recruitment each year. However, because growth rates are very variable, the individuals in each burst of settlement may reach harvestable size over several years. If growth and mortality vary much between years then estimates of juvenile recruitment may not be sufficient to predict how stocks will fluctuate.

MORTALITY:

Mortality rates were estimated at Point Cook both by following cohorts over time, and using the mark-recapture technique described by Beinssen and Powell (1979). Using the number of animals in a cohort to estimate mortality places more stringent demands on the data than estimates of mean size. As we cannot be sure that juveniles less than 15mm long were sampled with equal efficiency to those >15mm, our mortality estimates are restricted to cohorts with a mean size >20mm.

Each of the 1981 and 1983 cohorts were followed over more than one year, from initial average sizes of 36mm and 22mm respectively. Mortality rates were estimated as 57% and 50% per year. The mark recapture method was used to estimate the mortality of abalone between 40 and 110mm long in 1984-1985. The method assumes no overall directional movement of animals, and the data support this. Mortality was estimated as 67% per year, but this is based onpreliminary calculations with fairly small numbers, and we cannot be sure that some of the larger animals did not fall prey to poachers, as abalone divers were seen in the reserve area. Our estimate contrasts with the 32% mortality estimate of Beinssen and Powell (1979) for *H. rubra* at Tullabugera in eastern Victoria. Tag losses and the smaller animals we marked can account for only a small part of the difference. It appears that mortality may vary markedly between sites, and this in turn suggests local environmental factors are important

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What determines the catch of abalone from a reef?

Fisheries managers need to estimate the available stocks of fish so that they can calculate how many can be caught without reducing the future yield of the fishery. For most fish, they calculate stocks by measuring how successful the fishermen are. The argument is, very roughly, that if fishermen haul their nets, over, say, 100 kilometers of seabed and catch 100 tons of fish, then there is one ton per kilometer in the fish grounds. If the number of fish go down then the boats will catch fewer fish per kilometer of haul. The argument works well if the fish swim constantly, spreading out over the fishing grounds, so that as fish are caught the stocks thin out, and always cover the same area. (There are also problems if the efficiency of the fishermen changes.)

Unfortunately this simple method does not work for the abalone fishery. When abalone divers fish a reef the abalone on other reefs do not rapidly spread out to fill in the gaps. Each reef, and often each part of a reef, seems to go its own way. Experienced abalone divers say they can assess whether an area has been recently fished very quickly, so they do not waste their effort on areas with few animals - they spend their time fishing the patches where abalone are plentiful. Divers have also told us they can estimate how soon to go back to an area once it has been fished: some areas recover fast, others more slowly. All this means that the time and effort the divers put in, and the amount of fish they catch, do not indicate the size of the abalone stocks. A new approach is needed. The University of Melbourne project described here was set up, with funding from the Fishing Industry Research Committee, to study those factors that influence the production of abalone on reefs. If the production of abalone stocks can be predicted, then the fishery could be managed to maintain the levels of production.

The number of abalone sitting on a reef ready to be fished depends on four things: how many abalone larvae arrive on the reef each year and start to grow, how fast they grow up, what percentage die while growing, and how many of those that have reached legal size have already been taken. We have tried to measure the first three, which determine production, on two reefs in Port Phillip Bay. The first, Point Cook, is a reef that the fishermen regard as good, and Table Rock Point appears to be a poor reef. Both reefs allow a diver to find most, if not all the abalone in an area, by turning over all the boulders. This is important to us if we are to get accurate measurements of the member and sizes of abalone present.

Although the abalone larvae cannot be counted as they arrive on the reef, they can be found once they reach a size of about 2 mm long by carefully searching. These tiny animals live on the pink crusts of coralline one finds on the boulders. Their pink shells are hard to see against this background, which may protect them from the many predators which could eat them. Small numbers of larvae apparently arrive at various times of the year, but only two large scale invasions have been observed: in September 1983 and in January-February 1984 at Point Cook. We have some evidence that another large settlement occurred at Point Cook near the end of 1981, but Table Rock Point, and Kirks Point, another reef on the west side of the bay, apparently have had no major settlements between 1981 and 1986. We can conclude that production on some reefs is probably low because not enough larvae arrive. However when they do arrive, larvae may settle in very high numbers. More than 25 tiny juveniles per square meter have been observed at Point Cook.

Growth

When a large number of larvae settle and start growing at the same time, many of them match each other in size as they grow up, so when all the abalone in an area are measured, and the number of abalone of each size are counted, one can see how large the animals which settled together have grown. An example is shown in Figure 1. The number of animals of each size is plotted on the vertical axis, and the length of the shells on the horizontal. The figure shows the sizes of small blacklip abalone at Point Cook in February 1984. The peak is roughly at the average size the abalone which settled in September 1983 have grown to. One can also see a few new arrivals, 4-6 mm long. By measuring animals and constructing these diagrams at intervals, one can see how fast they grow. The growth of the abalone which settled at Point Cook can be seen in Figure 2.

Another way to measure growth is to mark abalone and then measure them at intervals to see how much they have grown. Of course not all abalone grow at the same rate, so many animals have been marked and the average growth calculated. Like most animals, the abalone grew more slowly as they became larger. Our study has also shown that growth rates were different on the two reefs, and growth was faster in spring and summer than in autumn and winter. These facts suggest that growth depends on factors which vary between seasons and between reefs. We suspect that the most important factor may be the supply of drifting seaweed which they eat. Our results show that growth rates are very variable. Each abalone grows at very different rates at different times, and at any one time some animals grow rapidly while others slow down. Because growth is variable the abalone which settle together will not all reach the legal size (100 mm in Port Phillip Bay) at the same time. The average time for the sites measured is about six years, but some will have grown faster and some much slower, so that the 1983/84 larvae at Point Cook may affect the harvest from the reef over several years. Irregular bursts of settling larvae could possibly sustain a fairly constant harvest.

Mortality

Most animals seem to be most in danger of being eaten by predators when they are small. Thus animals which grow fast are much less likely to die, which is another reason to measure growth rates. Measurements of how many abalone are lost to predators, such as the crabs, stingrays, and starfish we have seen eating them, must also take into account the size of the abalone. There are two basic methods to measure death rates. One is to identify animals of the same age and count them in a fixed area at different times. The second method is to mark abalone and see how many marked animals you have left after some time. Both methods were used in this study.

Using bar charts like Figure 1, animals of the same age can be counted as long as they all stay roughly the same size (that is, they form an identifiable cohort). One simply counts the animals 'under the hump' (between 8 and 26 mm in Figure 1). If one measures all the abalone in a fixed area at three month intervals, for example, you can see whether the numbers in a cohort decrease over time as some animals die. In our study, abalone were measured in about twenty fixed areas on the reef over about two years.

Unfortunately there are some problems with the method. The most important is that it is much easier to find large animals than tiny ones, so that as the small abalone grow larger you find more of them. We are confident that nearly all the abalone over 15 mm long were fund in our surveys, but this means we can only measure the mortality of animals once they reach an average length of about 20 mm (at about 9 months old). Another problem is that animals of the same age vary more in size as they grow larger. As a result the cohort spreads out, and eventually cannot be recognised. As a result we could not use this method for abalone over about 70 mm long.

The method has other problems too, but we have estimated the mortality of two cohorts, one in 83/84 and one in 84/85 over about one year each. In both cases there was about 50% mortality per year. This is a very high mortality rate for juveniles of this size. If it takes six years to reach legal size, and half die each year, then only 16% of the larvae which settle will survive to support the fishery. One would expect however, that mortality would be higher for smaller animals, and lower for larger animals. Our results also suggest that mortality might vary at different times of year.

The second method to measure mortality is best for large animals which can be marked easily. Because marked animals gradually disperse out of the area in which you mark them and search for them, some way of adjusting for the animals which move away is needed. An ingenious method to do this was developed by Beinssen in the Victorian Division of Fisheries and

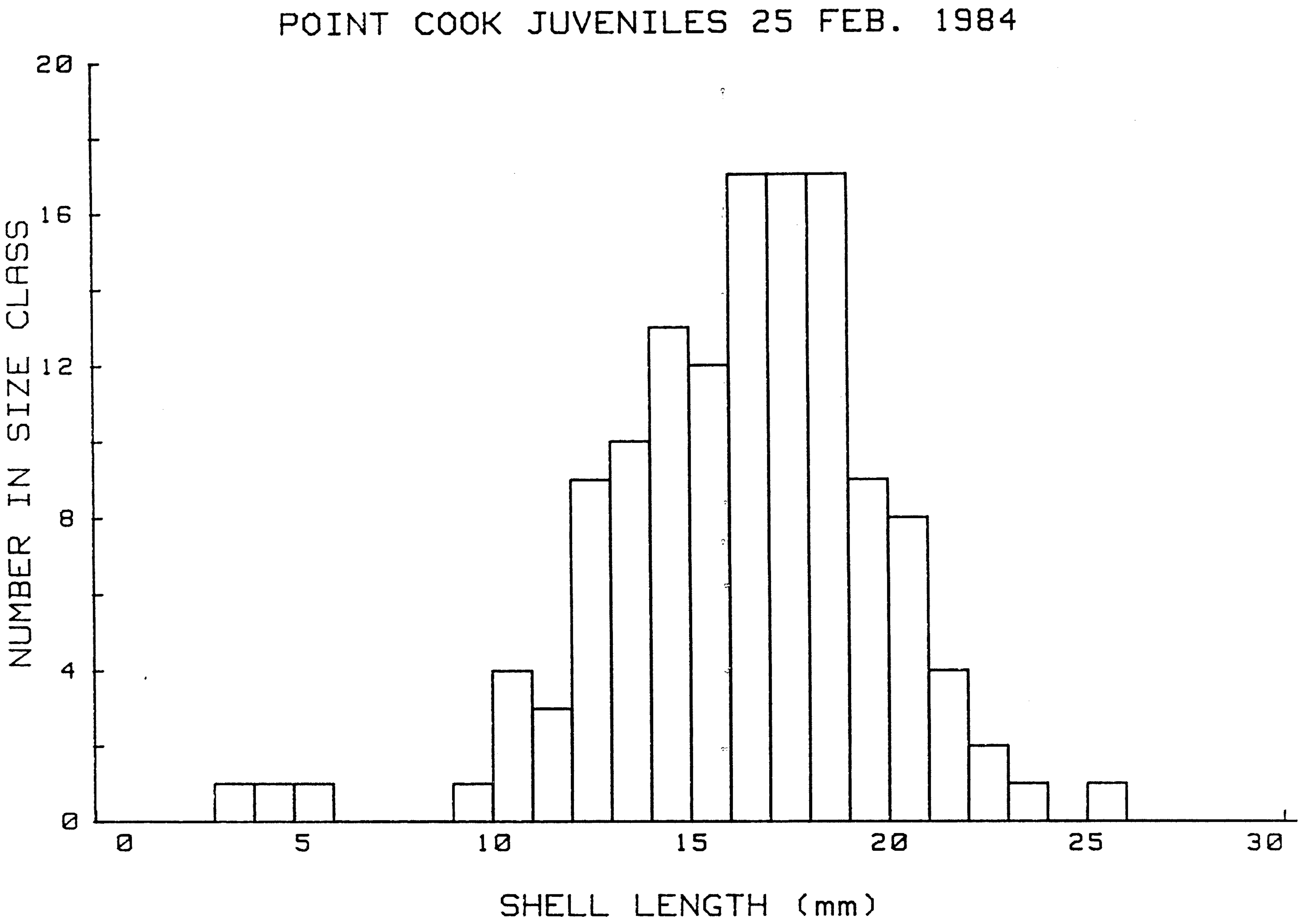
Wildlife. A grid is laid out over the search area of the reef, and the positions of animals are recorded. Movements within the grid are then used to adjust the number recaptured for those which would have moved out of the search area. Over one year, our preliminary estimate of mortality for blacklip abalone over 40 mm long is 67%, but this is based on small numbers of marked animals, and unfortunately we cannot be sure that our larger marked animals have not been taken by poachers.

Back to the question

We can now reassess the question of what determines the catch of abalone from a reef, and take it one step further. Our results show that in Port Phillip Bay the catch depends on very irregular bursts of settling larvae, on rather slow and very variable growth, and on a very high mortality rate. The fact that Point Cook is a productive reef would appear to be because very large numbers of larvae occasionally settle, and sustain the fishery over several years. Growth at Point Cook is faster than at Table Rock Point, and this will be important because a higher proportion of fast growing animals will survive to legal size: there is, in effect, less time for them to die.

But what factors determine how many larvae settle, and how often? What determines which reefs have rapid growth rates, or low mortality? These are the factors which ultimately control the abalone harvest. This study has provided some clues. We have found that abalone grow at markedly different rates when given different foods, and the availability of good food types varies between seasons, which may well explain why growth varies between seasons. We suspect Point Cook has a better supply of food than other reefs.

As abalone larvae are ready to settle onto a reef within a short time after the eggs and sperm are released by their parents, the number of larvae which settle on a reef may depend on how many abalone on that reef and nearby reefs reproduce Work by Scoresby Shepherd in South Australia, and Jeremy Prince in Tasmania supports this idea. We suspect food supplies may be important for reproduction and thus the number of larvae which settle. However, many other factors may also be important. Further work on the reproduction of abalone is needed to find out if it is linked to food supplies; and some means of assessing the supply of good abalone food on a reef is needed, to see if production can be predicted from food supplies.


POINT COOK JUVENILES 25 FEB. 1984
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12
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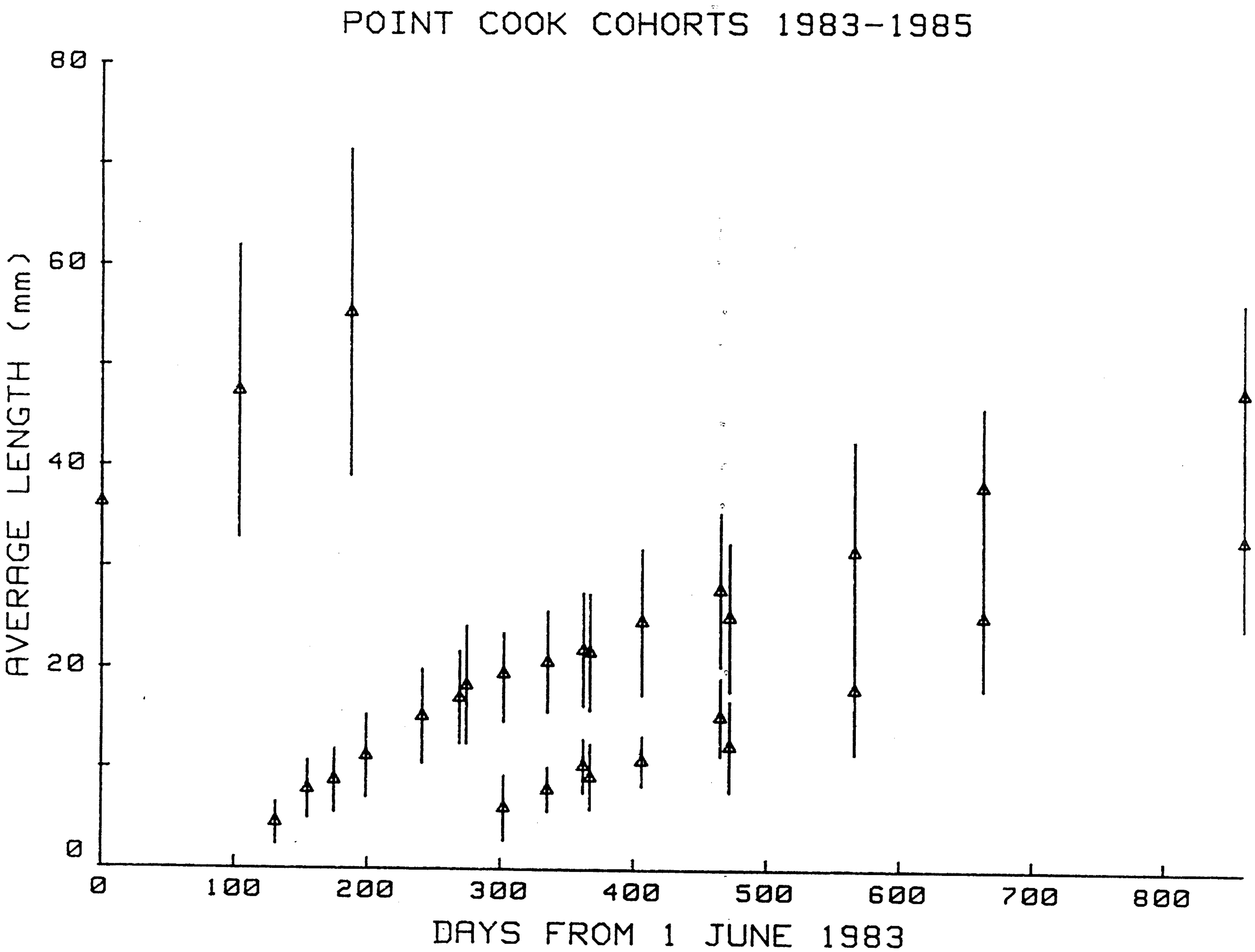
20
0
5
10
15
20
25
30
SHELL LENGTH (mm)


POINT COOK COHORTS 1983-1985
AVERAGE LENGTH (mm)
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60
40
20
0
0
100
200
300
400
500
600
700
800
DAYS FROM 1 JUNE 1983

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Growth rates of blacklip abalone (*Haliotis ruber*) in Port Phillip Bay.

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Growth rates of animals from 20-100 mm long have been measured using two methods of tagging individuals. Marked individuals are allowed to recover in cages before return as experiments have shown that animals respond to the stress of marking. They were subsequently measured *in situ* at three month intervals. To measure the growth of small juveniles individuals from 5-14 mm were labelled *in situ* and measured every 2-3 weeks, and growth of 2-15 mm juveniles was estimated from size frequency data. The methods were consistent with each other and with a von Bertalanffy model. There were significant seasonal differences with the lowest growth rates in winter and the highest in spring. Growth also varies significantly between sites and between years in the same season, so that short term studies will not give reliable results. Sainsbury (1980) argued that if individuals grow at different rates then growth increment data may produce biased estimates. Juveniles vary greatly in growth, but a repeated measures ANOVA shows that individuals do not differ consistently in growth. This points to environmental factors such as food determining growth rate.

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THE DISTRIBUTION OF BLACKLIP ABALONE, *HALIOTIS RUBER*, ON REEFS AND HOW THIS AFFECTS ESTIMATES OF THEIR ABUNDANCE

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It is generally believed that blacklip abalone, *Haliotis ruber*, move from cryptic to open habitats as they increase in size, hence the abundance of large animals living in open habitats is an accurate estimate of their total abundance. Quadrat sampling on two different types of reef indicates that while large abalone are more abundant in open habitats than small individuals, all sizes occur in cryptic habitats. The distribution of abalone within cryptic habitat was examined in relation to the size of boulders. Large abalone were more abundant under large boulders than small ones. Furthermore, large individuals were dispersed over the entire undersides of large rocks while small abalone were found mostly near the rock centre. Consequently, the abundance of blacklip abalone of all sizes would be grossly underestimated if only those animals found in open habitats or in cryptic habitats which are easily sampled, are measured.