Abalone Population Dynamics Studies and Reef Area Estimation (1978/43)

Objectives:

(i) To determine the total reef area covered by abalone fishermen in a year, and to monitor changes in this total reef area over three years.

(ii) To investigate abalone growth, stock density, reproductive periodicity, recruitment, competition, movement and natural mortality on three reefs over a three year period.

Organisation

NSW State Fisheries

Supervisor:

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Grants:

1978/79	1979/80	1980/81	1981/82	Total
$13,700	$13,500	$17,091	$10,565	$54,856

FISHING INDUSTRY RESEARCH TRUST ACCOUNT
FINAL REPORT

1. **Title of proposal:** Abalone Population Dynamics and Reef Area Estimation.

2. **Name of applicant:** New South Wales State Fisheries.

3. **Division:** Scientific Division.

4. **Proposal:** The project aims at monitoring the changes in total reef area fished by abalone divers and determining the population dynamics of abalone on several unfished reefs.

5. **Persons responsible for programme:**

   Dr.D.D.Francois, Ph.D., Director of Fisheries.
   Dr.W.B.Malcolm, Ph.D., Chief, Scientific Division.

6. **Staff employed on programme:**

   Mr.G.D.Hamer, B.Sc., Abalone Biologist
   Mr.T.H.Butcher, B.Sc., Technical Officer

7. **Location of operations:**

   Field work : Eden, Sydney, Port Stephens.
   Office and Laboratory Fisheries House,211 Kent St.,Sydney.

8. **Work schedule:**

   Commencement date : 1st February 1979
   Completion date 31st January 1982.

9. **Funds requested:** Nil.

10. **Funds provided by applicant:** Biologist's salary, office and laboratory resources, data analysis costs, publication costs.

11. **Variation in expenditure:** Nil.

12. **Final report.**

INTRODUCTION

Most Australian abalone fisheries are fully exploited and a comparison of the total catch of blacklip abalone, *Haliotis ruber*, in the three south-eastern states indicates a decline in population size from south to north. The catch distribution from New South Wales parallels that trend. This decline could be due to a decrease in available reef area, lower densities per unit area of reef, or both.

In the absence of fishing there are four determinants of the biomass of a population; recruitment of new individuals, growth and mortality of existing individuals, and area occupied by the stock. Since population sizes differ from south to north, one or more of these factors must be responsible, ie lower recruitment, lower growth rates, higher mortality or fewer productive reefs.

In addition to determining the basic population parameters, the basic aim of this research programme was to determine which factor or combination of factors contributed to the apparent declining trend in total population. The same factors would also play some part in New South Wales being the northern limit of the distribution of *H. ruber.* Another aim was to investigate, at least qualitatively, the association (if any) between sea urchins and abalone.

METHODS

The programme comprised two major segments - reef area estimation and population dynamics.

REEF AREA ESTIMATION

Large scale (1:10,000) aerial photographs of the whole New South Wales coast were purchased and commercial abalone divers were asked to draw on clear overlays the areas of reef from which they collected abalone during the previous twelve months.

They were asked to rate the areas A,B or C as follows:

A reef they visited more than once in the year;

B - reef that contained commercial densities but was only visited once during the year

C - reef that was found not to have abalone in commercial quantities.

To avoid difficulties of scale exaggeration, details were recorded of the offshore limit of each reef, either to a depth limit or in numbers or fractions of "hoselengths" from shore (one hoselength = 100m).

The reef area so drawn was calculated by measuring the shoreline and multiplying this distance by the average distance from shore or if the reef was large, by counting the number of $2500m^2$ or $10000m^2$ squares contained within the estimated boundaries of the productive reef area using specially prepared graph paper.

The State is divided into 24 areas for logbook statistics purposes and the total reef area for each of these was calculated, with a variance where this was meaningful. These reef area figures were combined with catch values for each area to give a productivity estimate.

POPULATION DYNAMICS

The aspects of population dynamics studied were movement, density, mortality, growth, recruitment, reproductive periodicity and competition with sea urchins.

Experimental grids were pegged out on the ocean floor with rock bolts and nylon cord and much of the information came from mark-recapture experiments. Small plastic tags were glued to the exterior of the shell with cyanoacrylate glue ("super glue") and the abalone were returned to the bottom by hand. A total of 930 abalone was double-tagged.

All recaptured abalone were scrubbed with a fish scaler to ensure tag recognition.

These experiments were conducted at Mowarry Point (Eden), Botany Bay and Long Reef (Sydney), and Broughton Island (Port Stephens),(Figure 1a). Research closures were gazetted to prevent fishing at Mowarry Point and Broughton Island. Long Reef is a marine reserve where abalone fishing is prohibited and Botany Bay is open to fishing.

Some samples were also collected at Disaster Bay, a good commercial fishing location at Eden.

Movement

Abalone were tagged and placed in two fixed 10m x 10m areas near Mowarry Point at approximately bimonthly intervals. After 12 months, intensive 24 and 17 diver-day harvests were conducted of the reef in and around 50m x 50m and 50m x 40m grids centred on the original $100m^2$ tagging grids. Figure 1c shows the location of these two grids (Mowarry 1 and 2).

Density

Absolute density of legal-sized abalone was estimated on six occasions by total census of a measured area at research sites and on two occasions at Disaster Bay.

Indirect measures of density were made by measuring the distance from a random point to the nearest five abalone (see Keuls et. al., 1963). Such estimates were made on two occasions at Mowarry and once in Disaster Bay.

On two occasions density estimates were made at Mowarry using $1m^2$ quadrats.

Density estimates were also made for the whole New South Wales coast and for the Mowarry research closure using reef area information and a standing stock estimate calculated from the commercial catch.

Mortality

The experimental design outlined above or a slight modification of it was used to collect information on natural mortality. The method is similar to that described by Beinssen and Powell (1979).

If all members of each group of tagged abalone were not found during the final census, then one or more of the following must have occurred:

a) there was some tag loss (post-release and time variable);

b) there was tagging mortality;

c) there was migration out of the census area (post-release and time variable);

d) there was natural mortality;

e) there was fishing mortality;

f) the census was less than 100% efficient.

It was assumed that there was no fishing mortality since the experiments were conducted in areas closed for research, or were conducted on juveniles not subject to fishing.

It was further assumed that each group of tagged abalone suffered the same tagging mortality, post-release migration and post-release tag loss.

Thus a regression of the percentage of each group found at the final census on time at liberty would yield a rate of disappearance of tagged abalone from which natural mortality could be calculated when tag loss and migration rate were known.

Twelve replicates of the mortality experiment were carried out, five at Eden, three at Sydney and four at Port Stephens. Details are given in Table 1.

<u>Growth</u>

Information on abalone growth was collected from tagged and untagged abalone which were collected as part of the movement/mortality experiments. Each tagged abalone was measured to the nearest 0.5mm and untagged abalone were measured in 5mm size classes.

Growth increment data from tagged abalone was fitted by desk top computer to the von Bertalanffy growth equation using the Fabens method. Analysis of the seasonality of growth was carried out using the SPSS Regression programme. Increment was regressed on number of days at liberty during the four standard seasons.

Cohort means from the length-frequency distributions of the untagged abalone were separated by mixed frequency distribution analysis (see McDonald and Pitcher, 1979) and by eye. Growth parameters were calculated using the method of Allen (1966).

Recruitment.

Following the cohort analysis relative abundance of year classes was compared qualitatively between sites, between years and compared with commercial catch statistics for appropriate years.

Reproductive Periodicity

Gonad samples were collected as frequently as practicable, fixed in 10 percent formalin and stored in 70 per cent alcohol.

The gonadal appendages were sectioned close to the digestive coil such that two concentric circles of gonad and digestive gland were evident. The areas of these circles were determined and a gonad index was calculated as area of gonad divided by total cross sectional area (Shepherd and Laws, 1979).

Competition

Several authors have suggested possible competition between sea urchins and abalone, the suggestion being that sea urchins alter the vegetation so that the habitat is unsuitable for abalone (Shepherd,1973;Breen and Mann,1976;Kan-no,1975). This has been reported by divers for New South Wales reefs where areas inhabited by the purple sea urchin, **Centrostephanus rodgersii,** are often desert-like and commonly called "white rock". Researchers in other countries have designated such areas as "barrens".

Possible competition between sea urchins and abalone was investigated by removal experiments. Sea urchins were removed as frequently as possible from three marked grids and vegetation changes were recorded photographically. Two grids (Broughton 2 - Figure 1b and Mowarry S.U.B. Figure 1c) were sea urchin "barrens" and did not contain abalone. The other (Mowarry S.U.G. Figure 1c) was a gutter between two rock platforms where sea urchins were removed from two quadrants but not the other two. Effects on abalone densities were to be determined by direct survey after two years.

In the movement/mortality grids, all abalone were removed during harvesting and subsequent changes in sea urchin densities were assessed qualitatively.

Controls for both removal experiments were nearby sections of reef which were not touched in any way.

RESULTS

REEF AREA ESTIMATION

The results of this segment are summarized in Table 2.

Twelve divers co-operated in the programme but the estimates north of Sydney were based on mapping by a single diver. Standard deviations varied from 12% to 60% of the estimates (mean 33%).

Reefs rated A and B were combined in the estimates after it became apparent that a diver's rating of a reef depended upon whether he was the first to fish it after a spell of bad weather or whether another diver had been there first. Also, a reef that was fished often by one diver (and therefore rated highly by him) would appear marginal to another diver who only occasionally fished there and who would thus not rate it highly.

The catch and catch-per-unit-effort values are averages for the two years 1978-9 and 1979-80; these were the most recent and complete data.

There is clearly a trend for both reef area per kilometre of coast and catch per unit of reef area to increase toward the south. There is no significant trend in reef per area division because the areas are not all equal, so the trend in production shown in Figure 2 is due to greater productivity and not greater habitable reef area.

However, because there is an increase in reef per kilometre of coast, it could be that the higher total catches in Victoria and Tasmania are due to both more reef combined with higher productivity of each reef.

There is no significant trend in catch per unit of effort which indicates that divers allocate their effort so that densities are kept reasonably constant throughout the state.

POPULATION DYNAMICS

Approximately 25% of tagged abalone recaptured were unrecognisable as such until scrubbed with a fish scaler. Of 440 double-tagged abalone recaptured after one to eighteen months at liberty, 10 had lost a tag: a tag loss rate of 1.2%.

MOVEMENT

The results from the movement experiments are summarized in Figure 3. Few abalone moved more than 20m during their one to twelve months of liberty and in fact the abalone that moved the furthest were not at liberty the longest. Casual observations of post release behaviour suggest that there is a large instantaneous, post-release movement by some individuals.

The maximum recorded movement was 45m at Mowarry and this was from a depth of 5m to a depth of 10m. Similar distribution patterns were observed during the other mortality censusses.

Density

Estimates of the density of legal-sized abalone made at various locations using four methods are shown in Table 3.

The closest individual method clearly overestimated density as did the direct census method when only small areas were harvested.

The quadrat estimate of the density in a part of the Eden closure before harvest seemed too high but the accuracy of the quadrat estimate from Mowarry 3, ($3/m^2$), was confirmed by the total harvest that followed it, ($3.2/m^2$).

The density estimates for the Eden research closure and the whole coast using reef area and standing stock were almost identical.

Mortality

The results from the twelve replicates of the mortality experiment are shown in Table 1.

The regression parameters shown are for linear regressions of "percentage of each tagged group found at the final census" on "time at liberty in months". The intercept represents the difference between 100% and a value which comprises average tagging mortality, census inefficiency, and instantaneous (post-release) tag loss and emigration. The slope is in units of "percentage not found at harvest-time per month at liberty".

Values of the independent and dependent variables relating to the last tagging before census were not included in the analysis for Mowarry 1 and 2 because the animals were only at liberty for 2 nights and this was not considered long enough for tagging mortality to act fully. All subsequent harvests were conducted at least four nights after the final tagging.

A second pair was not included in the analysis for Mowarry 1 because the tagging was carried out during the Port Jackson Shark mating season and tagging mortality seemed to be much higher than normal due to predation by sharks.

Mowarry 5 was fished between the final tagging and the census so the recovery rate was very low.

Botany Bay 1 and 2 were carried out as pilot studies on juveniles in a fished area, and hence were run for only four months. Botany Bay 2 was conducted in a single horizontal crevice which was found on a night dive during harvesting to be 3m deeper than expected and hence impossible to census. The bulk of the recoveries at that site were made on four subsequent site visits.

The Long Reef site was completely surrounded by sand. Adverse weather delayed the final harvest for four months and it was discovered at the census that the heavy seas had raised the sand level by 60cm, hence the low recovery rate.

The Broughton Island 2 site was a sea urchin "barren". At each tagging the sea urchins were removed and abalone were imported from elsewhere. This site was searched more extensively than the other Broughton Island sites as a high emigration rate was expected.

Analysis of covariance indicated that the slopes of the Eden results were not significantly different but the intercepts and variances were. The same situation arose with Botany Bay 1 and Long Reef and also with Broughton Island 1,3 and 4.

An overall regression could therefore not be calculated nor could the slopes from the three areas be compared statistically. Given the correlation coefficients for individual sites, averaging the annual disappearance rates is justifiable and the result is 22.9% per year.

The tag loss rate of 1.2% was so low that a time variable rate could not be determined and 1.2% per year is assumed.

Similarly the emigration rate appears from Figure 3 to be approximately 3% overall and is assumed to be about 3% per year.

All other variables are assumed to be equal for each tagged group and the annual natural mortality rate is therefore approximately 19%. This is equivalent to an instantaneous rate of about 0.2 (see Ricker, 1975).

Reproductive Periodicity

Gonad index values for all samples collected between 1977 and 1982 are shown for Eden, Sydney and Port Stephens in Figures 4,5 and 6. Although females frequently showed a higher average index, the differences were not significant and male and female data were combined. The average gonad index was higher at Sydney and Broughton Island than at Eden.

The Eden data indicate a spawning between November and February with possible autumn and spring spawnings.

The Sydney data show a possible spawning over summer but there is no clear cyclic pattern. Spawning was observed in tanks holding live abalone for export at Botany Bay in April 1981.

The Port Stephens data also show a possible summer spawning but again the evidence is not conclusive.

Recruitment

Surveys of the mortality grids yielded population length-frequency distributions which in some cases clearly showed cohort modes. Six such distributions from Eden are shown in Figure 7 and the progression of a large cohort can be traced through the series. Figures 8 and 9 show similar distributions from Sydney and Broughton Island; again the good year class is obvious, but the series are not quite as convincing, particularly the Broughton Island data.

Figure 10 shows population samples collected from approximately equal areas with similar effort in May 1982. It seems that there were smaller spatfalls at Port Stephens than at Eden and this was probably the reason for the less consistent distributions shown in Figure 9.

In three distributions (Sydney - November 1979; Eden - May and September 1980) two large cohorts and a gap between them are obvious. If these are related to the total reported catch (Figure 11) it can be seen that the large cohort at about 100mm produced a 650 tonne catch in 1979-80, the "gap" produced a 15% lower catch in 1980-1 (550 tonnes) and the large cohort at 40-50 mm produced a 625 tonne catch in 1981-2. Total effort in these years was reasonably constant in terms of reef coverage although there was a slight decline in nominal terms (total hours).

Growth

Table 4 shows the results of the tagging data analysis. Included are some data collected prior to this study.

Figure 12 shows the size distribution on a lightly fished reef at Eden in 1974. This is reported to be similar to the distribution of sizes in the commercial catches in the 1960's, and indicates that a realistic estimate of the maximum length attained - L(inf) - is greater than 145 mm.

Thus, most of the L(inf) values shown in Table 4 are obviously underestimates of the average maximum length in an unexploited population despite the fact that reasonable fits to the data are obtained (Figures 13,14). Exceptions may be the sites where growth is slower (Mowarry, Twofold Bay). This underestimation of L(inf) and subsequent overestimation of length at lower ages is caused by bias in the data.

Accordingly, the modes evident in the population census data were used to yield alternative estimates of length at age. From Figure 7 and to a lesser extent Figures 8 and 9, it is clear that the modes are year classes and that they move from about 40mm to 100mm in two years. It also seems that the growth rates at Eden, Sydney and Broughton Island are not as different as the tagging data analysis suggests. (see also Figures 10,15).

A statistical method for isolating the components of the mixed frequency distributions (Macdonald and Pitcher,1979) failed to give reasonable results because partially recruited cohorts could not be accommodated so the modes were fitted by eye.

While there were differences between the locations of modes at different sites, these differences were very small so all samples for all sites were combined to give a composite size distribution for each month for the whole coast. These are shown in Figure 16. Normal distribution curves were fitted to each composite distribution by eye and the means were plotted as shown in Figure 17.

The spawning period appears to be summer as it is in Victoria (N. Hickman, Marine Science Laboratories, personal communication). Thus, from Figure 17, 1, 2, 3, and 4 year old abalone are approximately 35, 65, 88, and 105mm in length. Average increments for abalone tagged at about these lengths indicate that these values are reasonable. Analysis using Allen's "Vonber" method gave final growth parameters of K=0.3, L(inf) = 160 and t_0 = .28.

The seasonal growth analysis results are summarized in Table 5. In most cases growth was highly seasonal but different seasons predominated at different sites. Generally growth was fastest in spring and summer and slowest in winter. These results are in agreement with Sainsbury's (1977) assertion that generally, growth is fastest before and during the spawning season.

Competition

The 100m^2 grid from which urchins were removed at Mowarry Point was vegetated substantially in 10 months and completely in 18 months. Figure 18 shows the grid just after the urchins were cleared (a), four months later (b), and after eighteen months (c). Each photo shows a different part of the grid. Photograph "a" shows a peg marking one corner and some untouched urchins outside the grid. Photograph "b" was taken in the middle of the grid. Photograph "c" shows a view along one boundary of the grid (the long crack in the rock running from the bottom of the photo to the top). Dense weed growth inside the grid is obvious as is a barren corridor along the boundary where sea urchins have made feeding excursions part-way into the grid between dives when urchins were removed.

The gutter which contained both abalone and sea urchins was fished before harvesting so the effects of urchin removal on abalone density could not be quantified. Collection of the abalone that remained and a close inspection of the terrain indicated that the areas may not have been large enough to yield a positive result (or the experiment had not run long enough) even if interference had not taken place.

In qualitative terms however, the culled quadrants were substantially vegetated and a few large abalone had established homesites on open rock adjacent to kelp holdfasts where previously neither existed. In contrast, abalone in the unculled quadrants were only found in cryptic habitats.

At Botany Bay sea urchins were removed from a 5 metre length of an 80 metre horizontal crevice and within 1 month their homesites were occupied by abalone. There were no apparent vegetation changes.

At Broughton Island, urchins were removed from a $100m^2$ area and tagged abalone were placed in their homesites. Vegetation cover increased during the ensuing six months but not as dramatically as at Mowarry. Abalone mortalities were understandably high and urchins gradually reclaimed the area.

In the reverse situation where abalone were removed completely during harvesting and subsequent site visits, changes were assessed qualitatively. In all cases there was a notable increase in sea urchin densities and very slow recolonisation of the area by adult abalone. At the sites where early, intensive surveys were conducted, there has been no noticeable abalone spatfall in two years.

DISCUSSION

Reef Area and Production

Reefs at Eden are clearly more productive than reefs north of Newcastle and it seems from the available evidence that the major factor is lower recruitment. Since abalone larvae are planktonic, an attempt was made to assess the strength, direction and periodicity of surface currents near the coast but sufficient information is not available for such an assessment, nor is it likely to be so in the near future. Also abalone have been impossible to find shortly after settlement, although some successful attempts to monitor juveniles less than 5mm in length have apparently been made in South Australia.

There appears to be a higher incidence of shell boring and encrusting organisms in the north, and high early juvenile mortality from this and predation may be a major cause of the lack of abalone. However, there is no real indication whether spatfall is negligible or whether spatfall is uniform and high juvenile mortality is the major factor.

Whichever is the case, because recruitment is the limiting factor in fishery dynamics terms, and growth is slightly faster and mortality may be slightly lower, if abalone culture is ever to be a feasible economic proposition, it is more likely to be so on the north coast than on the south coast.

Conclusions in relation to latitudinal variation of productivity however, are complicated by the amateur catch and poached abalone (unreported commercial landings). A recent omnibus survey indicated that about 33,000 people take abalone on an amateur basis each year in New South Wales. Information is not available on the area distribution or size of this catch but it could well be in excess of the commercial catch and is almost certainly not spread evenly over the whole coast. Similarly, poached abalone appear to be taken mainly from the central coast, not the Eden area.

Thus total landings are probably higher on the central coast than shown but the trend of increasing productivity in the south is probably only reduced in magnitude and not invalidated altogether. Obviously more information is needed, particularly about amateur catches.

In the original proposal for this study, monitoring changes in the reef area fished over a three year period was to be attempted. This proved logistically impossible and divers interviewed doubted that changes occurred quickly enough to be detected by this method within that time scale. Anecdotal evidence from older divers however, indicated that productive reef has been lost following heavy fishing.

Mortality.

It appears that natural mortality is higher in the south but this hypothesis could not be tested statistically. Mowarry Point is only a fair growth site and if scarcity of food causes a poor physical condition in abalone and thus greater vulnerability to the causes of mortality, then one might expect slightly higher mortality. No firm conclusions can be drawn, however, because experiments were not conducted at a "good" growth site at Eden.

It is noteworthy that mortality rates consistent with those from other replicates were obtained at Mowarry 5 and Long Reef despite disturbing influences. This confirms Beinssen and Powell's assertion that this experimental design is robust.

Growth.

The major reason for analysing growth is to establish a length at age curve for the fishery. Before lengths at age can be derived by fitting data to the von Bertalanffy (or any) curve it must be established that the model is applicable to the population and that there is no bias in the data used.

Sainsbury (1980) discussed this problem and concluded that non-linearity of a plot of annual increment against initial length does not preclude the use of the von Bertalanffy equation, but that there may be other sources of bias which do affect the result. Such a plot of the tagging data summarized here is non-linear (which may be related to the onset of sexual maturity) and there are indeed other sources of bias.

Firstly, the New South Wales fishery is heavily fished and there are few very old abalone in the population. This means of course that there are few to tag. It also means that even fewer will be returned because a tag on any large abalone at liberty long enough to grow significantly will be overgrown and unrecognisable. Thus, since deriving a reasonable asymptotic length by extrapolating outside the range of data is suspect (Knight,1968), it is not unreasonable to see the data analysis producing low values for L(inf).

It was assumed that having research closures would alleviate this problem but it seems that at Mowarry Point, 130mm is a realistic L(inf) value and neither Broughton Island nor Long Reef have been closed to fishing long enough to allow resident individuals to reach an old age. The Broughton Island closure has been extended for three years for this and other reasons.

It may also be the case that seasonal growth affects the parameters derived by the Fabens method. To check this, subsets of the data where time at liberty was restricted to about 52 weeks (48-56) were analysed. When all recaptures were combined, it made no difference. It also made no difference for Disaster Bay recaptures or Botany Bay recaptures. For Mowarry and Ulladulla data sets however, the L(inf) values increased from 130 to 143 and from 123 to 159. (Table 4). It should be noted that the latter sites are not good growth sites.

Tagging stress was also found to be a factor in abnormal behaviour of data sets. If recaptures under 5 weeks, 10 weeks, 15 weeks etc., are sequentially removed from a data set, the average time at liberty and mean size in the remaining data should increase and average increment should therefore decrease. In 6 out of 7 data sets however, such sequential removals resulted in the average increment per week increasing at first and then decreasing. This tagging stress effect seemed to last longer at Eden than at Broughton Island. The peak in increment per week occurred for different sets when 15,20 or 25 weeks was set as the minimum time at liberty.

It should be remembered however, that growth rate analyses such as these, in simple terms, assume the average growth rate over the whole period of liberty to be equal to the instantaneous rate at the time of tagging, (i.e. the slope of the segment of the growth curve is equal to the slope of the tangent) and this will apply only for short recapture periods. Thus only recaptures after less than 16 weeks at liberty were analysed: the L(inf) estimate increased dramatically (from 129 to 156) **and so did the mean increment per week**(.326 to .445) (Table 4).

Clearly, this anomaly in the results from the time at liberty subsets analyses requires the attention of an experienced applied mathematician.

Sex differences were analysed for four data sets, using likelihood ratio tests. Only in the Botany Bay data were male and female growth parameters significantly different but in all cases, growth data for males generated a higher K value and a lower L(inf) value than did data for females. Considering the difficulties of analysis outlined above, it has been assumed that males and females have different growth patterns.

Despite the bias and variability in the tag recapture data analysis, the von Bertalanffy model does appear to be suitable for modelling abalone growth and the latitudinal trend in growth shown in Figures 13 and 14 and Table 4 does seem to be real to a minor extent. Close inspection of Figures 7 to 10 reveals that at comparable times, the mean length of the 1979 cohort appears to be slightly higher at Botany Bay and Broughton Island than it does at Mowarry. This difference may, however, be due to a different spawning period rather than different growth rates, or merely to sampling bias and measurement error.

A comment is necessary regarding the length at age estimates obtained from the population length frequency distributions. Separation of cohorts by eye is at best subjective and at worst grossly inaccurate, and combining all sites when there may be differences between them can introduce further bias.

In this instance however there was no alternative. Classical methods of mixed distribution separation did not work because the ascending left hand edge of the histograms was frequently due to selectivity of the sampling method (small juveniles were impossible to sample adequately) and not absence of juveniles. Further, the descending right hand edge was no doubt due to fishing rather than senility, and in any case, given the variability of growth, cohorts older than four years are impossible to discern with confidence. If all samples for different sites and years were not combined, sample sizes were mostly too small to produce distributions with identifiable modes.

Also, one of the difficulties of the Fabens method of calculating parameters, is that the derivation of the equation to be solved cancels out t_0 from the generalised von Bertalanffy equation (Fabens,1965) and some independent estimate of length at age is needed to "fix" the curve in time.

Thus, growth parameters were calculated from the cohort analysis and the tagging data were used to substantiate the results rather than the other way around.

Recruitment and Reproductive Periodicity

There appears to be a relationship between numbers of 1+ abalone and commercial catch two years later. For this relationship to be confirmed and quantified, several more years of data will be needed and methods for separating mixed frequency distributions will have to be improved. The method of Schnute and Fournier (1980)appears promising.

The "gap" referred to between the good spatfalls of 1977 and 1979 apparently resulted from severe, "hundred year" storms of 1974 during which thousands of abalone were washed up onto beaches and whole reefs were decimated. The fact that this environmental calamity had repercussions for the commercial catch six years later should be enough reason for fisheries biologists to carefully consider the assumption that a highly fecund, long lived oceanic species will produce relatively stable recruitments irrespective of population numbers. It may be of course, that habitat destruction was more important than the reduction in fecundity but care should be taken before conclusions are drawn either way.

From the data available, spawning season cannot accurately be specified. There is considerable variability among all abalone species over small distances (Mottet,1978) and the relationship between water temperature and reproductive cycle is not clear. In addition abalone are known to resorb their gonads under some circumstances. Much more work is needed than was possible in this study. The correct approach is to measure egg diameters for each sample and to this end, all samples collected are being mounted in wax blocks for later histological analysis and gonad sampling is continuing.

CONCLUSIONS

The results from this work have relevance for abalone management in that there seems to be a relationship between parent stock and numbers of progeny recruited to the fishery at the current population level. Admittedly, the conclusion that a relationship exists based on only three cohorts and the subsequent catches two years later is a very tenuous one, but if there is a valid recruitment curve such as those shown by Ricker (1975,Chapter 11) then the New South Wales fishery may be operating at the lower end and adult population size should be allowed to increase.

Maintaining large adult abalone populations is also desirable because the evidence available indicates that when abalone are removed completely, the habitat does appear to be lost as productive reef.

The current long term goal of increasing population size is clearly a valid one (this is also the goal of other managers (Anon.,1982; Doi et. al,1977)) at least until a sufficient bank of data is available to clearly define the parent/progeny relationship and the importance of habitat destruction by natural forces. Obviously, the relationships between total fecundity/number of settling larvae and between number of larvae/recruits to the fishery also require attention.

It should also be noted that if recruitment is not found to be limiting in the southern states (and the inference is that it may not be), then abalone ranching cannot be economically feasible.

In general terms, these results confirm the wisdom of the fisheries management "rule of thumb" that the exploitation ratio (fishing mortality divided by total mortality) should not greatly exceed 0.5 (although see Francis,1974).

In achieving management goals, the density and reef area estimates have an important bearing on effort levels in the fishery.

Beinssen (1979) found that a diver covered $1200m^2$ of reef per searching hour. A provisional estimate of fishing power from the harvesting of the Mowarry Point closure is similar ($1100m^2$ per hour). The density at the site was reduced by 86% in two days of fishing indicating that the "gear efficiency" is high.

This gear efficiency and swept area data combined with overall densities and reef areas indicates that fewer divers could produce the same total catch in New South Wales. These data will be used for more sophisticated analyses in the near future, but their relevance to management is clear.

Economic analyses such as those of Phillipson (1982) can then compare costs and benefits and with such information available, success of achieving managment goals, whatever they are, must be more likely.

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TABLE 1 SUMMARY OF DETAILS FOR TWELVE NATURAL MORTALITY EXPERIMENTS.

	EXPERIMENTAL DETAILS								REGRESSION RESULTS			
LOCATION	No tagged each time	No of taggings	Duration of experiment (months)	Size range tagged (mm)	Nos tagged and recaptured alive	Confirmed mortalities	Area censussed (sq.m.)	Census effort (diver) (days)	-Slope (% loss per month)	Intercept (%)	Correlation coefficient (x-1)	Anuual % unaccounted for (slopex12)
EDEN												
MOWARRY 1	30 DT	7	11	59-117	214/142	7	3600	24	2.46	86.7	.96	29.5 (1)
" 2	30 DT	7	12	92-137	217/94	9	3000	17	2.14	50.7	.64	25.7 (1)
" 3	50	5	18	69-142	318/132	5	625	12	2.07	63.4	.77	24.8
" 4	50	6	12	62-143	299/162	14	2000	6	2.14	65.4	.42	25.7
" 5	50	6	12	99-143	268/44	13	1800	5	2.58	31.8 (2)	.98	31.0
SYDNEY												
Botany Bay 1	30 DT	4	4	39-76	134/118	1	150	5	1.33	91.5	.66	16.0
" 2	30 DT	4	4	41-77	138/96	-	150	8	5.97	85.4 *	.71	71.6 * (3)
Long Reef	30	5	16	52-132	144/32	3	300	3	1.16	33.2 (4)	.68	13.9
PORT STEPHENS												
Broughton Is 1	30 DT	8	12	34-152	248/91	5	1000	8	0.54	45.4	.22	6.5 *
" 2	30 DT	5	10	104-158	147/77	3	2000	7	3.36	60.4 *	.76	40.3 * (5)
" 3	30-90	4	21	85-140	212/84	2	1000	4	1.35	60.9	.47	16.2
" 4	40	4	18	76-152	160/67	3	1500	4	1.92	70.5	.34	23.0
OVERALL				34-158	2499/1139	66						22.9

Notes (see text for details): DT indicates that individuals were double tagged. * indicates values not included in overall averages.
(1) points ignored
(2) site fished prior to harvest
(3) site proved impossible to census.
(4) sand level increased 60cm during experiment
(5) artifically high densities in unsuitable environment.

TABLE 2 REEF AREA AND PRODUCTION FOR THE N.S.W. ABALONE FISHERY.

AREA CODE	NORTHERN LIMIT OF AREA	REEF AREA x1000 (sq.m.)	LENGTH OF COAST (KMS)	REEF PER KM x1000 (sq.m.)	AVERAGE CATCH Tonnes	CATCH PER UNIT REEF AREA kgs per 1000sq.m.	CATCH PER HOUR kgs
A	Tweed Heads	0	80	0	0		
B	Ballina	80	145	0.6	1.2	15.0	20.3
C	Woolgoolga	146	155	0.9	0.1	1.0	25.0
D	Pt. Macquarie	405	95	4.3	3.1	7.7	31.9
E	Forster	583	75	7.8	6.0	10.3	20.8
F	Pt. Stephens	716	65	11.0	22.8	31.8	21.4
G	Swansea	949	60	15.8	12.1	12.8	19.9
H	Broken Bay	1262	50	25.2	14.7	11.6	17.2
J	Botany Bay	1525	55	27.7	22.4	14.7	17.1
K	Wollongong	1023	55	18.6	27.4	26.8	27.8
L	Greenwell Pt.	930	45	20.7	7.7	8.3	21.8
M	Wreck Bay	391	25	15.6	7.8	19.9	19.2
N	Ulladulla	433	20	21.7	8.4	19.4	15.2
P	Brush Is.	1540	25	61.6	26.9	17.5	17.4
Q	Bateman's Bay	1035	20	51.8	15.2	14.7	17.2
R	Moruya	559	20	28.0	4.4	25.8	17.9
S	Tuross Heads	144	18	8.0	5.8	40.3	18.8
T	Narooma	675	20	33.8	41.3	61.2	19.4
U	Bermagui	829	18	46.1	34.6	41.7	21.1
V	Mimosa Rocks	726	17	42.7	47.3	65.2	23.1
W	Tathra	1196	22	54.4	33.8	28.3	20.1
X	Pambula	840	18	46.7	29.4	35.0	18.2
Y	Eden	2051	26	78.9	132.3	64.5	18.9
Z	Wonboyn	1018	28	36.4	52.9	52.0	25.7
		19056	1157		557.6		

TABLE 3 DENSITY ESTIMATES FOR ABALONE POPULATIONS USING FOUR METHODS.

METHOD	SITE	DATE				DENSITY OF LEGAL-SIZED ABALONE (per sq.m)
1. DIRECT CENSUS						
			AREA SQ.METRES	TOTAL HARVEST	LEGAL HARVEST	
UNFISHED	MOWARRY 1	MAY 80	2500	1002	524	.21
	" 2	SEPT 80	2000	501	212	.11
	" 3	NOV 81	400	1268(3.2/sq.m.)	257	.64
	BROUGHTON 3	MAY 82	1000	472	319	.32
FISHED	BOTANY BAY	NOV 80	300	495	94	.31
	EDEN GUTTER	MAY 82	430	492	160	.37
	DISASTER BAY	NOV 81	450	1163	177	.39
	"	OCT 82	25	260	19	.76
2.CLOSEST INDIVIDUAL DISTANCES						
					NO OF POINTS.	
	EDEN GUTTER	APR 82			10	.45
	EDEN CLOSURE	APR 82	(BEFORE HARVEST)		45	1.67
	"	MAY 82	(AFTER HARVEST)		31	.23
	DISASTER BAY	OCT 82			6	1.14
3. QUADRATS						
			NO OF QUADRATS	TOTAL HARVEST	LEGAL HARVEST	
	EDEN CLOSURE	APR 82	104	-	96	.92
	MOWARRY 3	NOV 81	20	60(3.0/sq.m)	-	-
4.REEF AREA + STANDING STOCK						
			AREA (SQ.METRES)	CATCH (NUMBERS)	STANDING STOCK (NUMBERS)	
	EDEN CLOSURE	MAY 82	76,500	13830	16000	.21
	WHOLE COAST	1980-82	19.1million	2.2million	3.7million	.19

TABLE 4. VON BERTALANFFY GROWTH PARAMETERS FROM TAG RECAPTURE DATA AND CORRESPONDING THEORETICAL LENGTHS AT AGE.

SITE	SAMPLE SIZE	K /yr	L(inf) mm	r *	LENGTH AT AGE mm 1yr	2yr	3yr	4yr	5yr	MEAN TIME AT LIBERTY weeks	MEAN LENGTH mm	MEAN INCREMENT PER WEEK mm/wk
DISASTER BAY	156	.66	130	.93	63	95	112	121	125	31.3	96.9	.38
MOWARRY	443	.42	130	.76	45	74	93	106	114	33.6	112.0	.12
MOWARRY 48-56	51	.25	143	.31	32	56	76	90	102	51.0	110.6	.15
TWOFOLD BAY	44	.34	124		36	61	79	92	101			
ULLADULLA	210	.53	123	.88	51	80	98	108	114	56.2	85.1	.36
ULLADULLA 48-56	25	.35	159	.51	47	80	103	120	131	50.2	75.5	.55
BOTANY BAY	350	.55	139	.82	59	93	112	124	130	29.0	75.1	.57
SYDNEY HARBOUR	140	.43	115	.76	40	66	83	94	102	22.9	92.5	.13
BROUGHTON IS.	288	.75	134	.84	66	100	117	126	130	49.7	111.4	.32
PORT STEPHENS	55	.49	132	.70	51	83	102	113	121	35.3	105.1	.26
ALL DATA	1570	.58	129	.80	57	89	106	116	122	39.2	97.4	.33
ALL DATA FROM COMMERCIAL SITES	1497	.62	128	.78	59	91	108	117	122	39.1	99.9	.31
ALL DATA 48-56	116	.57	130	.73	57	88	107	117	123	50.7	96.1	.36
ALL DATA 1-15	236	.34	156	.42	45	77	100	116	128	10.2	81.1	.45

NOTE : r is equivalent to the linear regression "correlation coefficient" - i.e.r=1 indicates perfect fit, r=0 indicates no trend.

TABLE 5. SEASONAL GROWTH PATTERNS.

SITE	SAMPLE SIZE	CORRELATION INCREMENT WITH DAYS				SLOPE INCREMENT WITH DAYS			
		SU	AU	WI	SP	S1	S2	S3	S4
MOWARRY	443	.60	.55	.39	.57	.25	.15	-.05	.39
DISASTER BAY	156	.72	.69	.74	.78	.23	.27	.18	.38
ULLADULLA	210	.57	.59	.67	.57	.18	.07	.56	-.08
BOTANY BAY	350	.75	.54	.59	.74	.39	.05	.19	.32
SYDNEY HARBOUR	140	.56	.54	.44	.61	.11	.39	-.42	.64
BROUGHTON ISLAND	288	.39	.60	.40	.37	-.31	.68	.05	.37

NOTE : The table shows the degree of correlation of total increment with days at liberty in each season and the slope of the standardised regression of increment on number of days at liberty in each season such that increment = (S1 X summer days)+(S2 x autumn days)+(S3 x winter days)+(S4 x spring days).

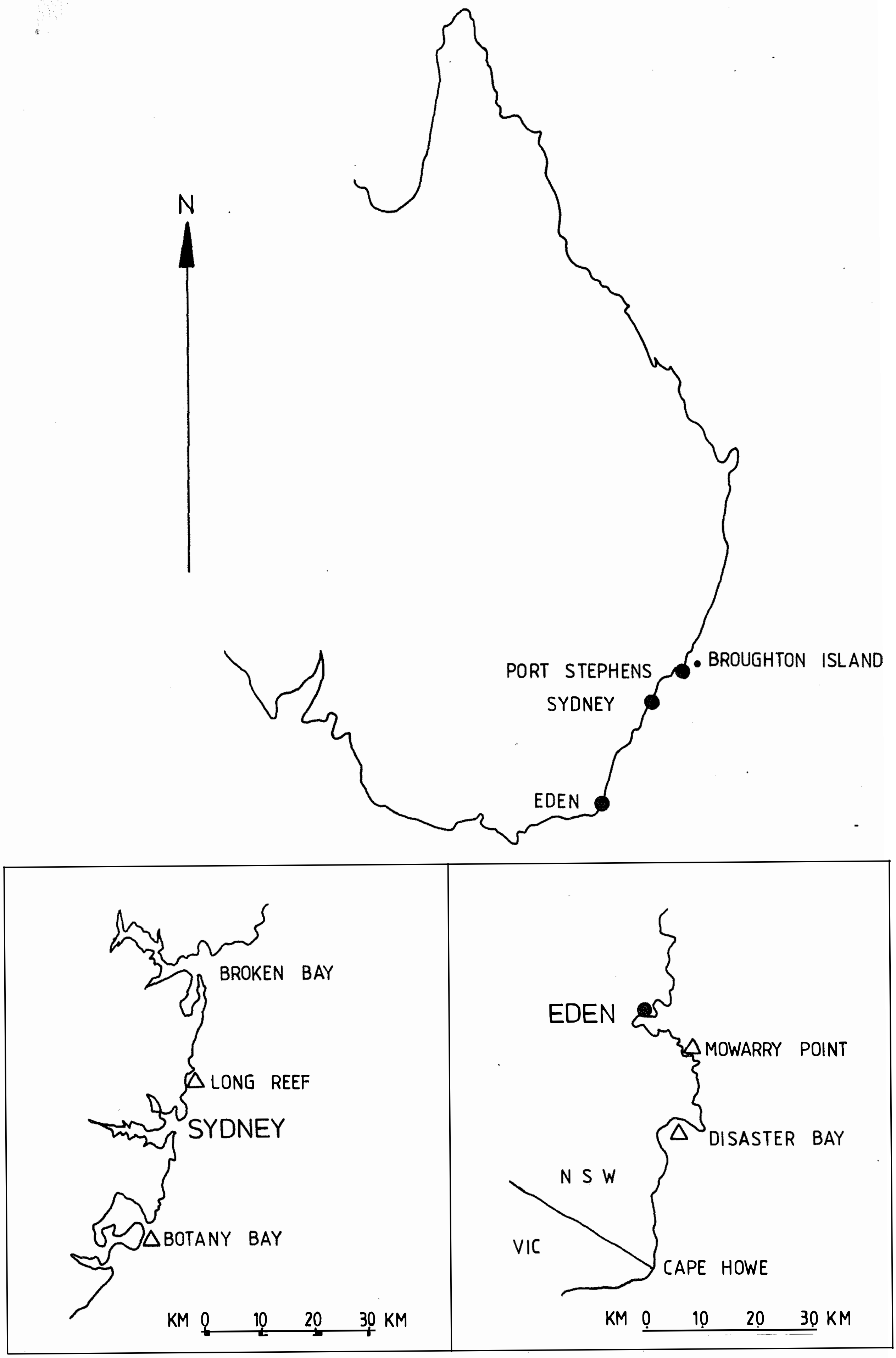

FIGURE 1a ● LOCATION OF STUDY AREAS

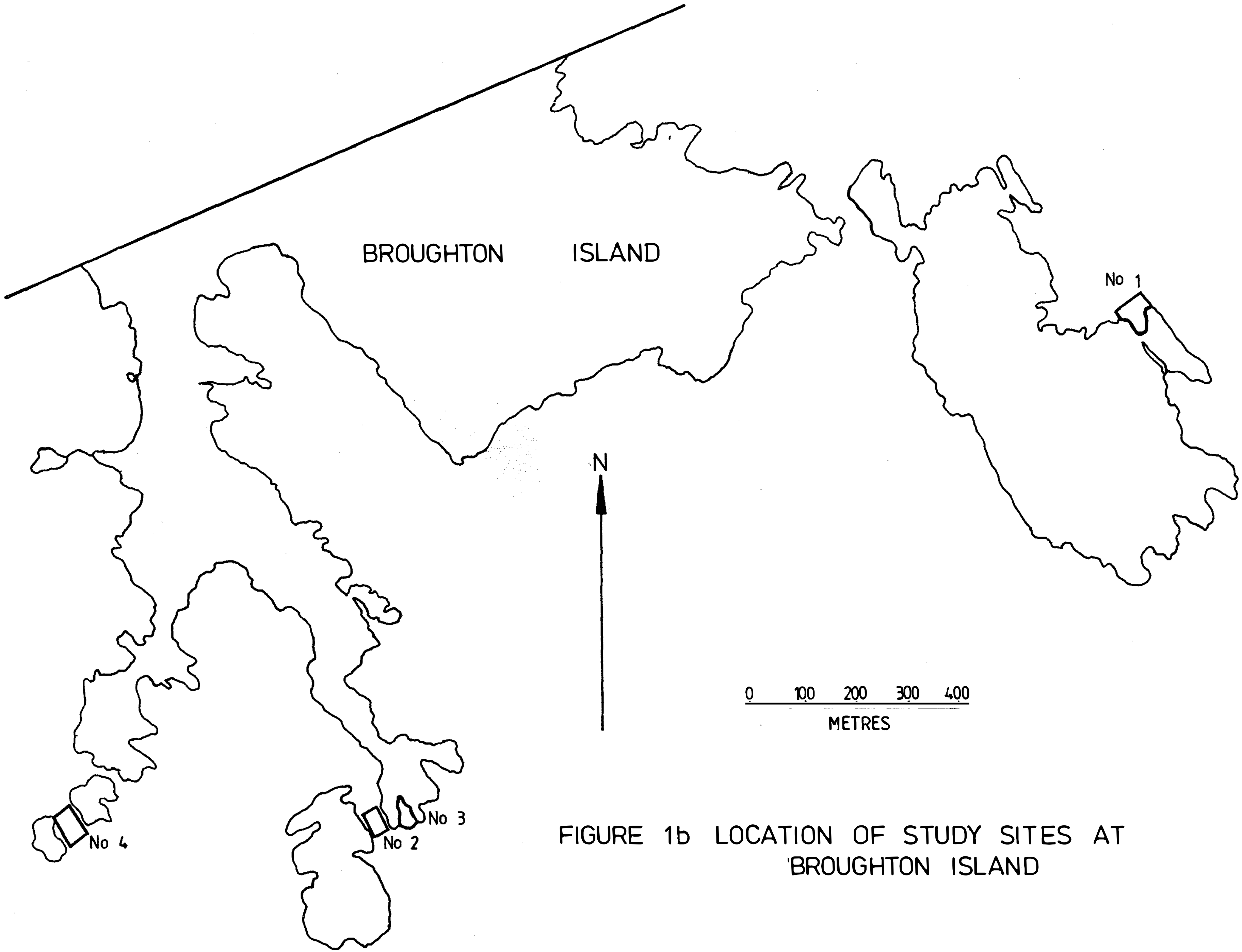

FIGURE 1b LOCATION OF STUDY SITES AT BROUGHTON ISLAND

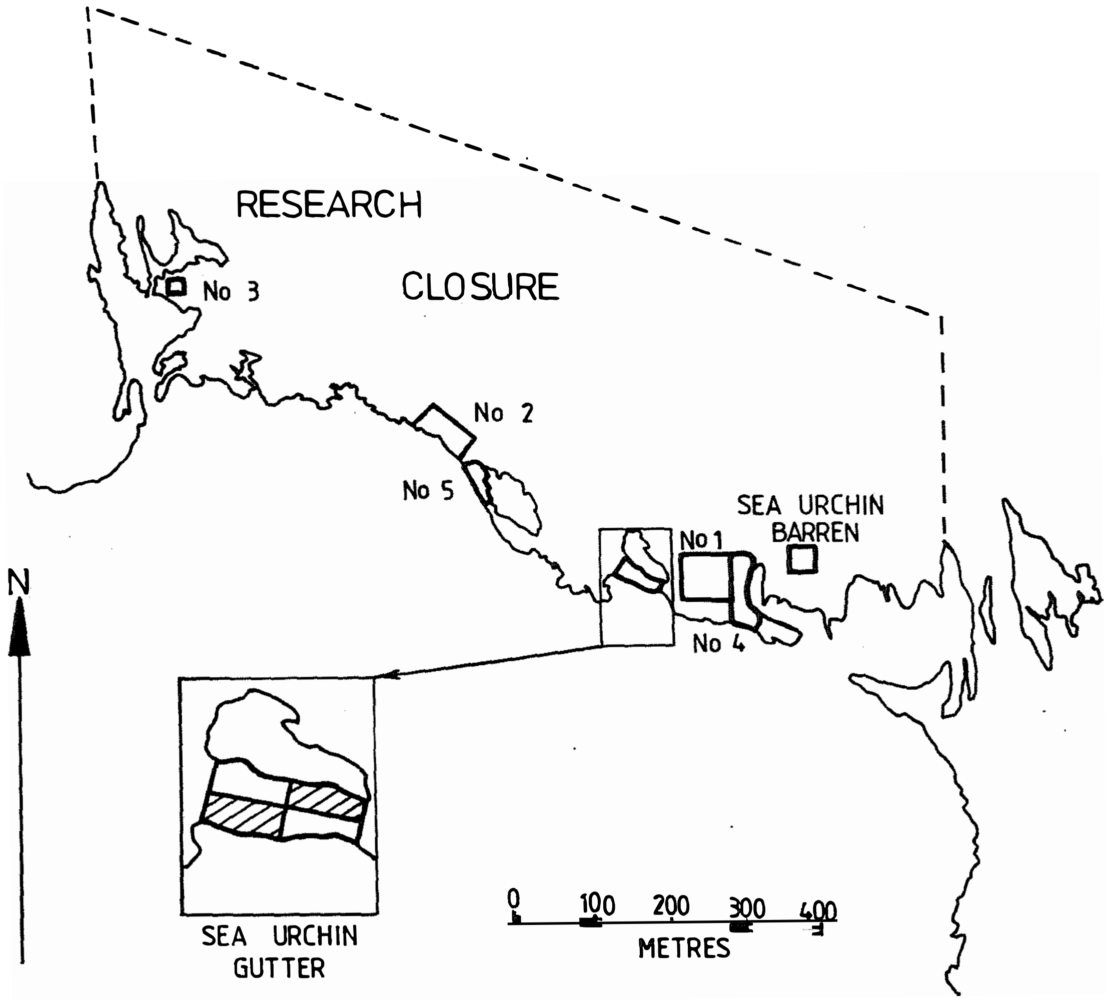

FIGURE 1c LOCATION OF STUDY SITES AT MOWARRY POINT

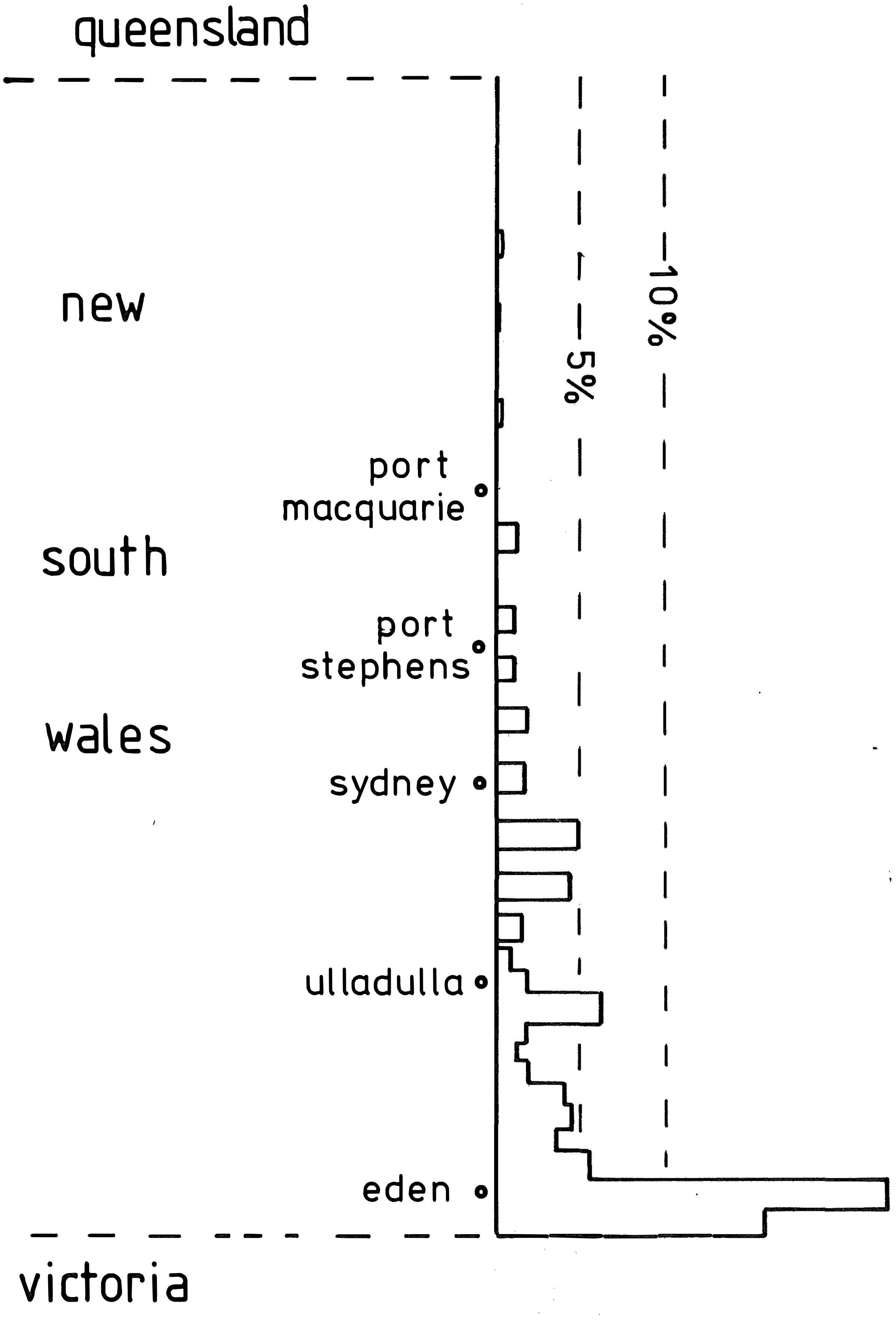

FIGURE 2. APPROXIMATE CONTRIBUTION TO N.S.W. CATCH BY 23 AREAS.

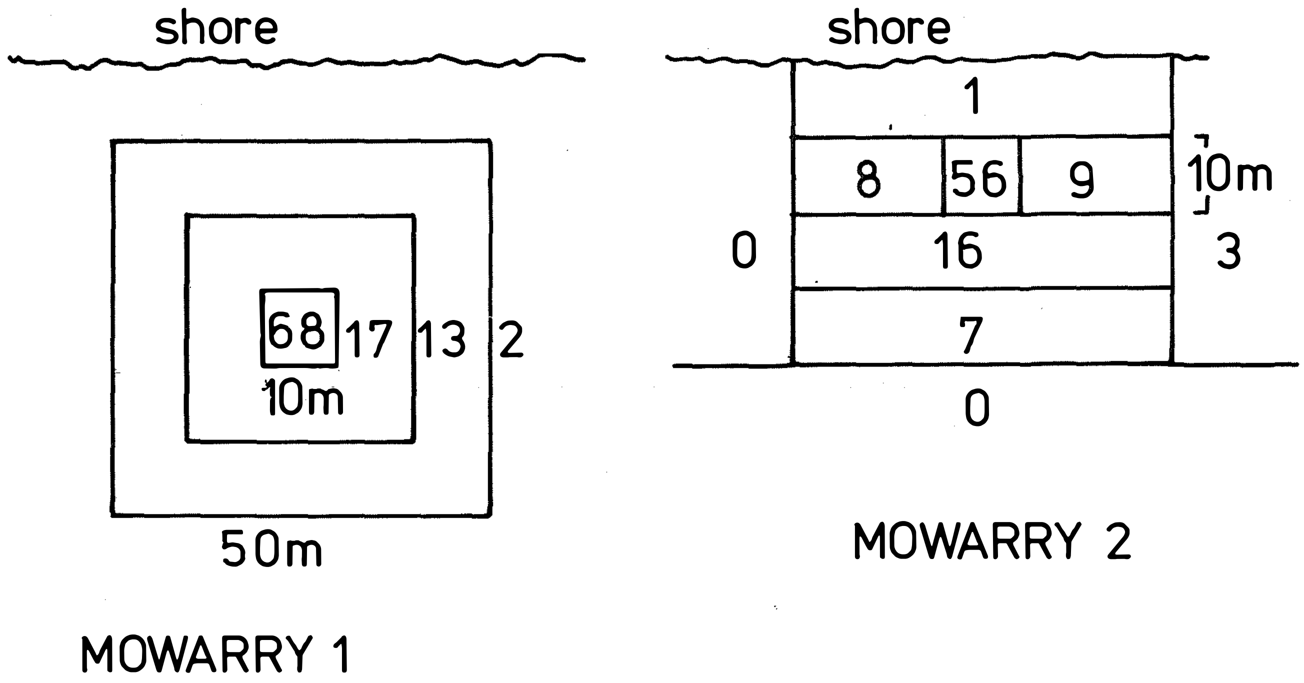

FIGURE 3 DIAGRAMMATIC REPRESENTATION OF MOVEMENT PATTERNS OF TAGGED ABALONE

Figures show the percentages of recaptured abalone found in and around the 10m x 10m tagging grid at 2 sites.

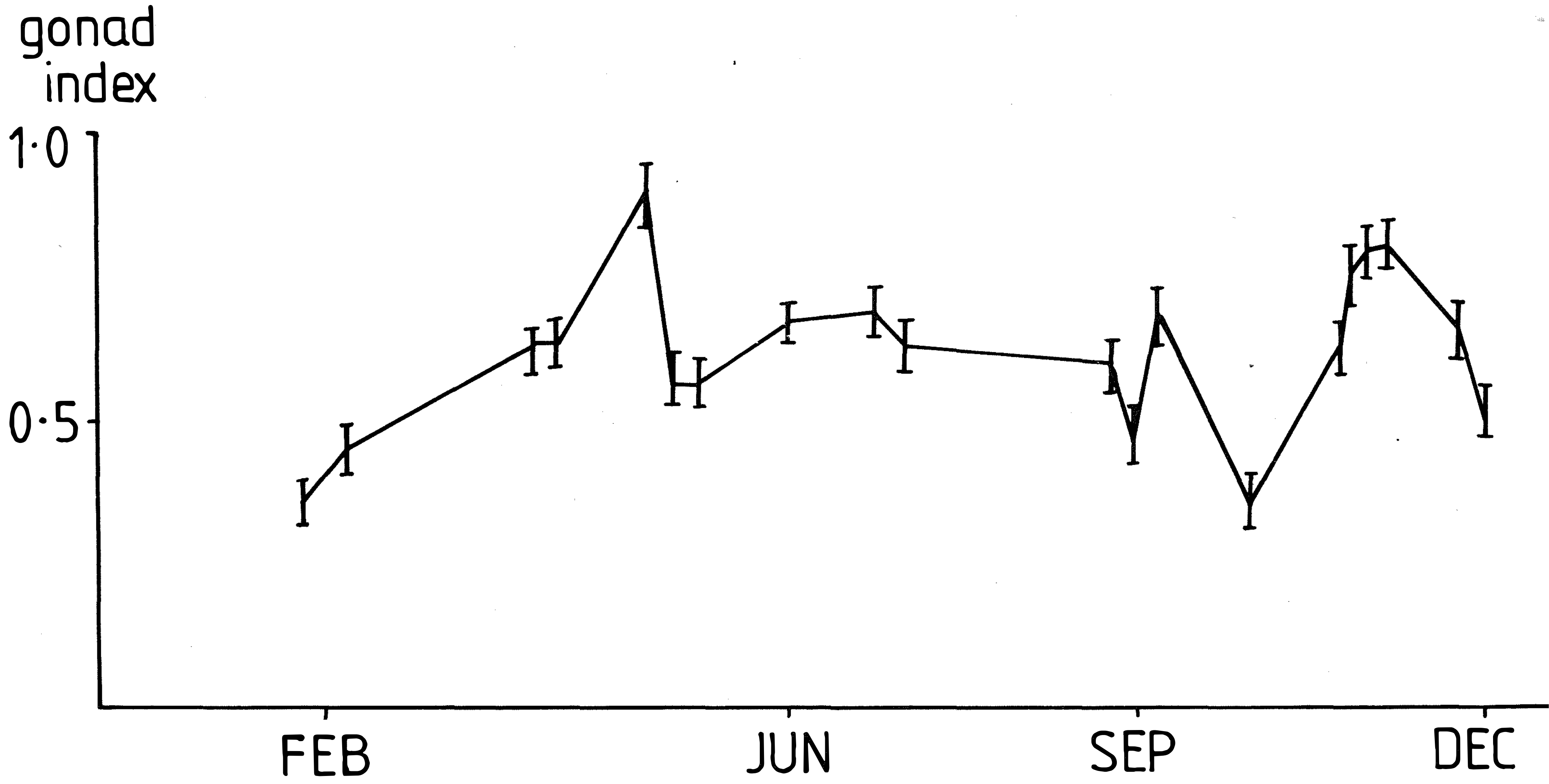

FIGURE 4 GONAD INDEX VALUES FOR 4 EDEN SITES
means are for males & females combined (I = 95% C.I.)

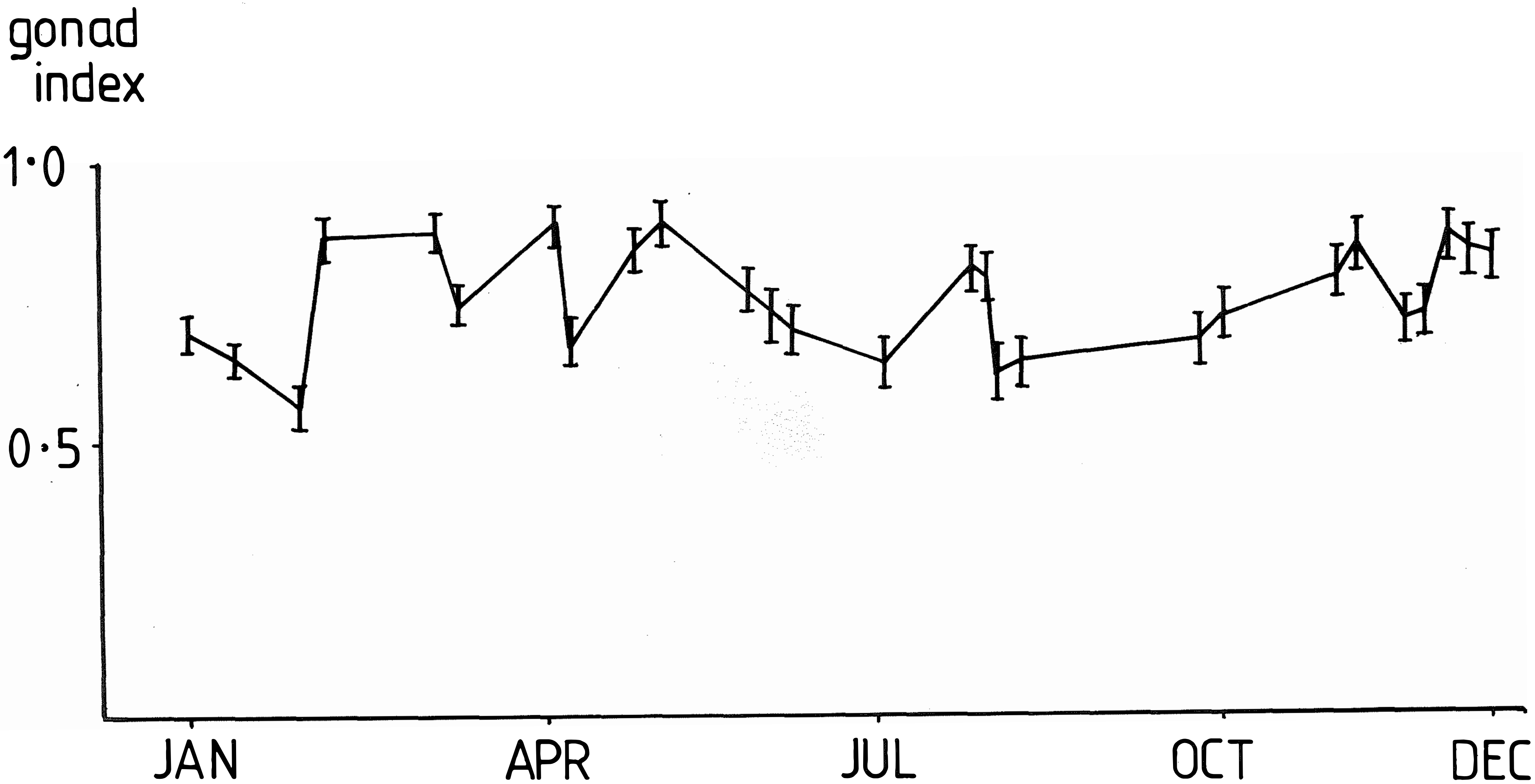

FIGURE 5 GONAD INDEX VALUES FOR 3 SYDNEY SITES

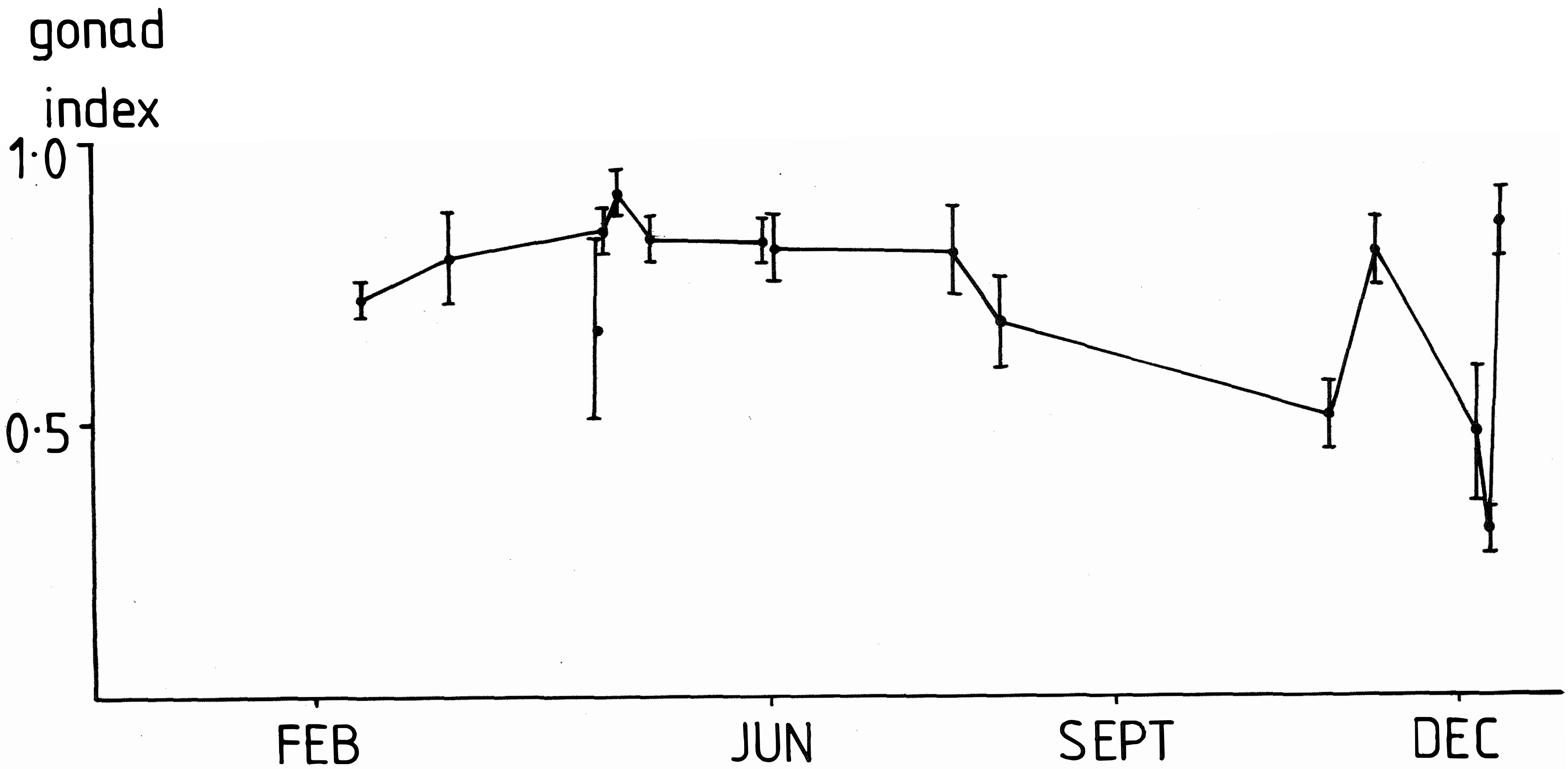

FIGURE 6 GONAD INDEX VALUES FOR 3 BROUGHTON IS. SITES

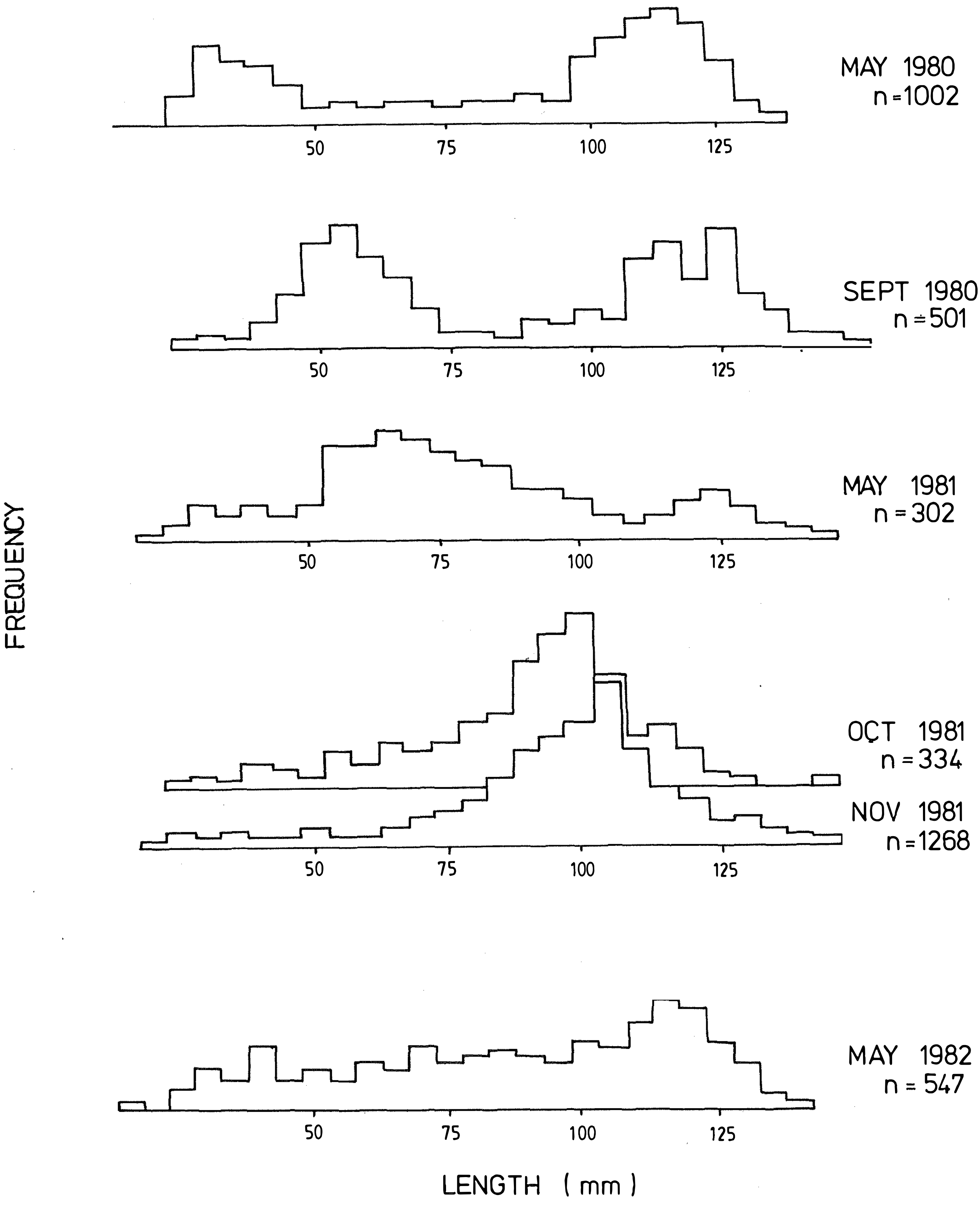

FIGURE 7 MOWARRY SIZE DISTRIBUTIONS

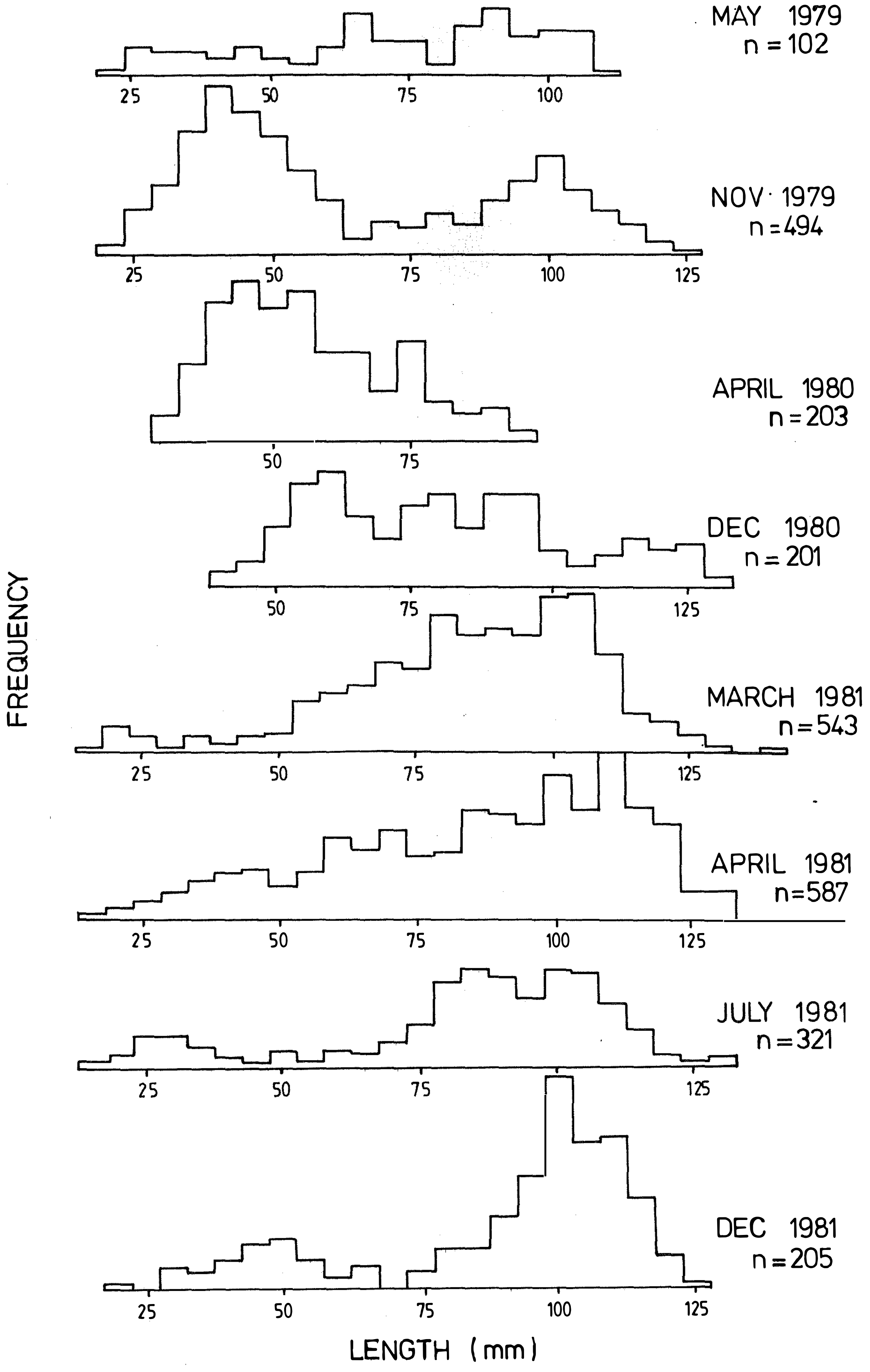

FIGURE 8 SYDNEY SIZE DISTRIBUTIONS

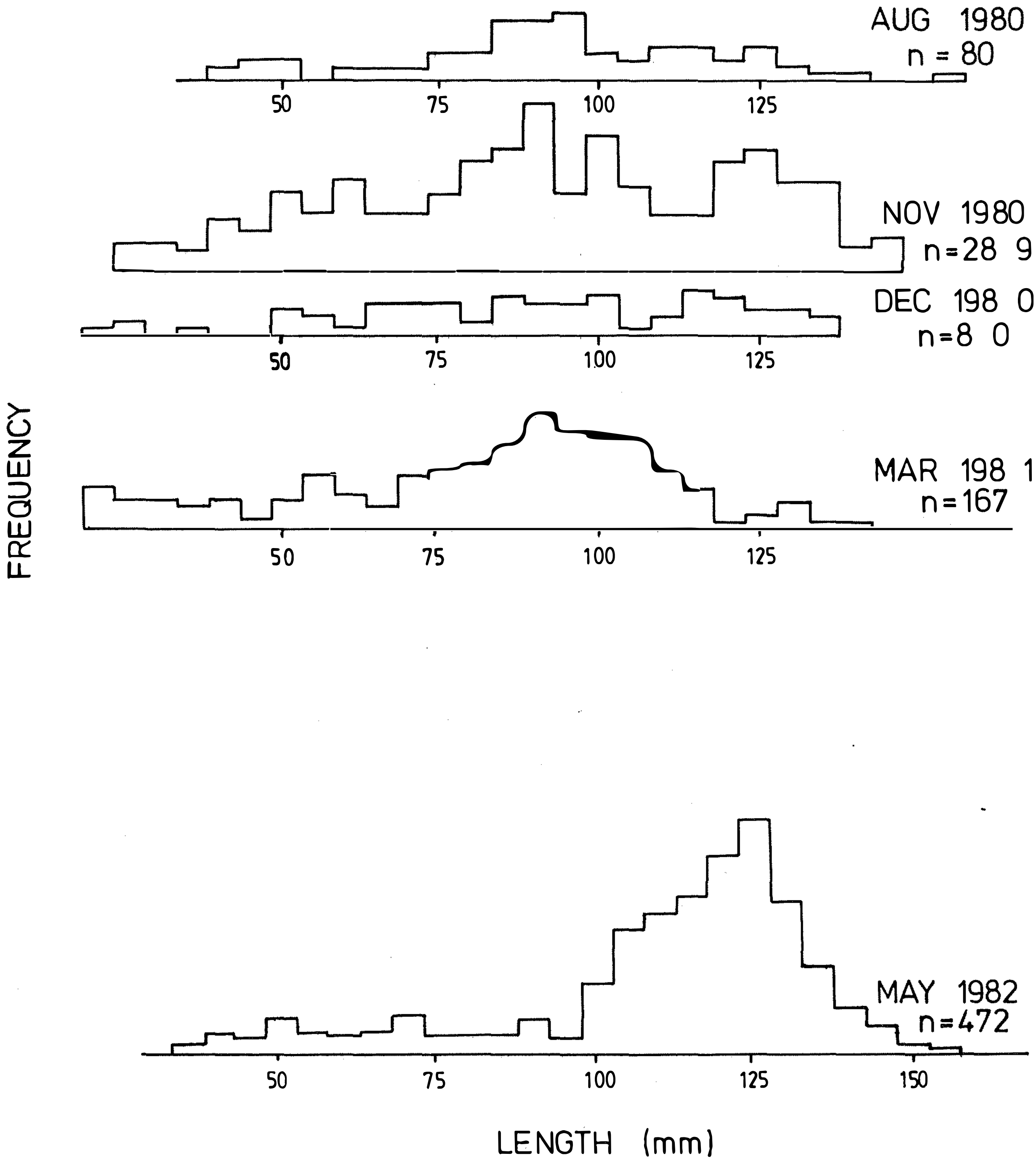

FIGURE 9 BROUGHTON ISLAND SIZE DISTRIBUTIONS

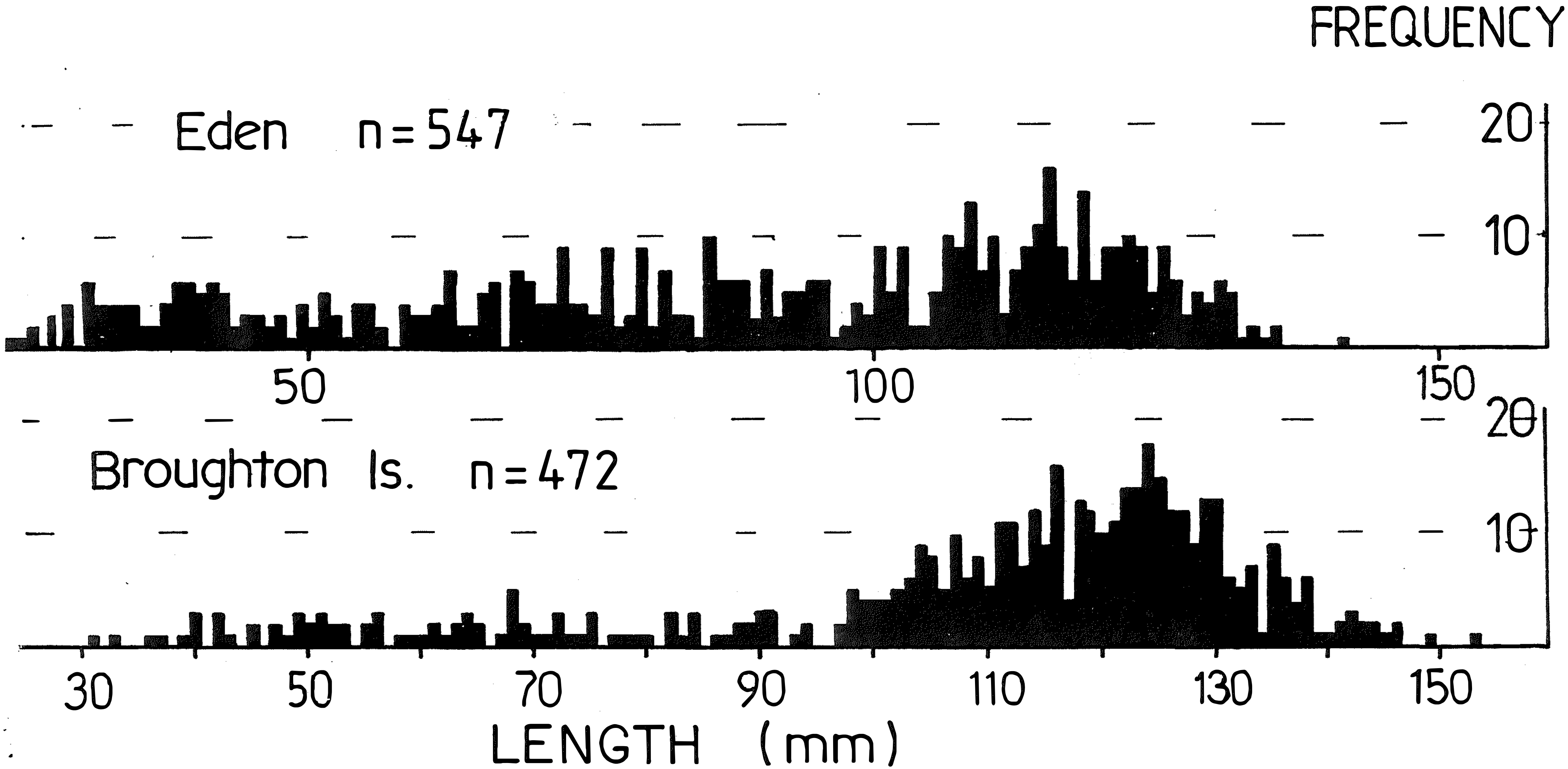

FIGURE 10 LENGTH-FREQUENCY DISTRIBUTIONS OF MAY 1982 SAMPLES

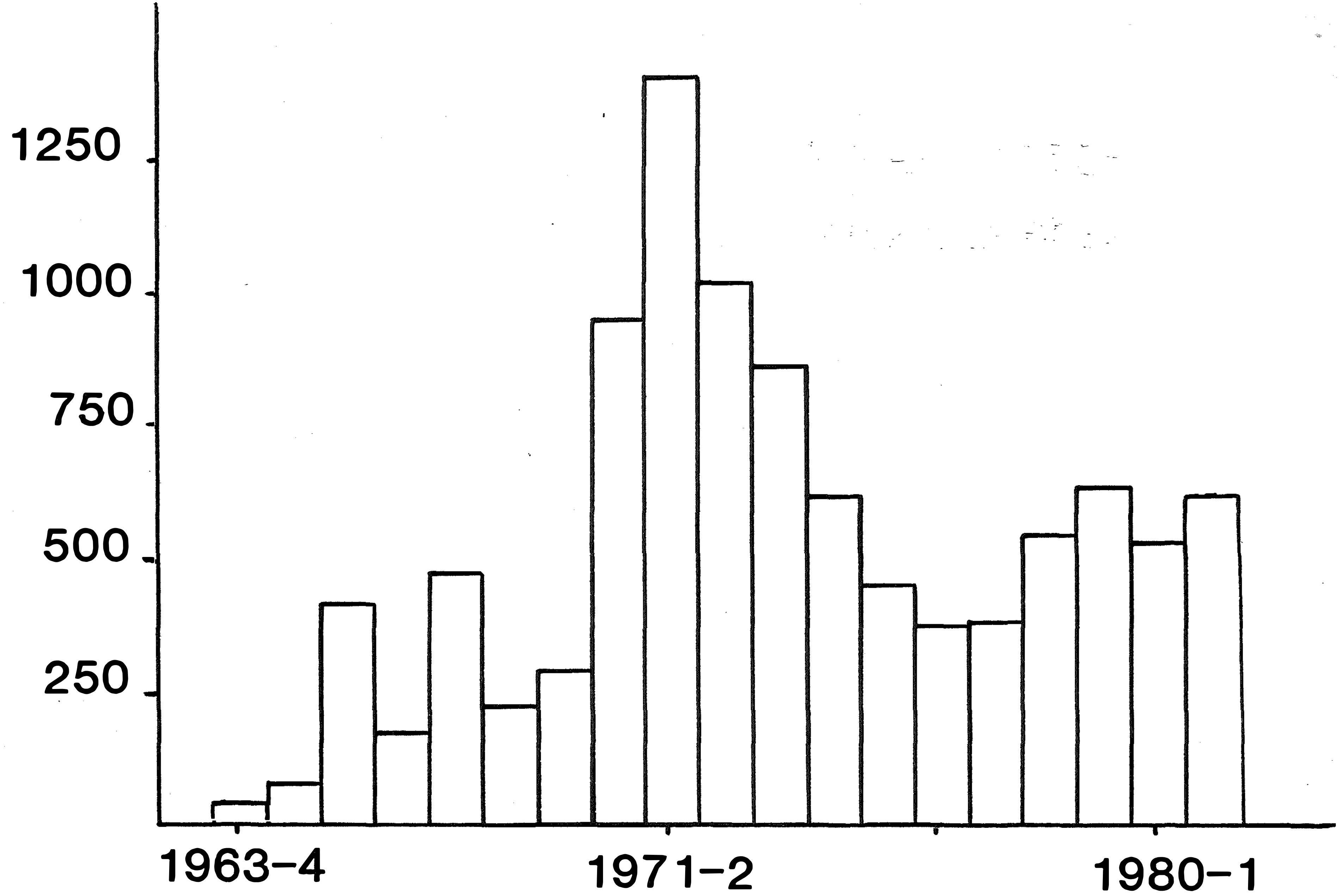

FIGURE 11 TOTAL REPORTED CATCH OF ABALONE
(tonnes live weight)

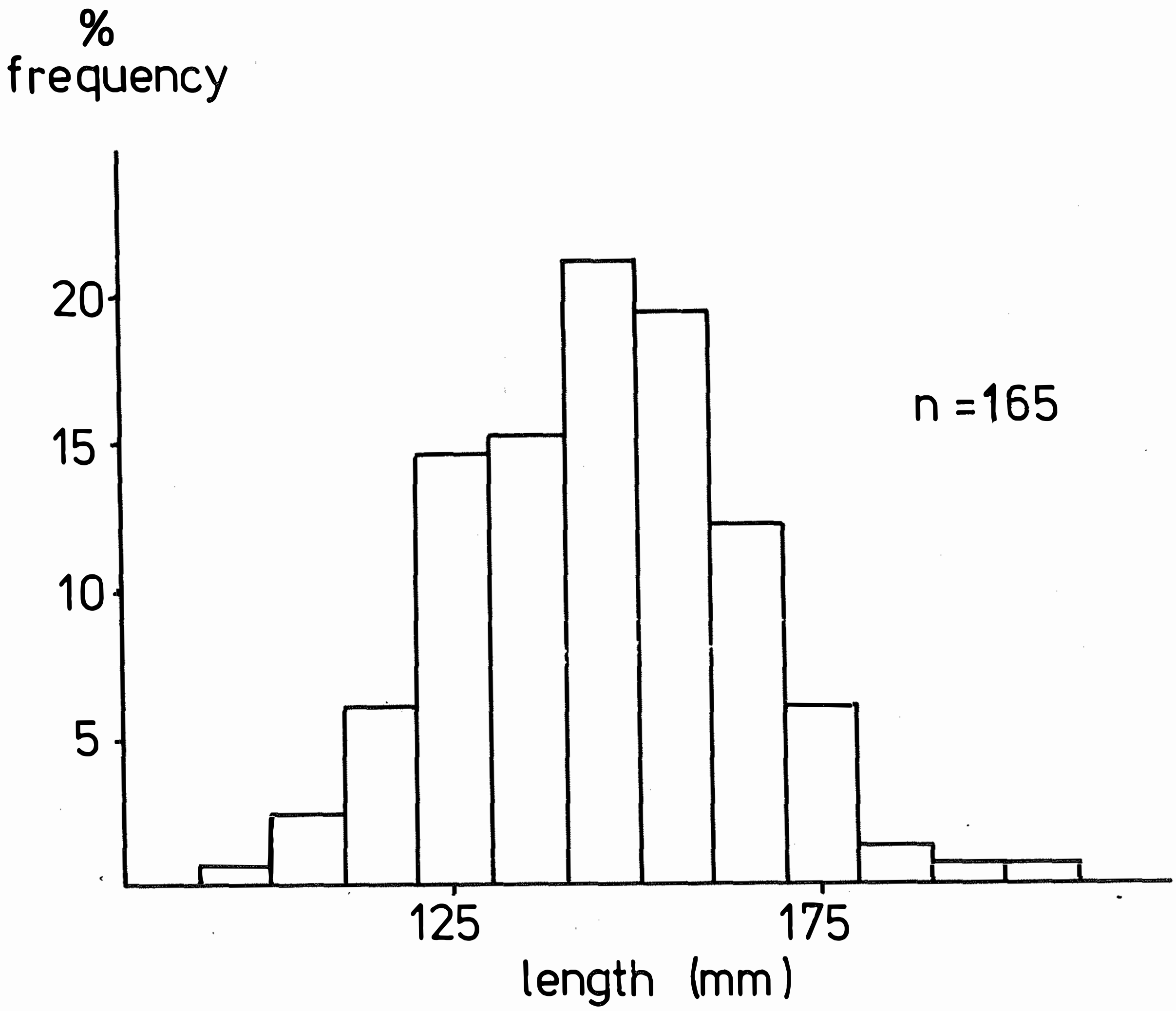

FIGURE 12 SIZE DISTRIBUTION OF A COMMERCIAL CATCH FROM AN UNFISHED REEF.

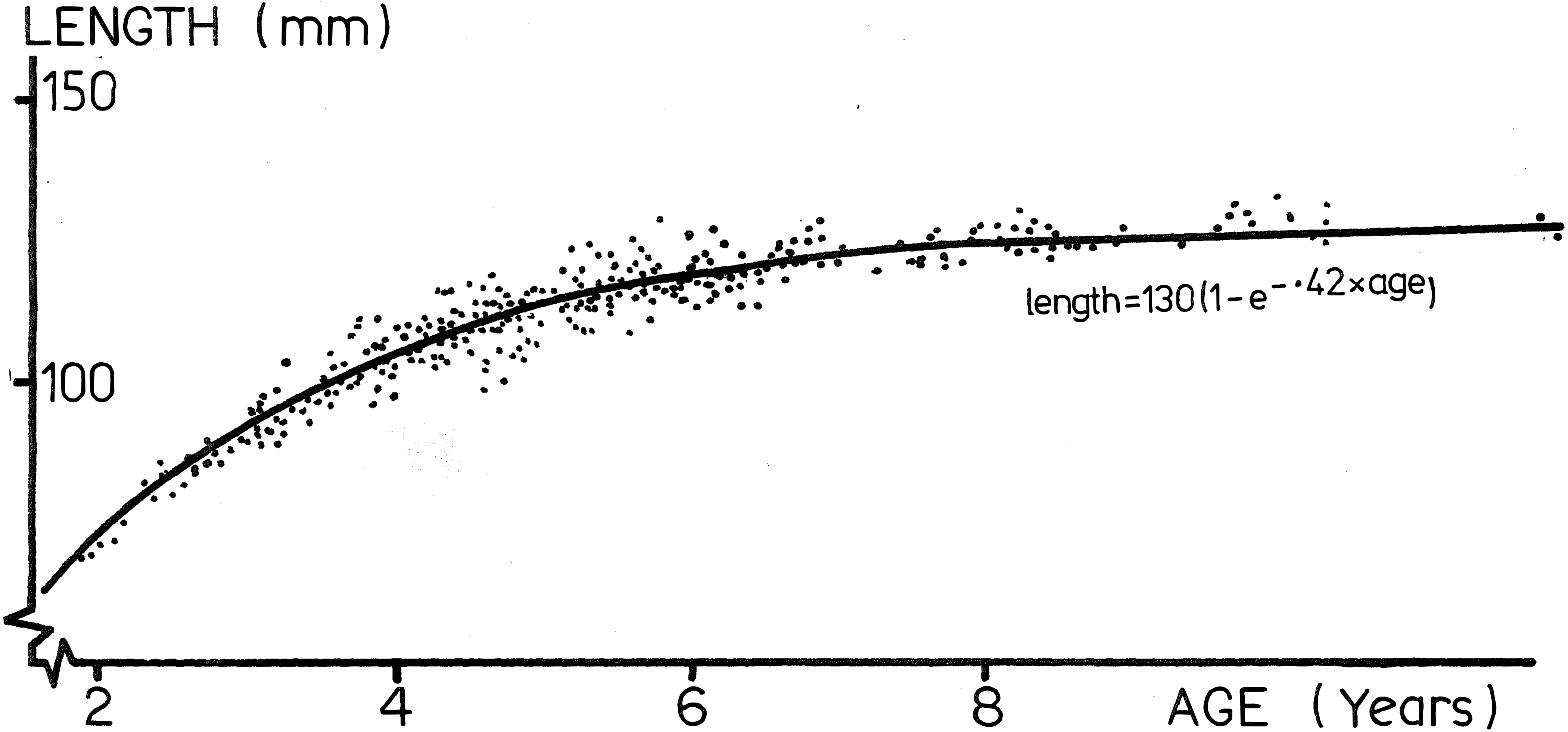

FIGURE 13 MOWARRY TAG RECAPTURE DATA n= 442

The curve represents the FABENS method line of best fit. Each point represents a recaptured abalone whose release age was assumed to be on the line. at the point corresponding to the length at tagging.

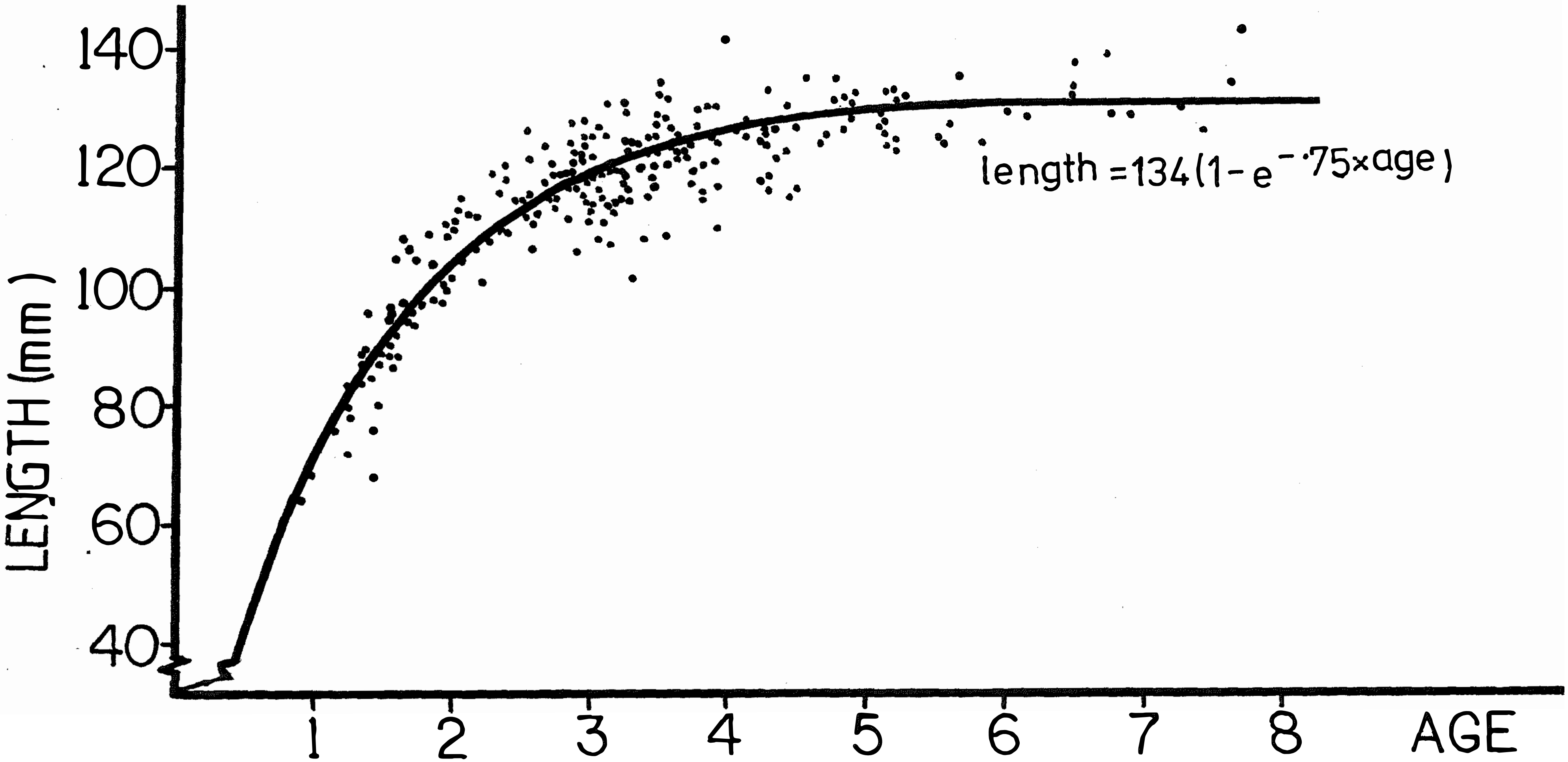

FIGURE 14 BROUGHTON IS. TAG RECAPTURE DATA

n=288

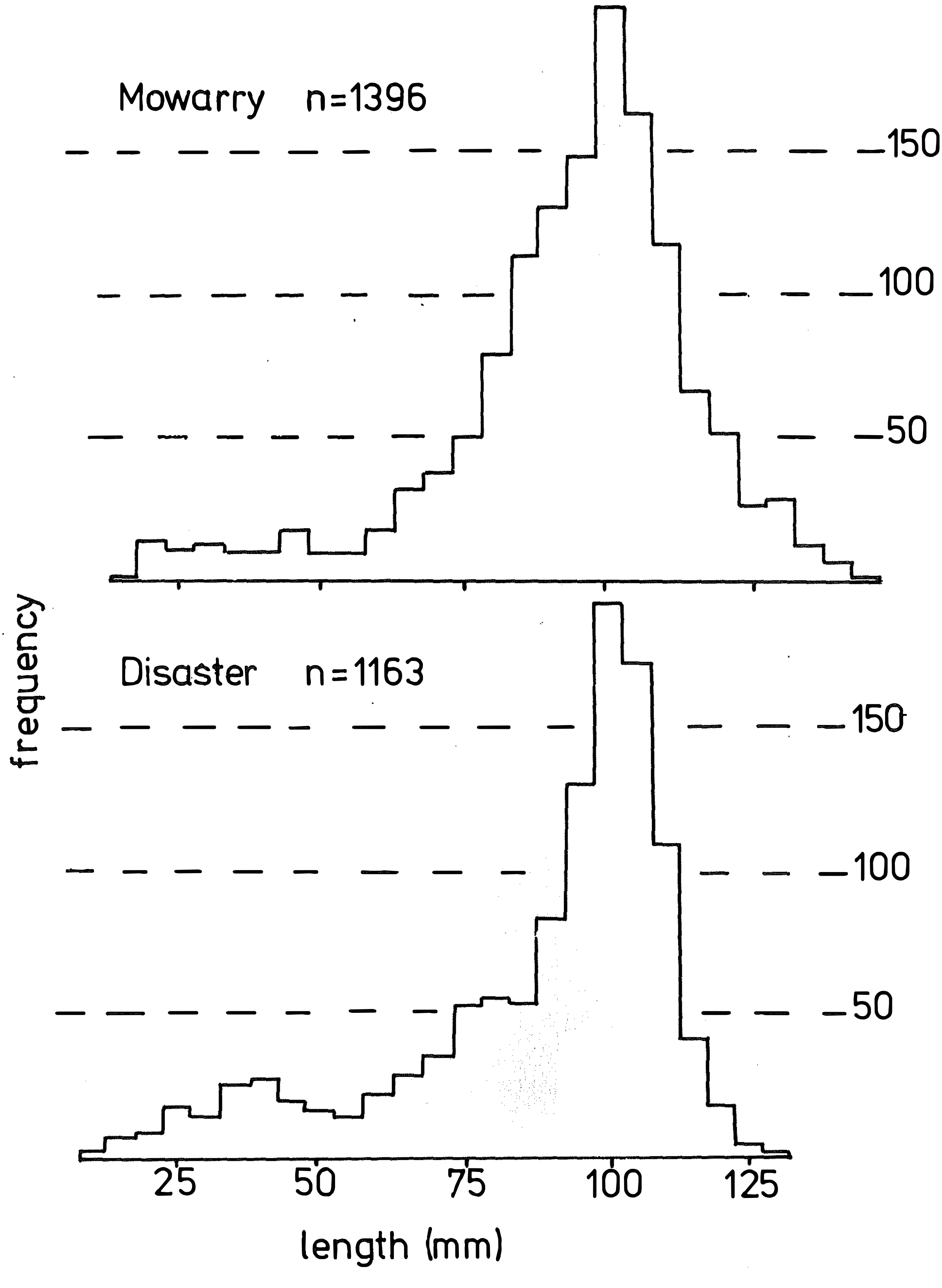

FIGURE 15 NOVEMBER 1981 LENGTH DISTRIBUTIONS FROM TWO EDEN SITES

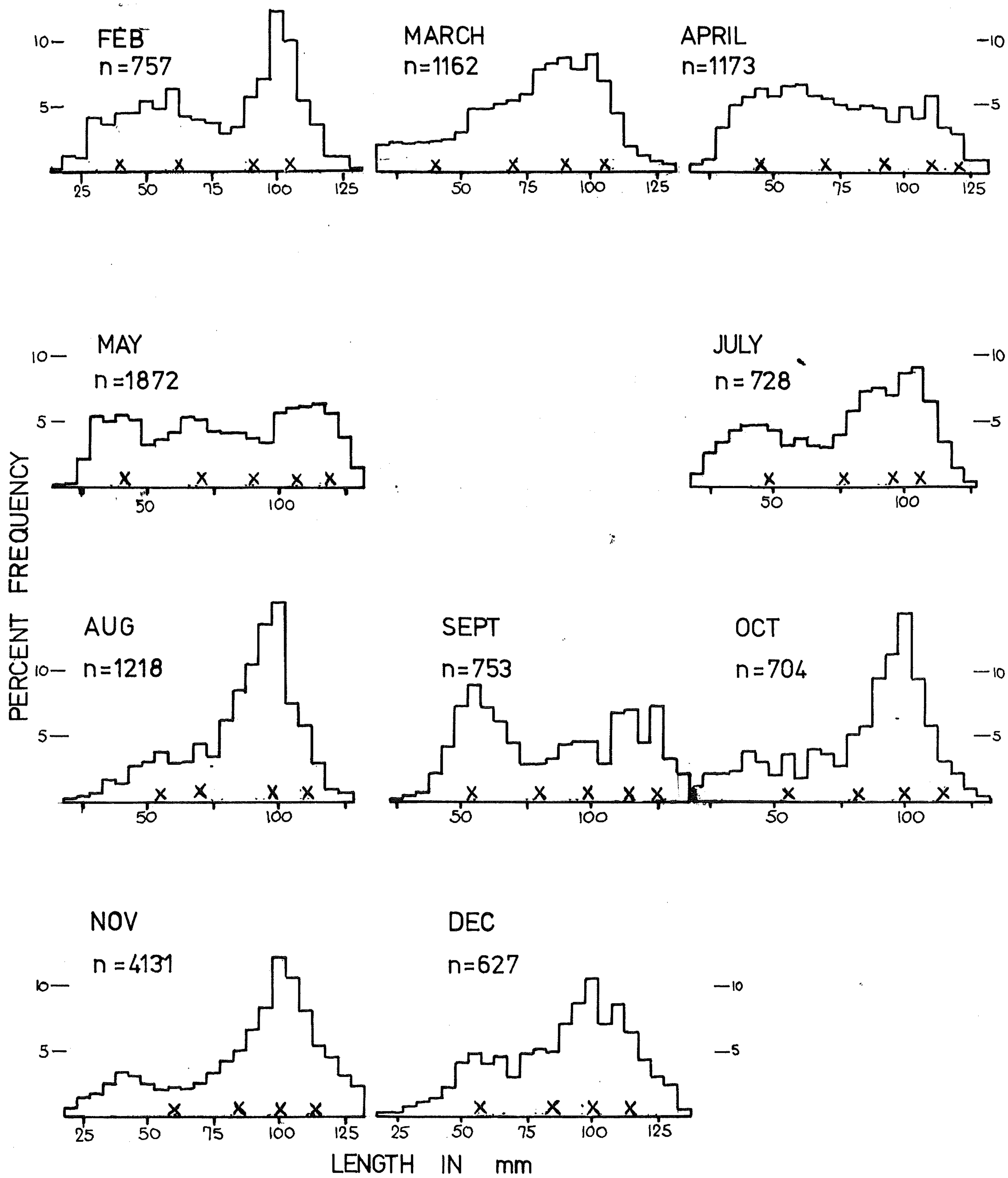

FIGURE 16 COMPOSITE SIZE DISTRIBUTIONS FROM ALL SITES SAMPLED

x = Approximate mean length of yearclasses.

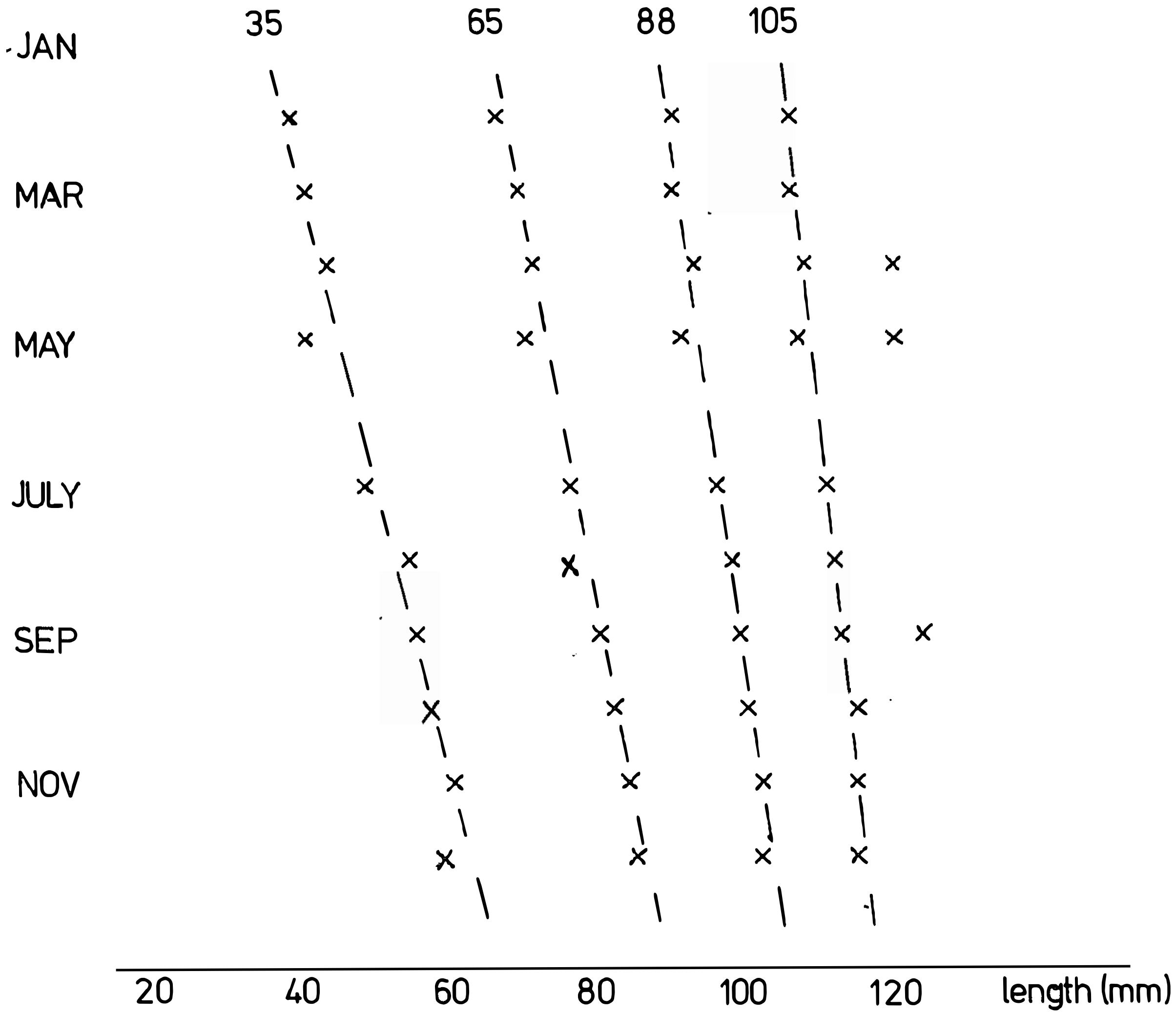

FIGURE 17 APPROXIMATE LOCATIONS OF COHORT MEAN LENGTHS FROM FIGURE 16.

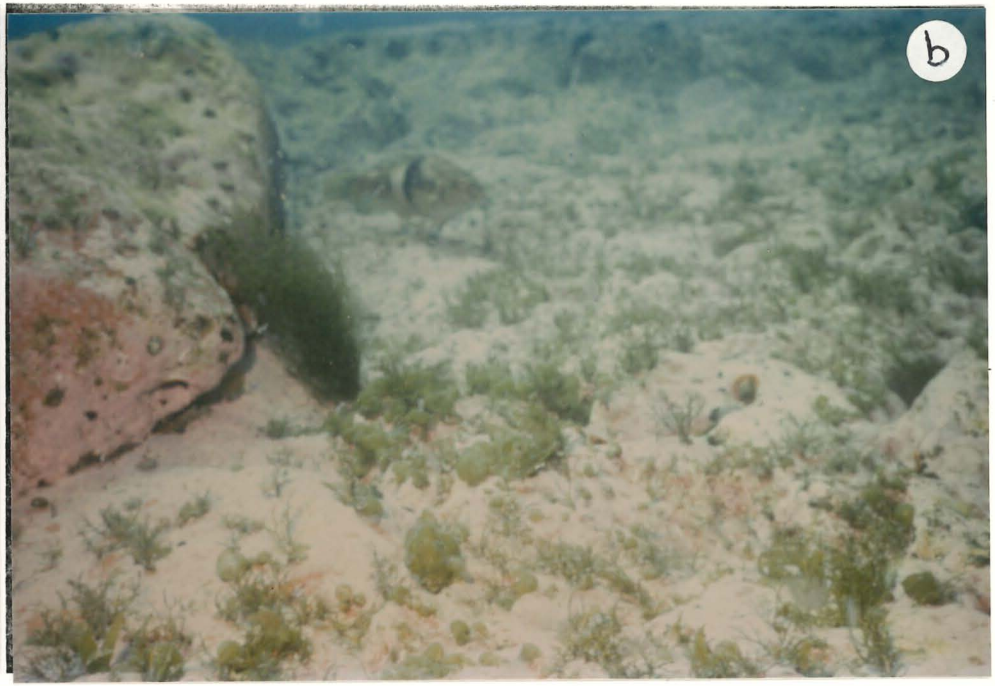

FIGURE 18 PHOTOGRAPHS OF A 10m×10m GRID FROM WHICH SEA URCHINS HAVE BEEN REMOVED

a) Immediately after culling

b) After 4 months

c) After 18 months (looking along the boundary line of the grid).