STOCK ASSESSMENT, AND ASPECTS OF THE BIOLOGY OF THE SOUTH AFRICAN ABALONE, *Haliotis midae*

By

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requirements for the degree of
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at the University of Cape Town.

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This thesis is dedicated to the memory of my father,
Raymond Quail Tarr,
for inspiring in me an interest in, and love for,
the sea and its creatures.

ACKNOWLEDGEMENTS

I would like to thank the Director, Sea Fisheries Research Institute for supporting these research programmes: without this infrastructure and manpower this magnitude of work would not have been possible. In particular Messrs P. Williams and A. Mackenzie contributed greatly to the many hundreds of man-hours necessary underwater, and in general technical assistance.

Statistical analyses in Chapter 2 were done by Dr T. Dunne, U.C.T. Department of Applied Mathematics. The assistance of members of the former Fisheries Development Corporation for operating the theodolites and preparing the initial depth contours is gratefully acknowledged. Initial digitizing of the kelp maps was carried out by the Surveys Department of the S.A. Navy. Ms C. Raubenheimer provided useful discussion on the various growth models, and wrote the maximum likelihood programme which was used to produce the growth curves.

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DECLARATION

I hereby declare that the formulation of the experimental approaches, and all the reporting and interpretation of the various projects described in this thesis, as well as creation of all the figures, were done by myself. The non-parametric statistical analyses in Chapter 2 were carried out by Dr T. Dunne, in consultation with myself. Members of the former Fisheries Development Corporation operated the theodolites during the kelp bed contouring, and prepared the draft depth contour maps. Digitizing of the 1:10 000 scale kelp maps was carried out by the Surveys Department of the S.A. Navy. General technical assistance was received from various sources within the Sea Fisheries Research Institute, but in particular Messrs A. Mackenzie and P. Williams were responsible for much of the technical and diving assistance necessary for projects of this magnitude. Ms. C. Raubenheimer wrote the maximum likelihood programme which calculated the growth parameters.

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ABSTRACT

The South African abalone fishery began in 1949, and is reliant on one species, *Haliotis midae.* Abalone divers operate from small trailered boats, launching from a limited number of access points. From initial unlimited entry to the fishery, divers numbers are now limited, and they now have a saleable, heritable entitlement to a percentage of the annual Total Allowable Catch (TAC). Annual total landings have progressed from initial unlimited amounts (a peak of 2800 tonnes in 1965), through a series of introduced controls, to the point where TAC's are now set annually for discrete fishing grounds, totalling around 640 tonnes. Research for management has been directed at diving surveys for stock assessment, habitat area determination, and tagging studies for growth rate information. Divers furnish detailed fishing statistics on catch and effort which are used, among other indicators, for management information. Management strategies incorporate a number of safeguards, and in general the prognosis for the fishery appears optimistic.

A series of diving surveys were carried out from 1980 to 1990 in eight coastal areas from Robben Island to Quoin Point. Transects covering 600m^2 were swum in 5 metre depth ranges from 0 to 20 metres. Density was found to decline with increasing depth, so the majority of the transects were swum in the 0 to 10 m range. Mean size increased with depth, with aggregations of sublegal abalone being found in the 0 - 5m depth zone. Two repeat surveys after intervals of from 4 to 6 years showed increased stock density, but high variance among results in general made statistical comparisons difficult. Buffeljags, the most easterly of the fishing grounds, showed the lowest overall as well as sublegal density. In general, sublegal populations appeared stable, and above-legal abalone covered a wide range of sizes, indicative of a broad age structure.

Mapping of the primary habitat of *H. midae*, namely the surface canopy of *E. maxima* forests, was achieved using infra-red aerial photography and superimposing the images on 1:10 000 orthophoto maps. An echo sounder survey of the kelp forests permitted 5 m depth contours to be plotted on the kelp maps. The maps were digitized, and are available in various computer formats. Habitat area data thus obtained enabled calculations to be made of the total stock of *H. midae* in discrete coastal areas. Comparison of the annual harvest with annual recruitment calculated from these results indicated a negative bias, which produced a probable underestimate of total stock. Reasons for this bias are discussed. A trend of declining depth penetration of *E. maxima* was noted from west to east, which may be related to water clarity as well as temperature.

Available growth data on *H. midae* needed to be supplemented, and accordingly tagging studies were carried out at six localities, covering fished and unfished populations, in environments ranging from the cold West coast to the warmer Eastern Cape coast. A stunted population unsuitable for production of a growth curve was found at Dassen Island, on the West coast. In general a high variability in individual growth rates was found. Contrary to expectations, the growth rates at Bird Island (Eastern Cape) were similar to those from the more typical abalone grounds of the South-western Cape. Typical von Bertalanffy growth curves were derived from annual length increment data using a maximum likelihood procedure. A movement study carried out over three years indicated that movement of large undisturbed abalone is low, and that previously reported high movement may have been due to tagging-induced disturbance of the abalone.

An unfished abalone population at Bird Island, Eastern Cape was studied on two occasions, one year apart. Length frequency distributions showed a smaller average size but similar maximum sizes, and similar mean densities compared to abalone from the SW Cape. Maturity occurred over a wide range of sizes, with 100% of the population being mature at around 60 - 64mm shell length. Study of recruitment modes indicated probable twice per annum spawning, but of intermittent success, and a growth rate of approximately 25mm p.a.

INTRODUCTION

Abalone (family Haliotidae) are large gastropod molluscs with a well-developed muscular foot. It is demand for the flesh of its foot in markets in the Orient which has led to the development of abalone fisheries in numerous countries (Mottet 1978). The South African abalone, *Haliotis midae* Linne, locally called *perlemoen*, was first harvested from the low intertidal zone on a small scale by aboriginal natives for at least 6000 years, and over the last 2000 years on a more intensive scale (Deacon *et al* 1986). However, the vast subtidal populations remained minimally exploited by man until the 1950's (Wardlow Thompson 1913), when demand for the product in Asia became known. This started a period of almost uncontrolled harvesting as an increasing number of divers, unhampered by quotas, collected and depleted the beds of abalone (Newman 1964). This resulted inevitably in a decline in availability and in catch rates, and amid anxiety for the future of the industry, a quota of 385 tonnes production mass (canned or frozen flesh) was instituted in 1968. For the first two years this quota was not filled, and was reduced each year until in 1970 (at 227 t) it first limited the already rapidly declining catch. As a result of this boom and subsequent concern, a research program was started in 1962. Its aim was to clarify various aspects of the basic biology of *H. midae* such as distribution pattern, growth rate, reproductive seasonality and movements. These were all reported on by Newman (1966; 1967; 1968; 1969) during an intensive 10 - year research programme. During the 1970's no research other than basic catch monitoring was carried out on *H. midae*. In 1980, after further concern had been expressed over continued declining catch rates, and divers were reporting that abalone numbers were severely depleted, a new research project was started. The objective of this programme was to attempt for the first time to determine the state of the existing stocks by direct survey methods and provide management advice on the status and future of the fishery. The present report comprises the first part of the collated results of the research undertaken by the author since 1980.

The first chapter serves as an introduction to the species and its fishery, and comprises a published paper on the history and management approaches of the South African abalone fishery. The paper was presented in La Paz, Mexico, in November 1989, at the First International Abalone Symposium. The contents are therefore slightly dated, but nonetheless provide valuable background and insight.

The second chapter presents the results of extensive stock assessment diving surveys which were carried out from 1980 to 1990. Density and length frequency distribution data were collected from various fished and unfished abalone populations. Chapter 3 presents the results of a kelp bed mapping and depth contouring exercise, carried out to determine the extent of the primary habitat of *H. midae*, namely *E. maxima* forests. Total stock calculations utilizing these habitat and density data yielded unsatisfactory results, and the potential causes of this are discussed. Chapter 4 presents the results of a series of growth studies by tagging, carried out over a number of years at six localities around the South African coast. Results showed that *H. midae* growth rates were previously underestimated, and, surprisingly, that no difference could be found in abalone growth rates from the

South-western Cape, and those from the warmer Eastern Cape waters. Chapter 5 presents the results of an investigation into aspects of the biology and population dynamics of a pristine abalone population from Bird Island in the Eastern Cape. Comparisons are drawn between the abalone populations of the South-western Cape, and those from the Eastern Cape.

CHAPTER 1

The Abalone Fishery of South Africa

ROBERT J. Q. TARR

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Chapter 31
The abalone fishery of South Africa

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ABSTRACT: The South African abalone fishery began in 1949 and is reliant on one species, *Haliotis midae*. Divers operate from the shore using small fibreglass dinghies or ski-boats. At the start of the fishery there were no controls on total effort by divers. Landings consequently fluctuated according to demand and then decreased rapidly as the availability of abalone declined. A production quota of 227 tonnes first limited total fishing effort in 1970. The production quota was changed to a whole mass quota in 1983. From 1986, total allowable catches (TACs) were set for each of seven fishing zones, and the sum of the TACs was 640 tonnes.

Research for management has recently been directed at obtaining data on habitat area for each fishing zone in order to facilitate annual TAC estimates for these grounds. Diving surveys have provided data on abalone densities and size composition in the fishing grounds and tagging studies will expand the knowledge on growth rates.

Since 1984, divers have been granted individual fishing rights to fixed percentages of the annual TAC, and are contractually obligated to deliver to specific factories. These 'entitlements' are fully heritable and saleable, but to date no new entrants to the fishery have resulted.

Catch statistics supplied monthly by the divers provide data on daily catch, diving time, place and area dived, and these data are presently used as indicators of fishing trends in specific fishing zones.

In the early days of the fishery a commercial abalone licence was available at a nominal £1, and is today a still nominal R60. Present export price for the canned or frozen product is estimated to be in excess of R110 per kg, with a total export value of some R16 million per annum.

Although expansion of the fishery is unlikely, the prospects for the existing fishery appear good; with catch rates improving.

RESUMEN: La pesquería de abulón de Sud Africa comenzó en 1949 y se basa en una sola especie: *Haliotis midae*. Los buceadores operan desde la costa utilizando botes de fibra de vidrio pequeños o medianos. Al comienzo de la pesquería no había controles sobre el esfuerzo total de los buceadores. Las capturas, en consecuencia, fluctuaban según la demanda y luego disminuyeron rápidamente en la medida en que la disponibilidad del abulón también se redujo. Una cuota de producción de 227 toneladas limitó en primera instancia el esfuerzo pesquero en 1970. La cuota de producción fue sustituida por una cuota de masa total en 1983. A partir de 1983 se establecieron Capturas Totales Permitidas (total allowable catches, TAC) en nueve zonas de pesca, y la suma de los tac fue 640 toneladas.

La investigación referente al manejo de la pesquería ha sido dirigida recientemente a la obtención de datos sobre las áreas habitat para cada zona de pesca con el objeto de facilitar las estimaciones anuales del tac para la zona. Prospecciones submarinas han aportado datos sobre densidades del abulón y composición por tallas en las zonas de pesca. Estudios de mercado permitirán un mejor conocimiento de las tasas de crecimiento.

Desde 1984 los buceadores recibían derechos pesqueros en forma individual sobre un porcentaje del tac anual, y por contrato estaban obligados a remitir a fábricas específicas. Estos derechos son hereditarios y vendibles pero hasta ahora no se ha registrado ninguna nueva entrada a la pesquería.

Las estadísticas de capturas entregadas mensualmente por los buceadores, proporcionan datos sobre captura diaria, tiempo de buceo, zona y área explorada, y estos datos son actualmente utilizados como indicadores de pautas pesqueras en zonas específicas.

En los comienzos de la pesquería una licencia para pesca comercial de abulón costabla 1 libra, y en la actualidad es 60 rands. El precio de exportación por el producto enlatado o congelado es 110 rand por kg, con un precio total de 16 milliones por año.

A pesar de que la expansión de la pesquería es probable, las perspectivas para la pesquería existente parecen buenas, con tasa de captura en plan de mejoría.

INTRODUCTION

This fishery relies on one species only, *Haliotis midae*, which is one of the largest of the Haliotids after the Californian *H. rufescens*. The adult fished population is mostly non-cryptic and readily visible, and most animals are to be found in depths shallower than 10 m in beds of the kelp *Ecklonia maxima*. The restricted habitat and largely non-cryptic behaviour make abalone vulnerable to divers, and the stocks are also fished by an ever-increasing number of recreational divers.

The growth, reproduction, movement and distribution of *H. midae* have been described by Newman (1964, 1966, 1967, 1968, 1969). Aspects of the assessment and management of the fishery comprise a chapter of Newman's PhD thesis (Newman, 1973). The diet was investigated by Barkai & Griffiths (1986), and the early development was described by Genade *et al.* (1988). A broad overview of the biology and fishery has been given by Tarr (1988).

THE FISHERY

The present fishery, based on subtidal stocks, began in Gans Bay in 1949, and soon expanded to cover the coastline from Cape Columbine to Quoin point near Cape Agulhas, which is still its present day extent (Fig. 31.1). This area incorporates a coastline totalling some 580 km, although not all of this is fished due to

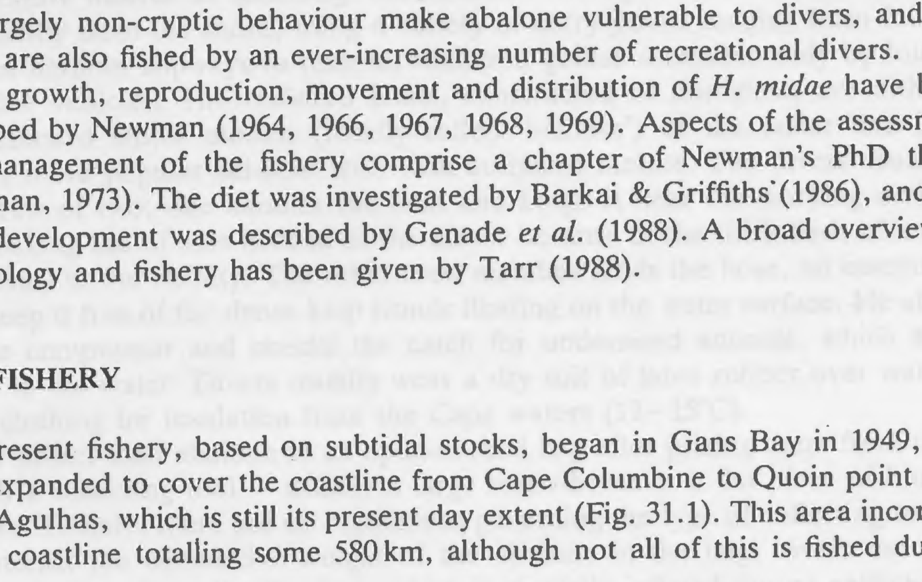

Fig. 31.1 The distribution of *Haliotis midae*, showing the commercially-fished area.

unsuitable (sandy) areas or closures. Newman (1964) described the fishery and research activities of the early 1960s.

A size limit of 10.16 cm shell breadth (12.4 cm shell length) was imposed in 1953, and increased to 11.43 cm (13.8 cm shell length) in 1954, which is still the standard today.

The fishery began with divers using traditional 'hard hat' helmet diving gear. With the dense kelp forests of *E. maxima* hindering progress they soon changed to the less cumbersome 'hookah' system which afforded divers greater mobility underwater. The hookah system is still used by today's divers so that, unlike many other commercial fisheries, today's abalone divers do not utilize advanced technology to increase their fishing efficiency. This has relevance to the use of catch-per-unit-effort indices in assessing the resource strength. The divers operate independently from the shore, using a variety of entry points ranging from fully-developed harbour slipways to remote, sheltered gullies accessible only by four-wheel-drive vehicles. The trailered boats, constructed of fibreglass, are either single outboard motor models (locally called 'bakkies') or the faster and increasingly more popular ski-boat with twin outboard motors. The divers usually have a crew of two; one handles the boat and keeps it near the working diver, usually making use of oars instead of the motor because of the thick beds of kelp (*E. maxima*) in the vicinity. The other crew member tends the hose, an essential task to keep it free of the dense kelp fronds floating on the water surface. He also tends the compressor and checks the catch for undersized animals, which are returned to the water. Divers usually wear a dry suit of latex rubber over warm woollen clothing for insulation from the Cape waters (12–15°C).

Divers collect their abalone in an open-necked bag after prizing them from the rock with a collecting tool – usually a large screwdriver or a flat piece of blunt iron blade. To date, there are no regulations governing the type of collecting tool. To counteract the cumulative weight of the abalone in the bag, divers use an airlift attached to the collecting bag, which is partially inflated during collection and fully inflated when surfacing. No use is made of shark cages, since this has not to date been deemed necessary by the divers. Furthermore, as most abalone are found in thick kelp beds, cages would be impossible to use.

A diving day consists of numerous short dives with a combined duration of about 3 hours. Due to the shallow water habitat of the abalone, and the exposed nature of the South African coastline, anything more than a light swell on the sea makes diving difficult and unprofitable as a result of reduced efficiency of the diver. Consequently, divers only operate when sea conditions are good, averaging some four days per month during the season (November–July).

After fishing, the catch is transported by road to a factory, where it is processed, mostly by hand, and either frozen or canned. There are four processing factories, three of them in Hermanus, the centre of the abalone fishery, with one near Cape Town. The factories have been compelled since 1984 by government legislation to market 10% of their product in South Africa. The balance is exported.

From April 1954 commercial abalone licences were freely available on payment of the requisite one pound fee, and the number of licensed divers swelled to some 104 in 1964. However, a phase of stricter enforcement of the licence conditions applicable to the divers forced many participants to leave, and the numbers were reduced to 68 by 1970 and to 47 by 1989.

The divers initially delivered freely according to their individual fishing effort to the various factories. From 1968, when the first production quota was set, each factory was granted the processing rights to a fixed percentage of the quota. In 1982, one of the processing factories was found guilty of major infringements of the permit conditions and its packing quota was cut permanently by 11 240 kg. This was granted to the newly formed Abalone Divers Association. Each diver therefore had an equal share of an export concession, which considerably improved their income.

In 1984, the divers became legally obligated according to their past affiliations to deliver to specific factories, ensuring the factories reliable deliveries and increasing the control of abalone transported overland. Furthermore, on the basis of individual past performance, the divers were each granted fishing rights to a fixed percentage of the existing quota, which was then called an 'entitlement'. This is fully transferable, heritable and saleable. With this development the divers were suddenly placed in a position of greater financial security, having a fixed 'investment' in the industry. A condition of sale, however, is that the members of the Abalone Divers' Association have first rights to any quota offered. This has resulted in the fishery remaining closed because any 'entitlements' which are offered for sale are bought by individual members or groups of divers, further increasing those members' share of the overall annual TAC. This has the effect of increasing the individual's total investment in the fishery, but at the same time has deprived the fishery of any 'new blood'. With the average age of the divers presently at about 45 years, however, the situation will soon change.

HISTORY OF THE FISHERY: PRODUCTION AND QUOTAS

Records of the quantity of flesh marketed after processing are only available from 1953 onwards. These are the best available indicators of historic levels of fishing and have been converted to whole mass to obtain an estimate of the annual abalone harvest. A 24% conversion rate, which is the approximate percentage meat weight (i.e. 'production') routinely recovered after processing (±23% for canning and 25% for freezing) was used up to 1975, after which actual catches are reported (Fig. 31.2).

In 1953, 770 tonnes of abalone were harvested, all of which were canned and exported to east Asia. The annual catch rose to 1500 tonnes in 1954, but then fluctuated at around 500 tonnes until 1959 because of decreased demand resulting from competition for the Oriental abalone market by other countries. Thereafter, the harvest increased considerably and peaked at 2800 tonnes in 1965. After this, despite a reasonable market, the catch declined annually as the original dense beds of abalone (accumulated stocks) became depleted.

Concern over the declining catch in the late 1960s resulted in the imposition in 1968 of a maximum production quota of 386 tonnes, which was allocated to six factories then in production on the basis of their past performance in the industry. However, this quota was not filled, and was reduced to 341 tonnes the following year, but again was not filled. Only in 1970 was the production quota of 227 tonnes filled, thereby limiting catches for the first time. It was, however,

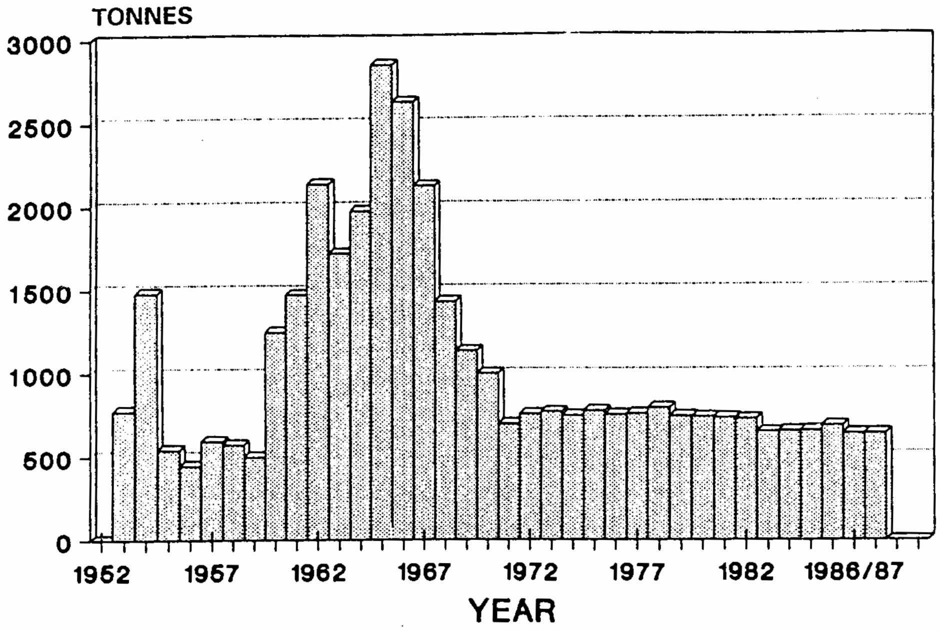

Fig. 31.2 Abalone landings over the period 1952 to 1988.

immediately further reduced to 181 tonnes in 1971, due to continued concern over the state of the resource.

From 1979 to 1982, the production quota was reduced by 10% to 163 tonnes because of concern that falling catch rates reflected declining stocks. In 1983, after certain irregularities in the implementation of the quota system had been discovered, the control system was changed from a production quota to a whole mass quota and monitored on the basis of whole mass delivered to the factories. This came about when an investigation (P. Goosen & A. Slater, unpublished report) showed that whole abalone were being cut up and marketed in pieces which, under the existing system. were not being declared against the quota. Using conversion factors arrived at during the investigation, the new quota was set at 660 tonnes whole mass, some 4% less than the whole mass delivery totals of the preceding years. The expectation that the new quota would enable production to be maintained was indicative of a substantial degree of wasteful processing in earlier years. The whole mass quota remained at 660 tonnes for a further two years.

In 1984, in response to complaints about the non-availability of abalone for local consumers, it was made compulsory to market 10% of production within the Republic of South Africa. This measure was also intended to reduce the level of black-market trade within the country. Up to 1985, the annual quota had been effective from January for each year, with the result that the quota was usually filled by November. With the advent of 10% local marketing it was suggested that the availability of fresh abalone over the holiday period was low due to the quota being filled by then. Accordingly, the season was opened two months earlier, in November 1985, and a three-month closed season was proclaimed from August to October. Since commercial quotas remained unchanged, the closed season only limited effort by recreational divers. There is no evidence that *H. midae* behaviour changes during spawning periods, so a closed season was previously not considered necessary on biological grounds.

In 1986 the quota was allocated as the sum of total allowable catches (TACs) in each of seven specific fishing zones in order to balance effort between the various fishing grounds. The more accessible fishing grounds were showing signs of excessive fishing pressure, whereas remote grounds showed higher catch rates and mean sizes. (The most heavily fished ground in the Hermanus area had also been subjected to a voluntary annual limit of 90 tonnes since 1983.) The TAC estimates for the 1986 season were based mainly on trends in catch rates and commercial sampling data. Area closures resulted in an effective 3% drop in the TAC to 640 tonnes in 1986. However, almost 50 tonnes of abalone were condemned as unmarketable due to discoloration, and the divers made special application to recover this loss by additional fishing. This was granted, so landings for 1986 are almost 50 tonnes above the TAC for that year (Fig. 31.2).

In 1986–7, a project to map the area and depth contours of the kelp forests was completed (Tarr, in prep.). This provided estimates of abalone habitat areas and TACs were then determined using these data and size and density data from diving surveys as a guideline. The sum of the TACs remained at 640 tonnes.

RECENT RESEARCH FOR MANAGEMENT

Tagging of *H. midae* has been carried out in five of the seven fishing zones in order to determine whether growth rates differ between them (Tarr, in prep.). More than 6000 abalone have been tagged, with a recovery rate of about 18%.

Stock-assessment surveys have been carried out by research divers in all the major fishing zones. Numerous 600 m^2 belt transects were swum at 5 m depth intervals and data collected on density and size composition of the abalone populations (Tarr, in prep.).

More than 90% of the abalone population are found within kelp (*E. maxima*) stands visible from the sea surface. To obtain data on the habitat area of fishing zones, kelp forests were photographed from the air using infra-red film (Plate 31.1) and maps were prepared at a scale of 1:10 000 (Tarr, in prep.). These data are presently used in TAC estimates for the four main fishing zones, which together yield over 80% of the total annual TAC.

Because *H. midae* distribution is related to depth, depth contouring of the main fishing zones was performed using an inflatable boat and echo sounder. Position fixing for mapping purposes was carried out by shore stations using theodolites (Tarr, in prep.).

STATISTICS

From the inception of the industry in 1949 until 1972, divers were not required to submit catch returns. From 1960 to 1970, rough catch per unit effort (CPUE) analyses were derived from factory delivery and production records. The only measure of effort then obtainable was 'licensed diver months' (Newman, 1973). After this period, divers submitted monthly catch returns which provided data on

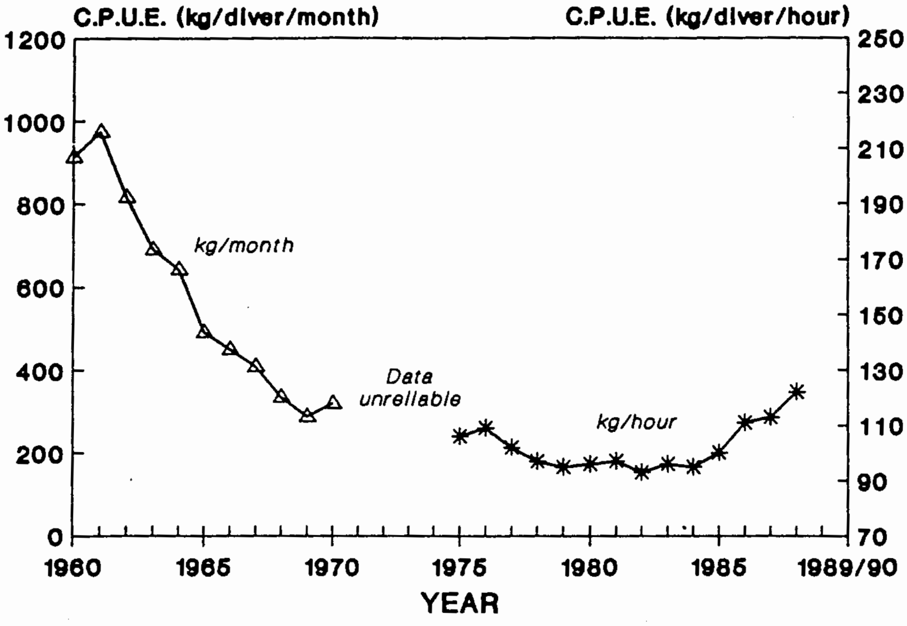

Fig. 31.3 Catch per unit effort (CPUE) trends for all areas combined using two different indices.

numbers and mass landed, diving place, total hours dived and the factory to which the catch was delivered. These data were used from 1975 for CPUE analyses, with CPUE being measured as kg whole mass per diver hour. The CPUE trends are shown in Fig. 31.3, using two different *Y*-axis scales. (Data from 1970 to 1975 in prep.). A clear declining trend is apparent up to 1970, which may have continued at a slower rate up to 1982. It appears, however, that an overall improvement in catch rates began in 1984. In the present fishery management, CPUE from the entire fishery is not used directly for assessment since combined figures may partly reflect changes in fishing patterns and not purely abalone abundance. Accordingly, CPUE per fishing zone is now used with other information in TAC estimations (Fig. 31.3).

From 1981. more detailed information was required regarding the locality dived in order to assess fishing effort more accurately on the various fishing grounds. Various checks were introduced to ensure greater accuracy of the catch and effort data.

When the whole mass quota system was changed for the 1985–6 season to a system of TACs for discrete fishing zones, the allocation of TACs was based mainly on fishery trends such as total catch per zone and CPUE assessed for each fishing zone. Thus, the statistics submitted by the divers contribute valuable data which are used directly in the management of the resource.

ECONOMICS

From 1953 to 1955, the total value of abalone exports was estimated to be between £70 000 and £85 000 per annum, which amounted to an export price of about £0.40 per kg (approximately R1.60/kg). A commercial abalone licence was then obtainable at £1, or the equivalent of about 2.5 kg exported product. The licence fee was raised to a still-nominal R40 in 1966 and to R60 in 1986–7. The current export price is kept secret among the various companies, but is conservatively estimated to be above R110/kg. Thus the cost of a licence for a diver has decreased from the equivalent of 2.5 kg export product to about 0.6 kg export product. The present value of the export industry is estimated to be R16 million, which is all marketed to Hong Kong.

In recent years the market for shells has improved, with most being exported to east Asia for use in various handicraft industries. Present export price estimates range from R500 to R800 per tonne. *Haliotis midae* does not, however, have a very good quality shell for craft use due to a high incidence of boring organisms.

Abalone divers in the past were considerably underpaid by the factories, for example in 1973 at R0.15 per kg whole mass. After the formation of the Abalone Divers Association in 1982 the negotiating power of the divers increased and their price improved. Divers are presently (1989) being paid R9/kg. This, combined with their recently acquired export concession, has meant that by virtue of their early entry into the fishery the present abalone divers have attained a position of considerable financial security for a relatively low capital investment.

CONCLUSIONS

With a highly accessible and relatively non-cryptic adult population and with no clear indication as to what minimum stock size is adequate to ensure continued recruitment, management strategies incorporate a number of safeguards. Present measures include the following:

(1) A relatively large size limit which ensures 3 to 4 years' protected spawning during which natural aggregations are not disturbed.
(2) Commercial fishing effort is monitored and regulated on an annual basis for each of the seven fishery zones. These TAC estimates are based on the habitat area of each zone as well as analysis of the normal fishery trends.
(3) Legislation ensures maximum availability of abalone products on the local market during peak holiday periods, thereby reducing black-market pressures.
(4) Recreational divers require a permit to catch the daily bag limit of five per person per day.
(5) A 3-month closed season limits the effort of the recreational diver.
(6) An abalone reserve (proclaimed in 1983) and a general marine reserve are situated within the most heavily fished coastline, and may provide an additional larval supply to adjacent fished grounds.

The policy of limited catches per area which was first implemented voluntarily by the divers for one area (near Hermanus) in 1983, and then formally for the whole fishery in 1985–6, appears to be working. The area near Hermanus which has been the most heavily fished area since the start of the fishery, due to its close proximity to the homes of most of the divers, serves as the best example. Figure 31.4 shows the CPUE trends for this zone since 1977, together with the annual percentage of the sampled commercial catch which occurred within the first 5 mm

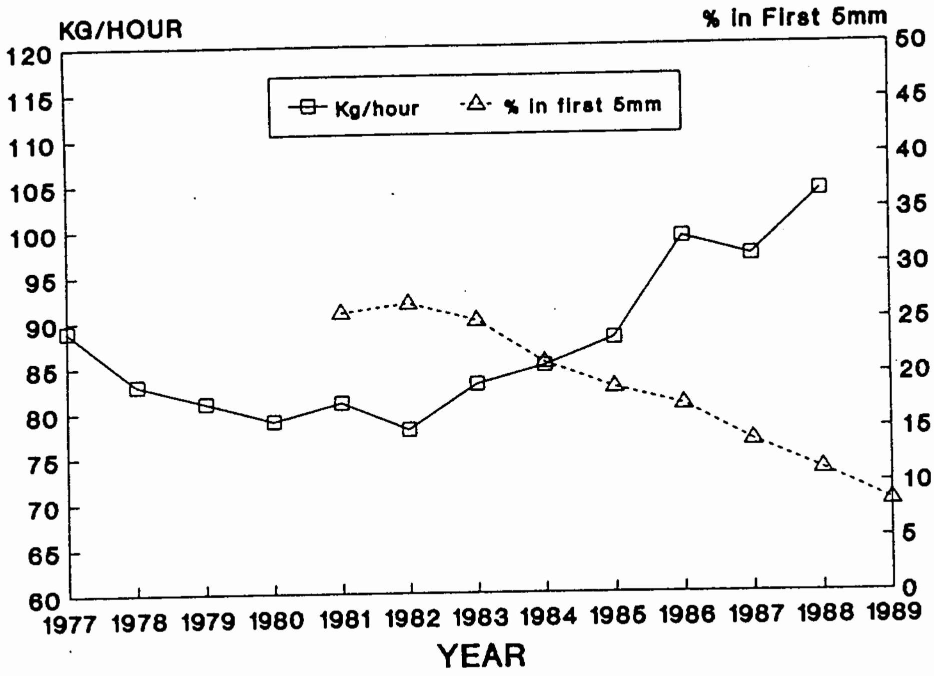

Fig. 31.4 Catch per unit effort (CPUE) and percentage recruit fishing in zone C.

size class above the size limit (i.e. the approximate percentage of the commercial catch reliant on growth recruitment). These indicate a trend of increasing catch per hour since 1982, which is mirrored by a steadily decreasing dependence of this fishing zone on growth recruitment.

The abalone fishery in the southwestern Cape appears to have progressed from a 'free-for-all' situation in the 1960s with few controls, when dense accumulated beds of large abalone were harvested at will, to a closely monitored and tightly managed fishery which is apparently showing signs of an improvement for the first time.

ACKNOWLEDGEMENTS

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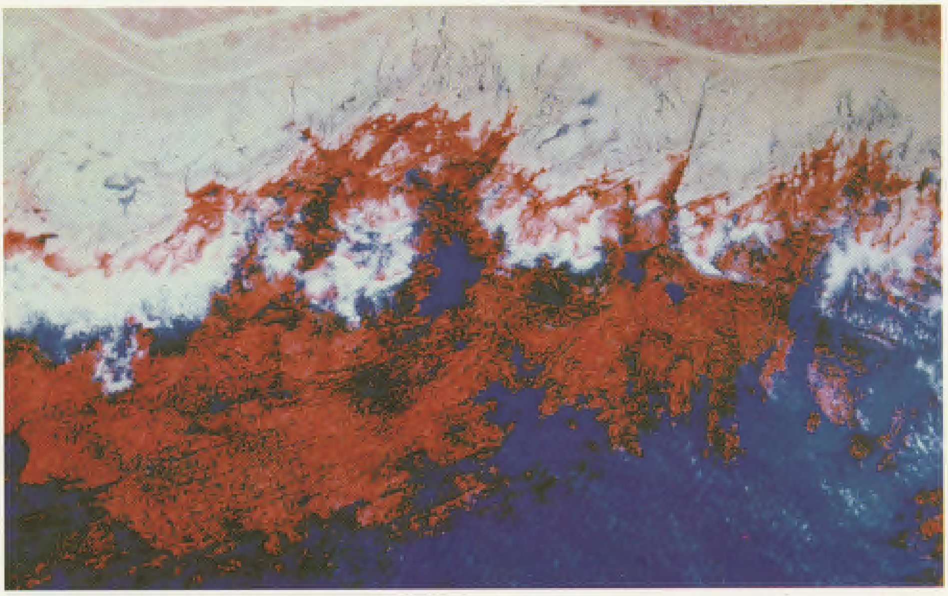

Plate 31.1 Infra-red aerial photograph of kelp forests at extreme low tide.

Plate 31.1 Infra-red aerial photograph of kelp forests at extreme low tide.

CHAPTER 2

STOCK ASSESSMENT SURVEYS

INTRODUCTION

Traditional monitoring of many fisheries often relies heavily on indirect indices of stock abundance such as catch per unit effort (CPUE) to provide an indication of trends in stock abundance (Murray 1982; Harrison 1983; Bates 1984; Geaghan and Castilla 1986; Tegner 1989). The CPUE trends for the South African abalone fishery up to 1980 indicated that a continuous, gradual decline in biomass had taken place since the start of the fishery (Tarr 1992). Together with this, there were repeated rumours from fishermen, as well as from recreational divers, that abalone were becoming scarce. There were also allegations that recruitment was failing because few small abalone could be seen by commercial or recreational fishermen.

It therefore became essential to attempt a direct survey of the abalone stocks in the major fishing grounds. The objectives were to assess the density and length frequency of the "undersize" resource, as well as that of stocks above the legal size limit, and to determine whether the population showed any signs of overfishing. It was expected that if the allegations of past overfishing were correct, the population would reflect a very low density of legal-sized animals, possibly showing a knife-edge cut-off of numbers above the size limit (Witherspoon 1975; Farlinger and Bates 1986); and/or a very limited range of size- and age-classes above the minimum legal size (MLS) of 114 mm shell breadth. If recruitment overfishing had been taking place for an extended period, then extremely low densities of sublegal abalone would also be expected.

METHODS:

A pilot survey of the abalone beds was carried out in 1979 by a small team of divers from the Sea Fisheries Research Institute (Pollock, D.E. pers comm). Results are not available, but this survey demonstrated that it was not possible to lay series of weighted transect lines through the dense upper canopy of *Ecklonia maxima* kelp forests from an inflatable boat. Consequently, the first objective of the new survey, which began in 1980 in the H.F. Verwoerd Marine Reserve at Betty's Bay, (Fig. 1), was to determine the most effective survey technique to be used to assess abalone.

A number of factors needed to be considered in establishing the most practical survey technique. Large areas of seabed were involved, and, like abalone populations world-wide, the abalone were extremely patchy in their distribution (Newman 1969; Breen and Adkins 1979; Branden and Shepherd 1982; Clavier and Richard 1984; Guzmán del Próo 1992; Schiel 1992), on a scale of tens of metres. It was therefore desirable to cover as large an area of seabed as possible during any dive, in order to obtain as representative as possible a coverage of the seabed (Forster 1962; Clavier and Richard 1984; Petherick 1986; Peck and Culley 1990). A transect method therefore appeared more practical than the use of

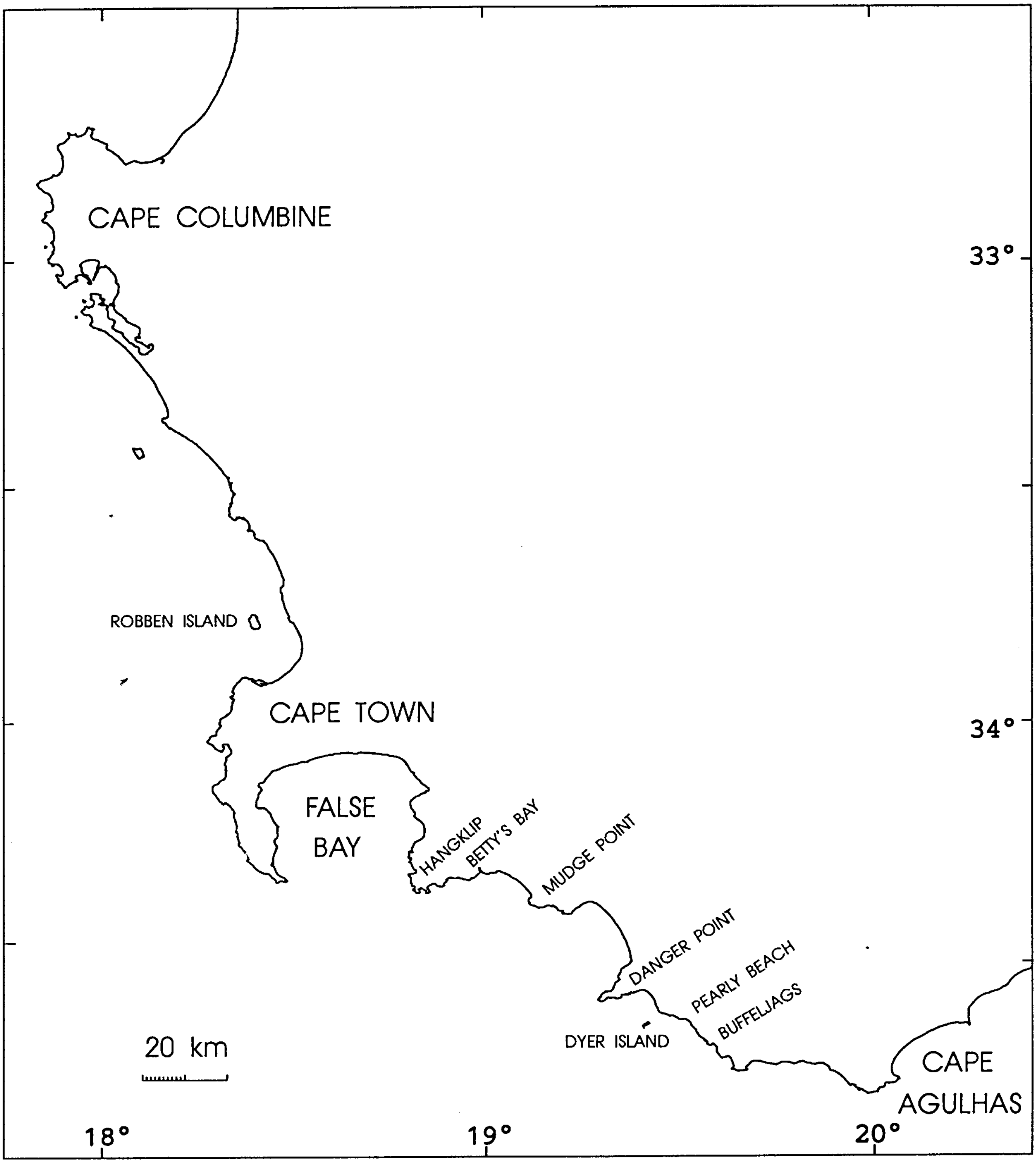

Figure 1: South Western Cape coastline showing survey areas.

quadrats, given the practical difficulty of moving a quadrat around in dense kelp, as well as the limited area coverage offered. Furthermore the extremely dense surface canopy of *E. maxima*, particularly at low tides, made both access and moving about by inflatable boat extremely difficult. Thus the survey method had to involve the minimum amount of movement on the surface by boat, as well as maximum coverage of the seabed once a station was occupied. Diving time was limited by both the endurance of the divers' twin 7 litre SCUBA, as well as cold (temperatures usually ranged from ~11 - ~16°C). The method developed was a belt transect two hundred metres long and 3 metres wide, swum parallel to the shore. Because abalone densities were known to decrease markedly with increasing depth (see Fig. 6) transects were swum in 5 metre depth ranges, covering from 0 - 20 metres depth, the maximum depth at which significant numbers of *H.midae* were found in Betty's Bay. Each complete survey station therefore consisted of 4 transects covering the 0 - 5 metre, 5 - 10, 10 - 15 & 15 - 20 metre depth ranges. In practice, however, it was soon found that particularly in commercial areas, insignificant numbers of abalone were to be found deeper then 10 metres depth, and in consequence few transects in these areas extended deeper than 10 metres.

Once a station had been selected, the starting position of each transect was determined at a point which would avoid exposed reef or sandy areas. Thereafter the course of the transect was dictated primarily by a compass bearing, with occasional deviations necessitated by rough water. The transect line, on a reel, was fixed to the anchor of the inflatable boat, then swum along the bottom by two divers, one of whom periodically weighted down the line with loose rocks. The empty reel at the end of the line was then buoyed. The divers returned along the line, one on each side, counting all exposed abalone within 1,5 metres on each side of the line. The counting width was initially determined with the use of a 1,5 m length of line which was the equivalent of a diver's outstretched arm span. With experience, however, the line was discarded, and each diver used his own arm-span to determine the width of the swathe, occasionally checking with the line for confirmation. This greatly simplified this transect method. Counts and depths were recorded every 10 metres by each diver, resulting in 40 counts, each covering 15 m^2 of seabed. This method provided information regarding abalone density, distribution and patchiness. Simultaneously another dive pair would make a random collection of exposed / emergent abalone near the transect.

It is recognized that this method intentionally underestimates the small (< 50 mm) cryptic size classes of abalone in the population, since only non-cryptic abalone were counted and sampled (Breen and Adkins 1979; Clavier and Richard 1984; Tegner *et al* 1989). Sampled abalone were then measured in the boat after the dive and shell breadths recorded to the nearest mm. The abalone collected were subsequently returned to the seabed. On the assumption that the size composition of the random sample was representative of those abalone counted along the transect, the estimated size frequency distribution of the actual population in each 600 m^2 transect was calculated.

This survey technique permitted a single site to be occupied by the boat for the full duration of a dive, which usually lasted from 50 to 75 minutes. The counts, being recorded every 15 m², gave an indication of the population distribution over the seabed, and the sum of the diver counts provided data on the density of abalone over a 600 m² sector of seabed. Both anecdotal information from commercial divers and experience gained from the early stages of the survey indicated that the major proportion of the abalone population existed in kelp forests. Therefore all stations were chosen so as to commence within a kelp forest, and the direction of the transect was chosen so as to, as far as possible, remain within the kelp.

The primary objective of the diving surveys was one of standing stock assessment, and no quantitative records were made of other biota encountered on the transects, although comments were recorded on the transect logs on an *ad hoc* basis, when significant features were noted by divers, for example major reef coverage by the reef worm *Gunnarea capensis* or large "barren" areas dominated by crustose corallines. The typical kelp forest ecosystem within which the abalone occur has already been adequately described by Field *et al* (1977), Velimirov *et al* (1977), Field *et al* (1980) and Branch and Griffiths (1988).

This survey method, like most abalone diving surveys (Forster 1962; Branden and Shepherd 1982; Petherick 1986; Carolsfeld *et al* 1988; Tegner 1989; Peck and Culley 1990; Gilberto and Mauricio 1992; Guzmán del Próo 1992) was extremely manpower - intensive, which imposed certain logistic constraints on the frequency with which surveys could be carried out. In addition, due to the shallow areas

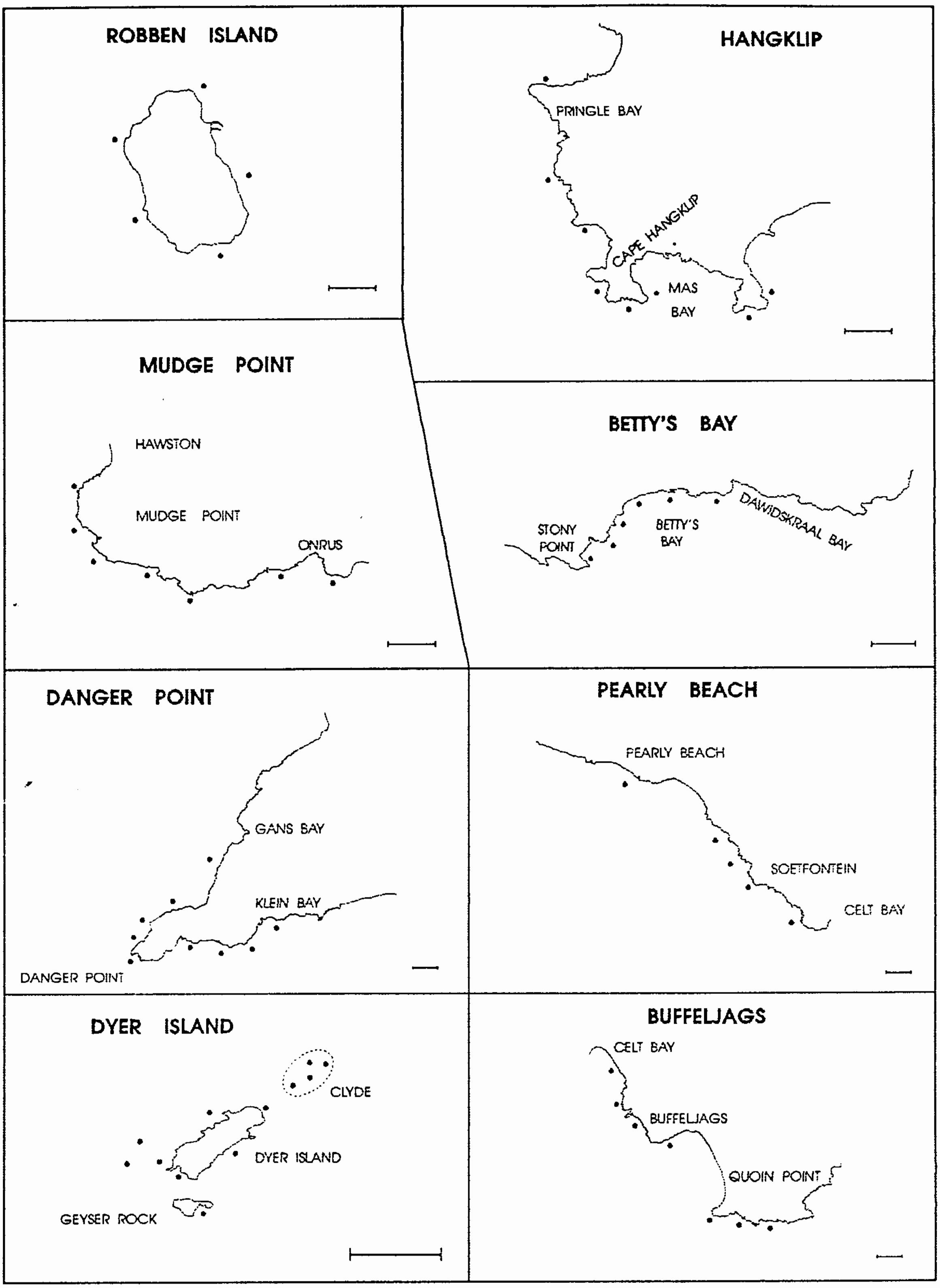

Figure 2: Map showing survey areas. Approximate positions of stations are indicated (•). Scale Bar = 1 km.

involved and the inherently high - energy nature of the Southwestern Cape's seas, major surveys (involving sixteen or more transects) were usually possible only once per annum, during the late summer periods of February or March. A total of eight coastal regions: Robben Island, Cape Hangklip, Betty's Bay, Mudge Point, Danger Point, Dyer Island, Pearly Beach, and Buffeljags (Fig. 1) were surveyed. Mudge Point and Dyer Island were re-surveyed after intervals of 4 and 6 years respectively. Fig. 2 shows the survey areas and the approximate positions of the diving stations (all depths inclusive). This report thus covers the results from these ten diving surveys over the period 1980 to 1990. Results will be presented for each area surveyed, moving from west to east, and the combined results presented in the Discussion.

RESULTS:

Data from individual transects showed extensive evidence of clustering of animals. It was not, however, possible to find a suitable method for retrieving and utilizing the clustering information included in the transect data (T. Dunne, *pers comm*).

Density data from the surveys have been summarized as numbers of abalone per 600m^2 transect. These were averaged for each survey, to yield an estimated mean density (± SE) for each survey area and depth range. This aggregation into transects as units of observation did not fully compensate for the effects of clustering, and substantial variation occurred between transects at most of the survey areas.

	0 - 5 m DEPTH			5 - 10 m DEPTH		
AREA AND YEAR	No. OF TRANSECTS	MEAN ± SE	% LEGAL	No. OF TRANSECTS	MEAN ± SE	% LEGAL
Robben Island 1985	5	506 ± 412	67	5	117 ± 33	78
Hangklip 1983	9	175 ± 51	25	10	57 ± 11	60
Betty's Bay 1980	6	484 ± 114	69	5	106 ± 20	92
Mudge Point 1981	8	185 ± 46	21	8	28 ± 5	61
Mudge Point 1985	9	603 ± 196	24	9	70 ± 15	49
Danger Point 1982	10	323 ± 80	17	9	82 ± 15	39
Dyer Island 1984	6	512 ± 161	29	11	177 ± 62	23
Dyer Island 1990	5	853 ± 234	41	6	407 ± 220	39
Pearly Beach 1987	5	180 ± 64	36	5	27 ± 08	71
Buffeljags 1986	8	142 ± 36	44	6	19 ± 5	62

Table 1 (a): Average abalone density (± SE) per 600m² transect for all areas. SE based on number of transects.

	0 - 5 m DEPTH		5 - 10 m DEPTH	
AREA AND YEAR	No. OF TRANSECTS	MEAN ± SE	No. OF TRANSECTS	MEAN ± SE
Robben Island 1985	5	169 ± 150	5	25 ± 10
Hangklip 1983	9	132 ± 43	10	23 ± 9
Betty's Bay 1980	6	149 ± 56	5	8 ± 3
Mudge Point 1981	8	147 ± 45	8	11 ± 3
Mudge Point 1985	9	457 ± 149	9	36 ± 11
Danger Point 1982	10	267 ± 72	9	50 ± 12
Dyer Island 1984	6	365 ± 143	11	137 ± 54
Dyer Island 1990	5	505 ± 139	6	247 ± 144
Pearly Beach 1987	5	115 ± 50	5	8 ± 4
Buffeljags 1986	8	80 ± 23	6	7 ± 2

Table 1 (b): Average density of sublegal abalone (± SE) per 600m² transect for all areas. SE based on number of transects.

Moreover the variation as measured by the variance of transect counts was subject to substantial changes within survey areas. The causes of these differences were probably related to factors such as differing reef profiles, substrate types, exposure to wave action or possibly historic larval recruitment patterns. These results are summarized in Tables 1(a) and 1(b).

Comparisons of sites were therefore based on methods which made minimal assumptions about the source of the transect data, and conventional t-tests and their equivalents were avoided (T. Dunne *pers.comm.*). A reasonable assumption was that it was meaningful to compare the survey areas, and that the comparisons would not be radically affected by the fact that surveys were completed in different regions. (The Clyde area data (from Dyer Island) were not used in these analyses because they reflect incompatible depth ranges (3-8m) over the survey years.)

Mann-Whitney (MW) tests for the comparison of two data sets and the Kruskal-Wallis (KW) tests for the simultaneous comparison of several independent data sets, were applied to the complete sets of transect totals. These non-parametric methods are conservative in that they rely on the data alone to establish evidence of changes without any simplifying or pertinent information being derived from associated models for the data.

There was very clear evidence for the fact that abalone are more abundant in the shallower 0-5m waters rather than the 5-10m range ($p < 0.001$). This conclusion is based on the observation that at each survey area in each year, the transect means were substantially different across the depths, and the shallow water value is consistently larger than its deeper water counterpart. It was therefore appropriate

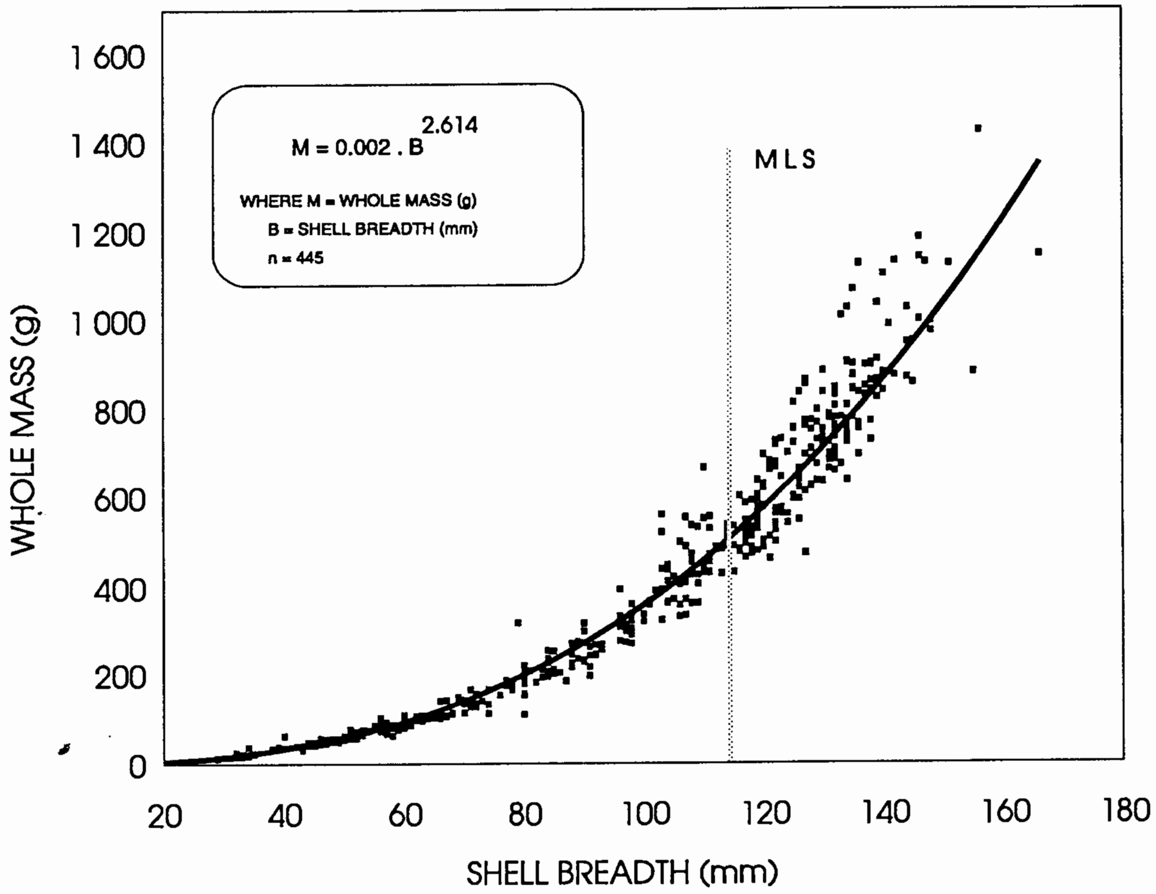

Figure 1: Shell breadth: whole mass relationship for *Haliotis midae.*

to examine depth levels separately.

In addition, it is valid to consider population strength in terms of biomass (Petherick 1986), especially since fecundity in abalone is directly proportional to biomass (Newman 1967; Poore 1973; Avilés *et al* 1985; Wells and Keesing 1989). Since the sampling procedure under-represents the smallest size classes of abalone, biomass also reduces the effect of this sampling error (Clavier and Richard 1984). Newman (1968) did not determine shell mass in his morphometric determinations, therefore for the purposes of this study, a sample of 444 fresh abalone from 30 mm shell breadth was used to determine the shell breadth : whole mass relationship for *H. midae*. The resultant regression is shown in Fig. 3, and reflects the relationship:

$$\text{Whole mass (g)} = 0{,}002 \bullet B^{2.614} \quad (R^2 = 0.985)$$

where B = shell breadth in mm

Shell breadth data were then converted to biomass and this was applied to the transect data. These results are summarized in Table 2.

	0 - 5 m DEPTH		5 - 10 m DEPTH	
AREA AND YEAR	BIOMASS (kg)	% LEGAL BIOMASS	BIOMASS (kg)	% LEGAL BIOMASS
Robben Island 1985	306	83	78	92
Hangklip 1983	59	47	32	78
Betty's Bay 1980	268	85	79	97
Mudge Point 1981	61	36	14	76
Mudge Point 1985	204	40	32	65
Danger Point 1982	101	32	34	61
Dyer Island 1984	178	51	50	49
Dyer Island 1990	348	65	157	64
Pearly Beach 1987	72	58	16	86
Buffeljags 1986	61	69	11	82

Table 2: Average abalone biomass in kg. per 600m² transect for all areas.

Results by coastal region:

Robben Island 1985:

This island is situated in Table Bay on the cold West coast, and due to the imposition of a 1 mile security zone around the island, its abalone stock has historically been protected. However, it was never a proclaimed marine reserve, and a commercial catch quota was allocated when the security zone was conditionally lifted in 1986. Our surveys however predate this allocation to harvest the virgin stock.

Five stations were selected, at which 0 - 5 m and 5 - 10 m transects were swum. One 10 - 15 m transect was swum with no abalone recorded. Three stations were on the sheltered southern and eastern sections of the island, and two on the exposed western side (which can only be approached on exceptionally calm days).

One station, on the NE corner of the island, yielded exceptionally high counts of abalone, with a total count of more than 2300 abalone / transect (nearly 4 animals/m^2: higher than recorded on any other survey). The highest density per sector recorded on this transect was 9,6 animals/m^2. Average densities from the five transects are given in Table 1.

The length frequency distributions (Fig. 4) clearly demonstrate the accumulation of large abalone above the size limit in both depth ranges. This is commonly

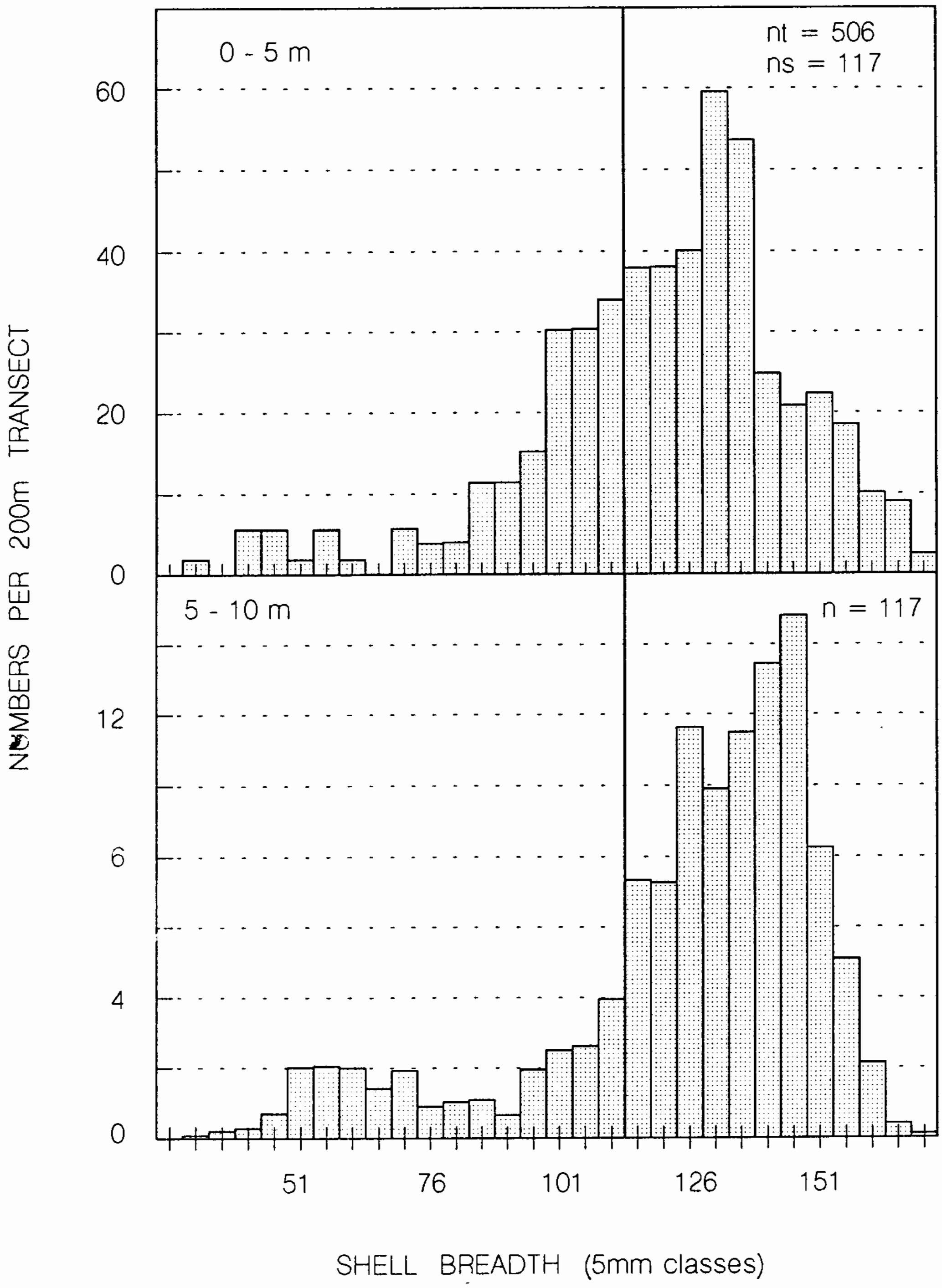

Figure 4: Robben Island (1985): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

associated with abalone populations which have not been fished for many years (Shepherd 1984; Carolsfeld *et al* 1988). The modal size was 131 mm for the 0 - 5 m depth range and 146 mm shell breadth for the 5 - 10 m depth range.

Hangklip 1983:

This area comprises a convoluted coastline with small bays and headlands (Fig. 2). The shoreline is frequently exceptionally steep, a pattern which is reflected in the inshore sublittoral. This has the result of restricting the area of seabed within the 0 - 10 m zone, and in consequence the kelp beds are narrow, other than in the few bays.

A total of nine 0 - 5 m and ten 5 - 10 m transects were swum, and the average abalone density is given in Table 1.

The average length frequency per transect is illustrated in Fig. 5, which shows a high proportion of sublegal abalone in the 0 - 5 m range. The abalone population in the 5 - 10 m range appears to comprise mostly legal-sized animals, and there is not the marked cut - off above the size limit which is often associated with heavily fished commercial areas (Witherspoon 1975).

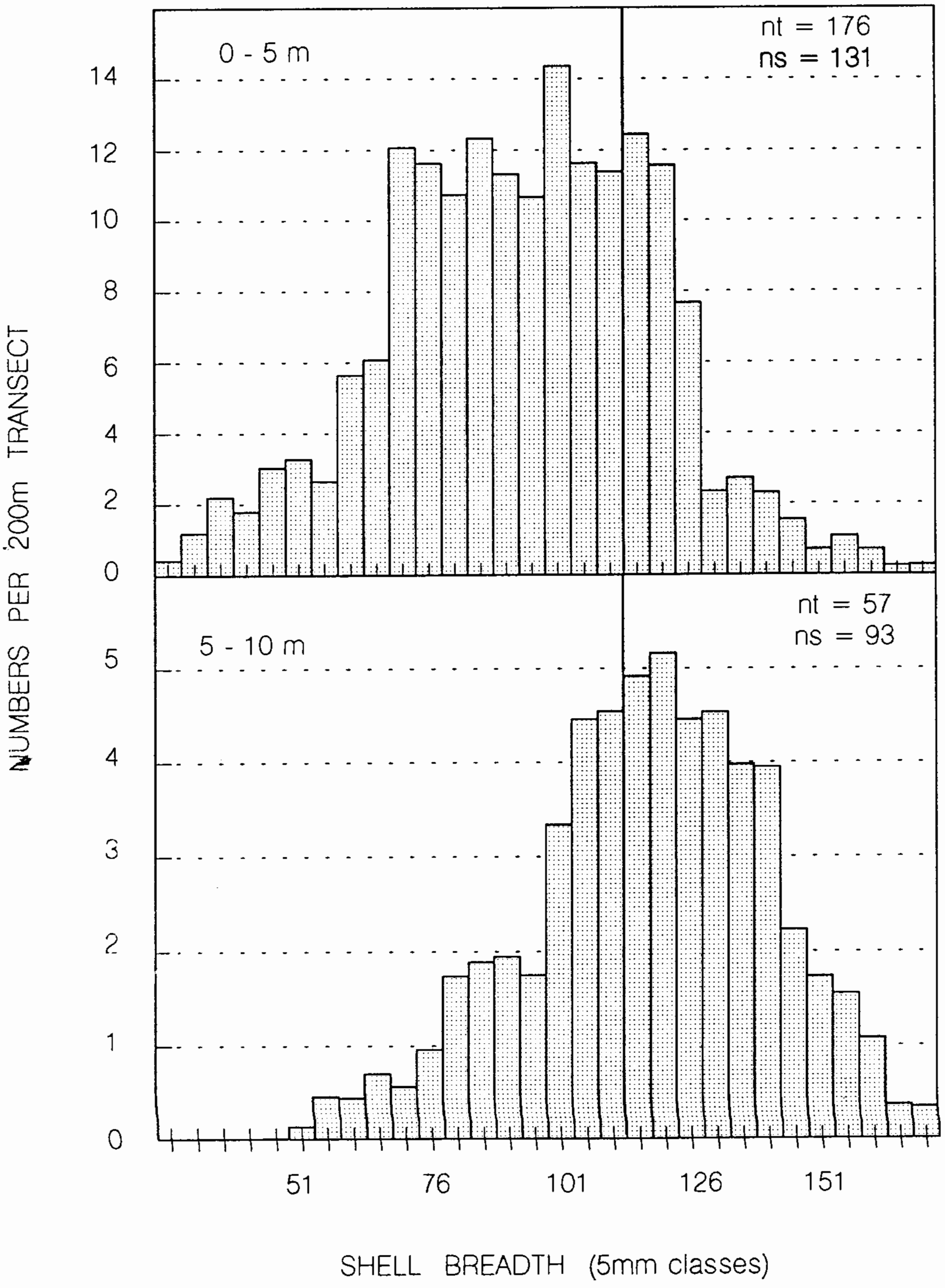

Figure 5: Hangklip (1983): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

Betty's Bay 1980:

This area, unlike most of the others, was surveyed at intervals between March 1980 and January 1981, during which time the final survey technique was developed. Betty's Bay is situated within the most productive sector of the coast, and was proclaimed a general marine sanctuary (H.F. Verwoerd Marine Reserve) in 1966. Consequently it was chosen as a testing ground for initial survey trials in 1980. In addition, it provides a comparison of abalone population structures between fished and unfished areas, the bay having been closed to both commercial and recreational fishing for some 14 years prior to our first surveys.

Six stations were sampled at which six 0 - 5 metre, five 5 - 10 metre, three 10 - 15 metre and one 15 - 20 metre transects were swum. It was during this trial period that the typical depth distribution of *H. midae* became very apparent. This is illustrated in Fig. 6 which shows the average size and density distribution of abalone per 600 m^2 transect within each depth range. The vertical scale on the graphs has been held constant in order to illustrate the changes in abundance with depth. It can be seen that the modal sizes occur at 121 mm & 136 mm for the 0 - 5 m and 5 - 10 m ranges respectively. No data are shown for the 15-20 m transect since no abalone were encountered. This illustrates the typical "top-heavy" population structure characteristic of natural abalone populations (Breen and Adkins 1979; Branden and Shepherd 1982; Clavier and Richard 1984; Shepherd 1984) which occurs due to the longevity and low natural mortality of adult abalone. As

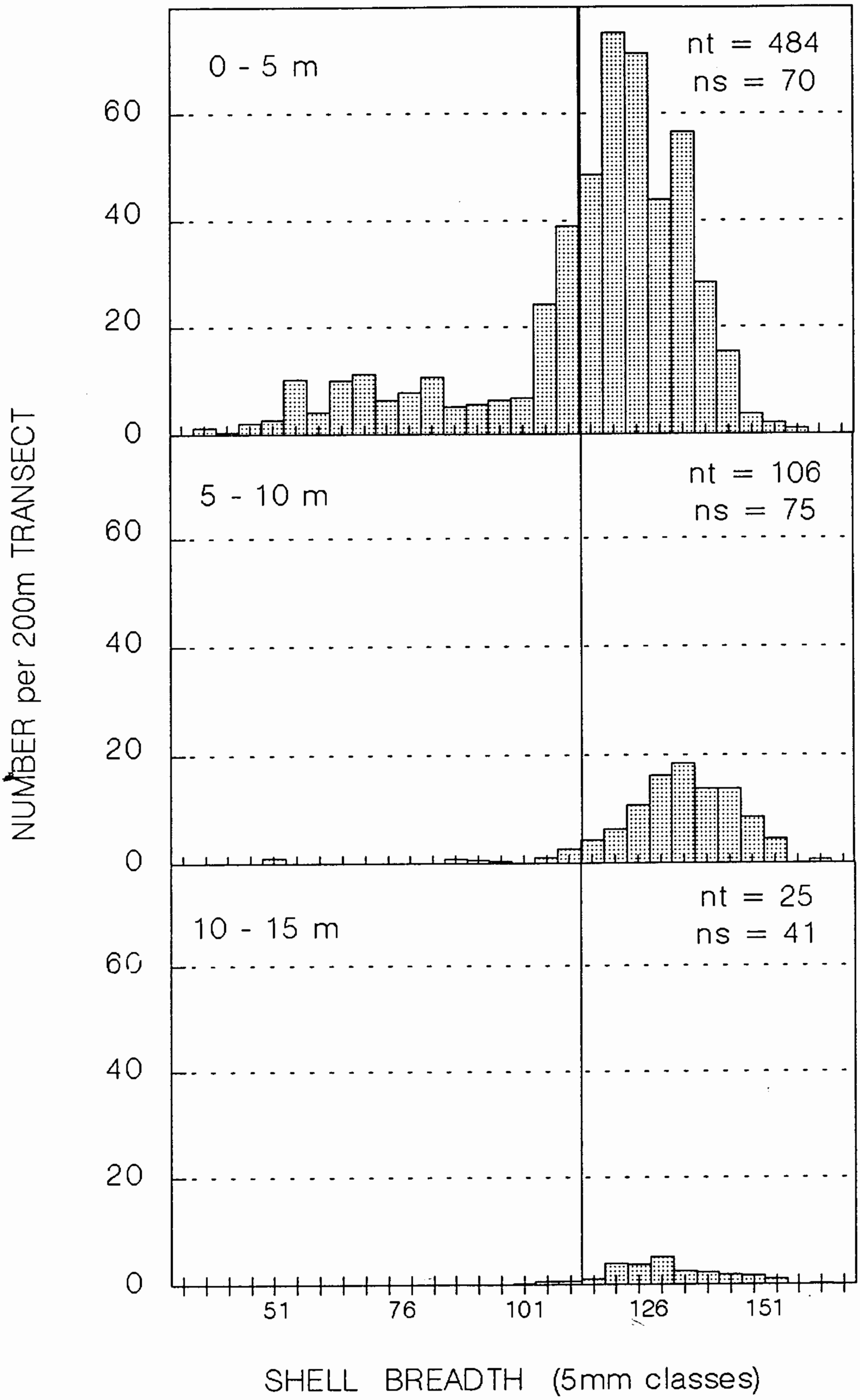

Figure 6: Bettys Bay (1980): Mean abalone shell breadth distribution per transect.nt = number of abalone per transect; ns = number of abalone per sample.

with Robben Island, occasional very high densities (up to 10,3 animals/m² per transect sector), were again encountered. Actual densities are given in Table 1.

Mudge Point 1981:

This 9 km stretch of coast was first surveyed in February 1981 by two three - man teams of divers. This fishing ground, as evidenced by analysis of commercial catch return data, had shown the highest concentration of fishing effort for many years, yielding an average of 25 % of the annual South African quota.

The kelp beds of Mudge point, the major area of this fishing ground, are extremely dense, particularly in the 0 - 5 metre depth range. In places they extend in a continuous belt for many hundreds of metres offshore. This provides a considerable swell - dampening effect (Jackson and Winant 1983), and in some areas dense stands of the "sargassum" seaweed *Sargassum longifolium* were encountered which hindered the transects. The seabed was mostly solid reef of moderate profile, intersected with occasional long boulder - bed gullies.

A total of eight stations were occupied at each of which transects were swum at 0 - 5 m, 5 - 10 metre and 10 - 15 metre depth ranges. Spot dives and one transect confirmed that no significant numbers of abalone occurred in the 15 - 20 metre depth range. No data will be presented for the 10 - 15 metre transects since an average of only three abalone per transect was counted. In total, 23 transects were swum, covering some 13 800 m² of seabed. The average length frequency

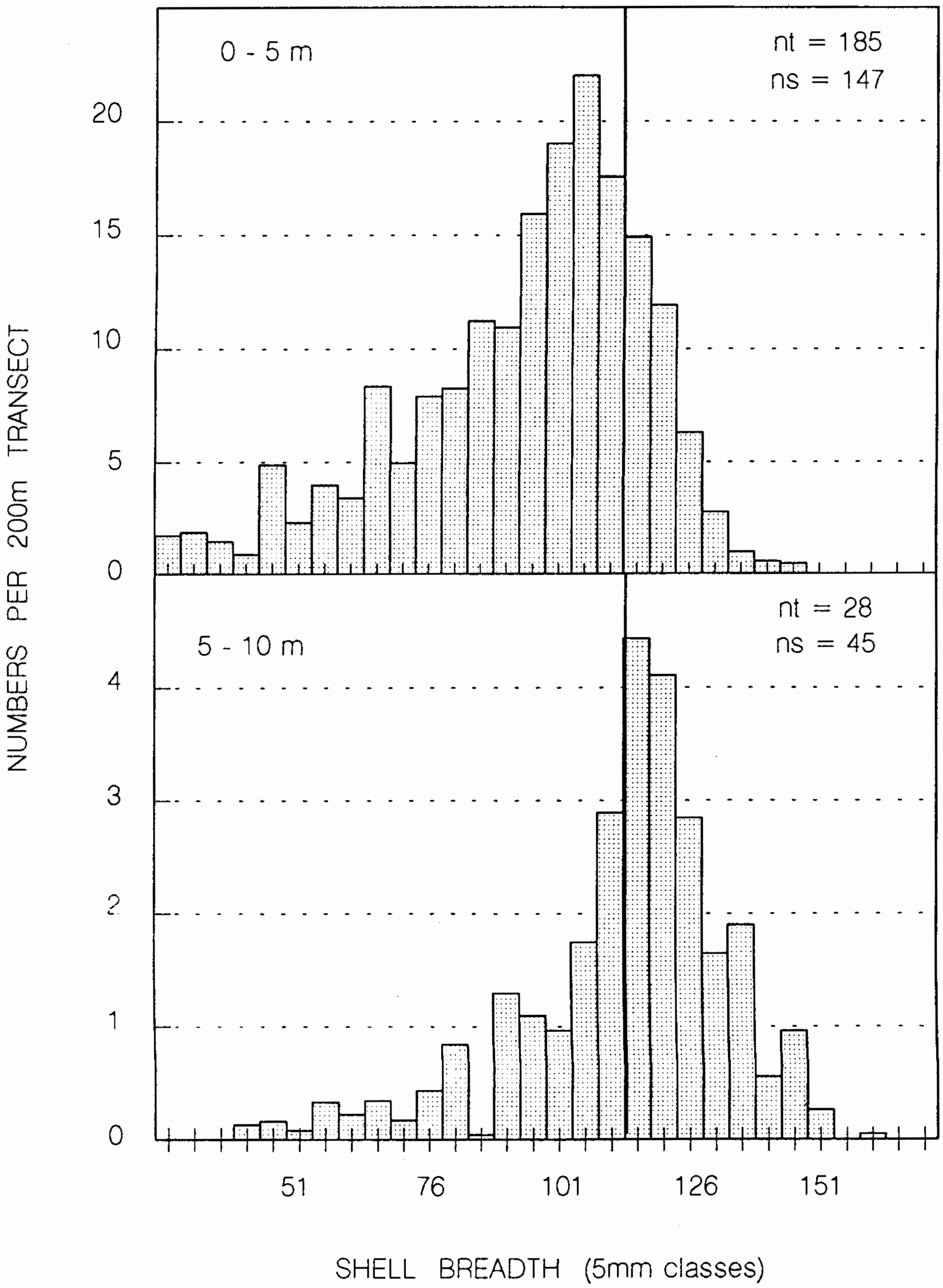

Figure 7: Mudge Point (1981): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

distribution of abalone per transect are shown for the two shallower depth ranges in Fig. 7 and the density of abalone per transect is shown in Table 1. Fig. 7 shows the population mode at 106mm for the 0 - 5 m range, and 116 mm for the 5 - 10 m range. This shows a major shift in mode when compared to the unfished Betty's Bay population (Fig. 6). This was to be expected, but the apparent reduction in abalone density in the size class just below the size limit and the type of change in overall length frequency distribution gave cause for concern. This may reflect the area's history of high fishing effort, and in addition it is possible that bar-cut mortality may have been significant (Burge *et al* 1975; Mottet 1978; Boutillier *et al* 1985; McShane and Smith 1986; Tegner *et al* 1989), whereby the sublegal population suffers mortality from damage associated with being erroneously picked and measured before being returned to the water.

Mudge Point 1985:

The Mudge Point area was resurveyed after a period of four years in order to determine whether any discernible changes had occurred in the population. The same seven station positions were chosen and one additional station was occupied.

Since the purpose of the survey was comparative, every effort was made to situate the transects in the same areas as in 1981. However, by the very nature of the transect method, exact duplication of a transect position from one survey to another is impossible. The 1981 survey had shown very low numbers of abalone deeper

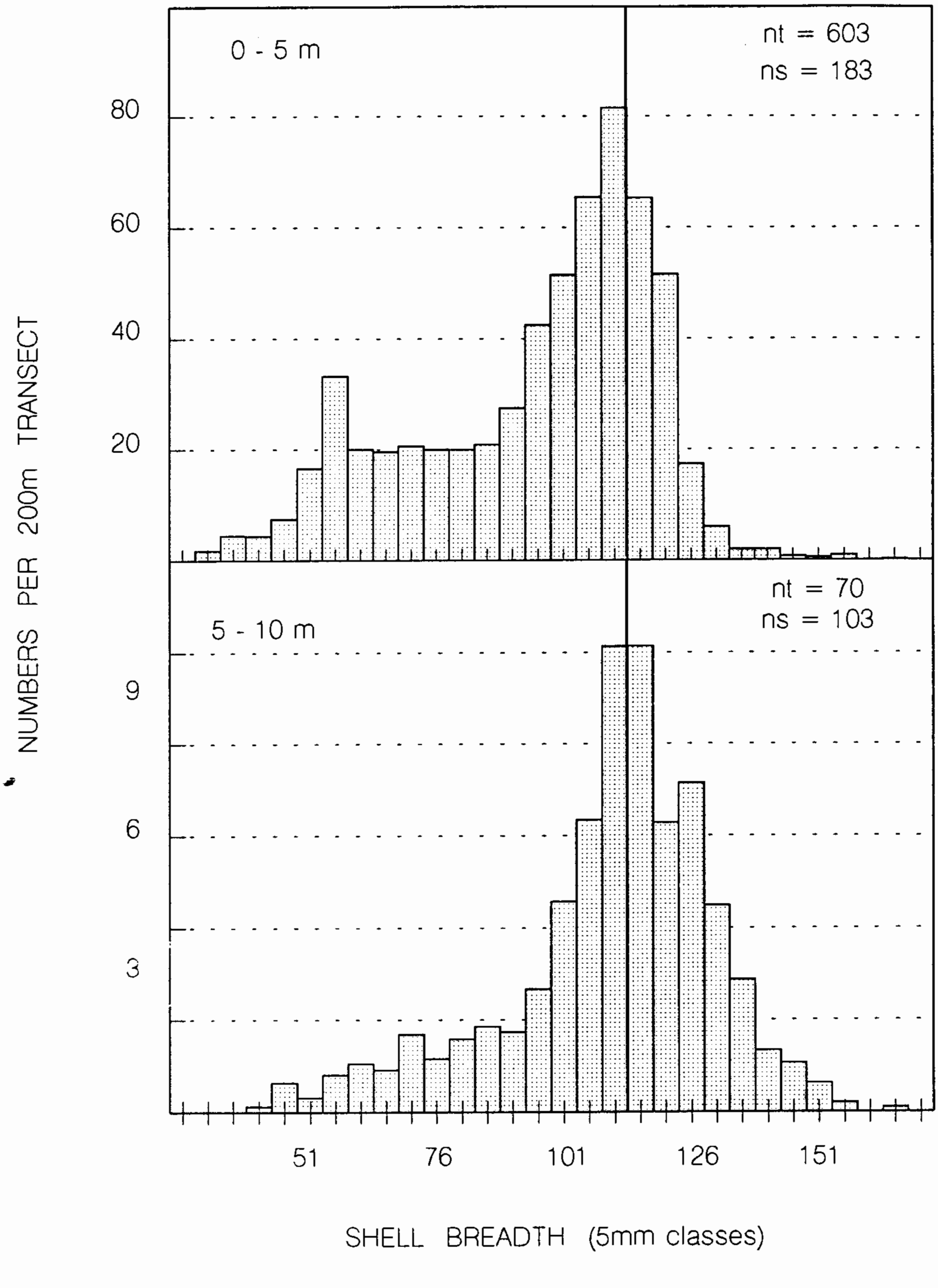

Figure 8: Mudge Point (1985): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

than 10 m, therefore far fewer transects were swum in the 10 - 15 m range (3), and only one in the 15 - 20 m range. A total of 22 transects were swum, (9 each in the 0 - 5 m and the 5 - 10 m range), and the mean density of abalone per transect is shown in Table 1. The average length frequency per transect is shown for the two shallower depth ranges in Fig. 8.

These showed a major increase in numbers since the earlier survey, particularly in the 0 - 5 m range, where the difference was statistically significant (Mann-Whitney $p < 0.025$) Possible reasons for this difference are discussed later (p.27). Fig. 8 shows an upward shift in modal size in the 0 - 5 m range which may also indicate an improvement in length frequency distribution. However, despite the apparent numerical improvement, the length frequency distribution still shows a rapid drop-off in numbers immediately above the size limit, which is probably a reflection of the area's history of intensive fishing.

Danger Point 1982

The area surveyed consists of a 12 km length of coastline from Gans Bay harbour to van Dyk's Bay, on the Danger Point Peninsula. This comprises the major proportion of the abalone habitat of the peninsula, with very low levels of fishing taking place outside this area. Nine stations were occupied, and transects 100 metres long were swum in the 10 - 15 m range for all stations, and at five of the stations 100 m transects were swum in the 15 - 20 m range.

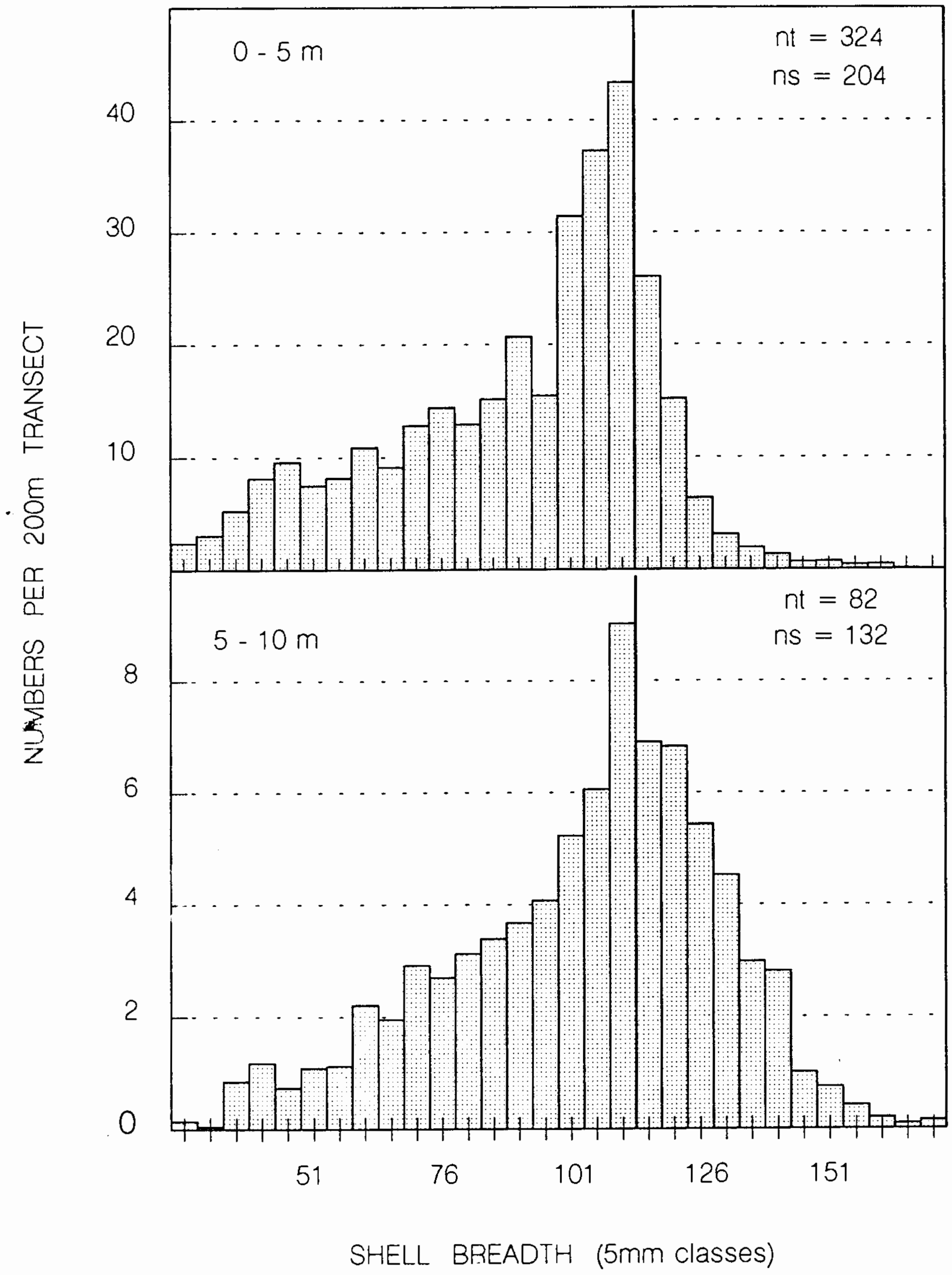

Figure 9: Danger Point (1982): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

Extensive beds of *E. maxima* were again encountered, the density decreasing with depth until from approximately 10 m depth, *Laminaria pallida* became abundant. This is a pattern typical of most kelp forests in the SW Cape (Field *et al* 1980), however the trend appeared more clearly defined in this area. The ascidian *Pyura stolonifera* was common, but exceptionally dense in the exposed shallow reef areas around Danger Point, where 100% coverage of the reef occurred over large areas. Sea urchins, *Parechinus angulosus*, were abundant in certain areas. Large patches of crustose coralline algae were occasionally found encrusting rocks in areas in excess of 50 m^2 in the shallow stations. These typically formed "barren" gaps in the middle of kelp beds, and supported numerous small abalone (<6cm) in association with sea urchins. These grazers may have served to maintain the integrity of the crustose coralline cover (Shepherd 1973; Pearse and Hines 1979).

Once again, a very low average abalone density (5 per transect) was found in the 10 - 15 m range, therefore the abalone density in numbers per transect is shown for only the two shallower depth ranges in Fig. 9. The density of abalone per transect is given in Table 1.

As was found at Mudge Point, there was a clear drop-off in numbers above the size limit, which again can probably be ascribed to the past activities of commercial fishermen. There appeared, however, to be a good reservoir of undersized abalone for future growth recruitment. In both depth ranges the population mode occurred just below the size limit.

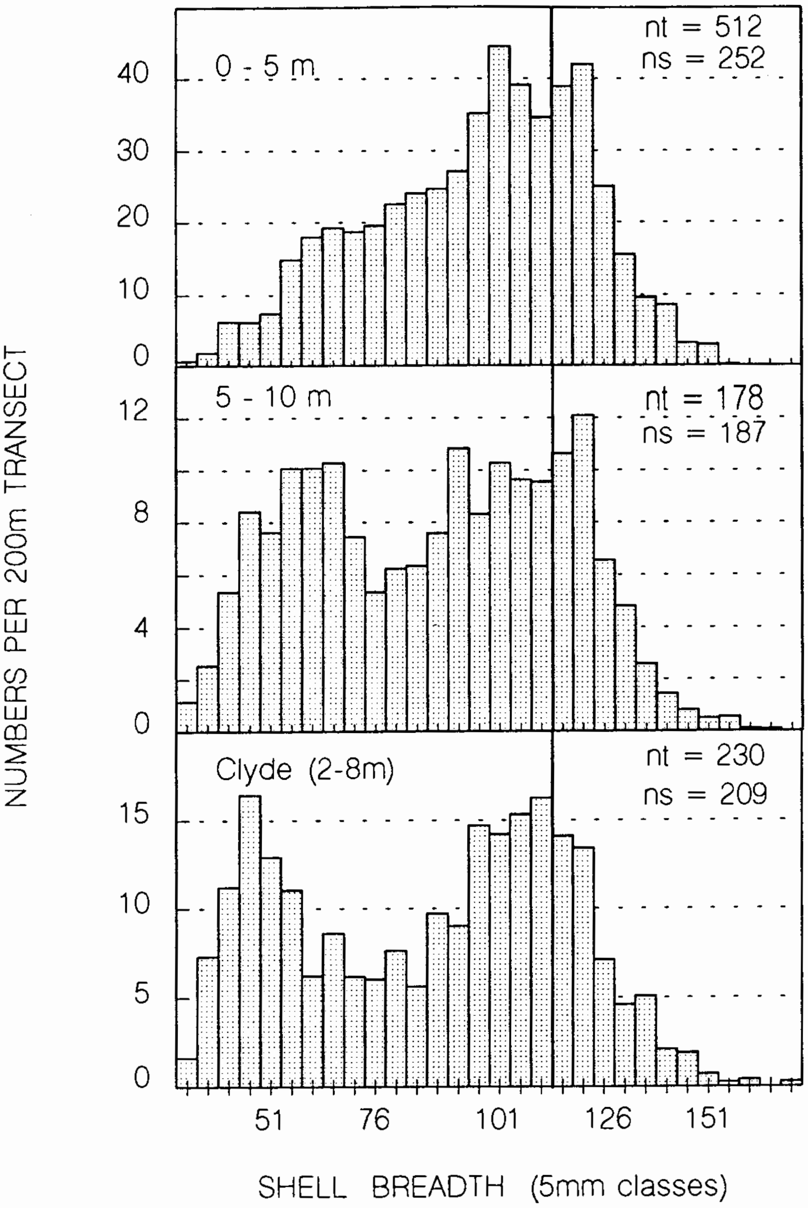

Figure 10: Dyer Island (1984): Mean abalone shell breadth distribution per transect.nt = number of abalone per transect; ns = number collected for size analysis.

Dyer Island 1984:

This area is situated 8 km from the nearest ski - boat slipway, and was commercially fished up to the end of 1983, but not to the same extent as the mainland grounds. This history of lower fishing effort can be ascribed not only to the area being an island, but also to the fact that the island harbours a seal colony and is notorious among divers for the numbers of attendant white sharks (*Carcharodon carcharias*). The island, and the major portion of an adjacent area of shallow reef called the "Clyde", were closed to abalone fishing in December 1983. This survey was undertaken in order to compare the island population to mainland ones, and to establish a baseline of information in order to assess the effect of the closure on the population in the future. A total of 26 transects were swum, with six in the 0 - 5 m range, 11 in the 5 - 10 m range and four in the 10 - 15 m range. The Clyde area consisted of a shallow kelp forest with depths ranging from 3 to 8 metres, therefore it was not possible to maintain the normal 5 metre depth separations. This area will therefore be reported on separately.

The entire island complex was surrounded by a surface canopy of *E. maxima* with two major beds running west and north east of the main island. A notable feature of the substratum was the parallel nature of the reef outcrops, resulting in a series of ridges running in an east - west direction. It was these ridges which supported the majority of the typical kelp bed biota and abalone. In between the ridges were

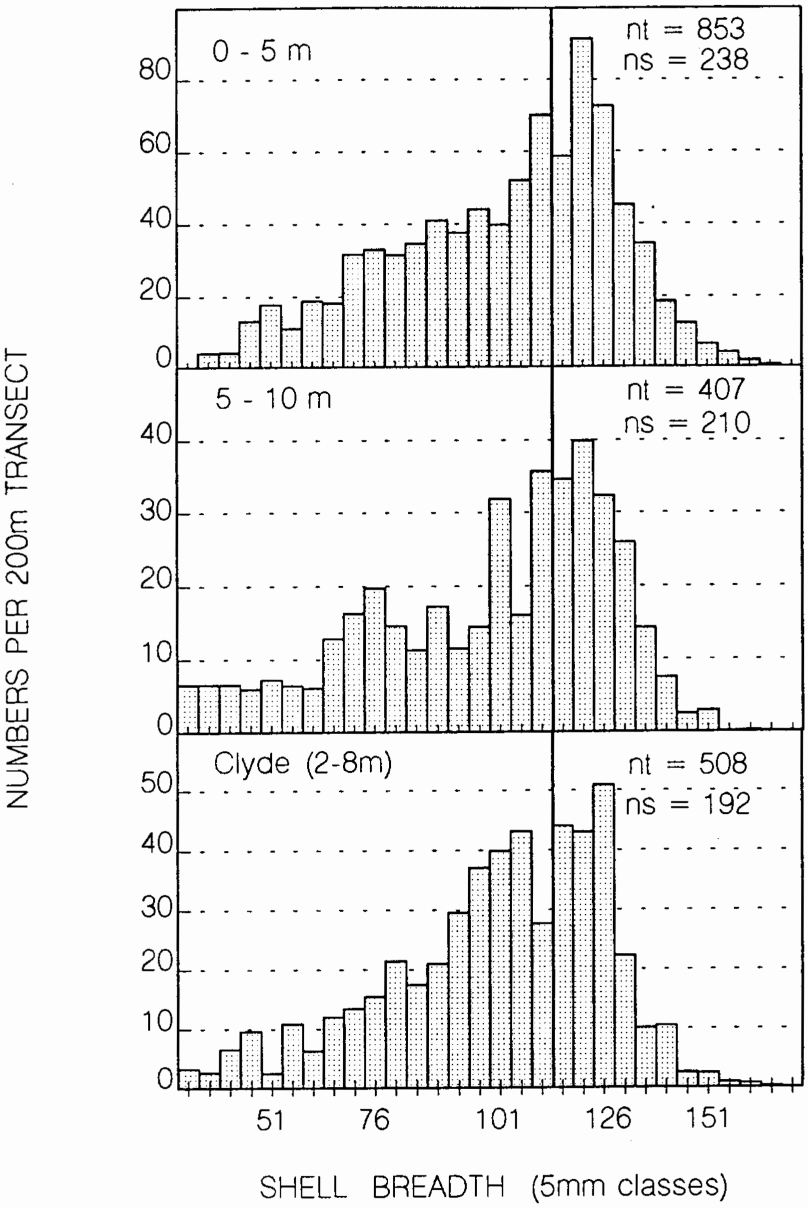

Figure 11: Dyer Island (1990): Mean abalone shell breadth distribution per transect.nt = number of abalone per transect; ns = number collected for size analysis.

gullies formed of a largely barren unstable bottom commonly of loose, smooth - edged stones.

The 10 - 15 m range supported even fewer abalone than normal, with only three individuals being found on four full transects. The results of the two shallower ranges are given in Table 1. The exceptionally large standard errors shown for the 5 - 10 m range result from some very high density clusters of abalone being found among the more normal lower densities characteristic of this depth. This may have occurred because the large kelp beds had numerous outcrops of shallow reef breaking the surface, immediately adjacent to deeper areas, and it was therefore not always possible for the transects to maintain proper separation of the depth ranges. However, it was very clear that densities overall were higher than in mainland commercial areas, and this difference was significant. The average length frequencies per transect are shown in Fig. 10. The absence of a sharp cutoff immediately above the size limit is probably a reflection of lower fishing pressure. In addition, the high proportion of sublegal abalone in the population would probably result in high densities of reproductively active abalone in the future in this sanctuary. Both the 5 - 10 m range and the Clyde area showed apparent strong recruitment cohorts ranging from 36mm to 61 mm shell breadth, indicative of a past exceptionally strong larval settlement in this area.

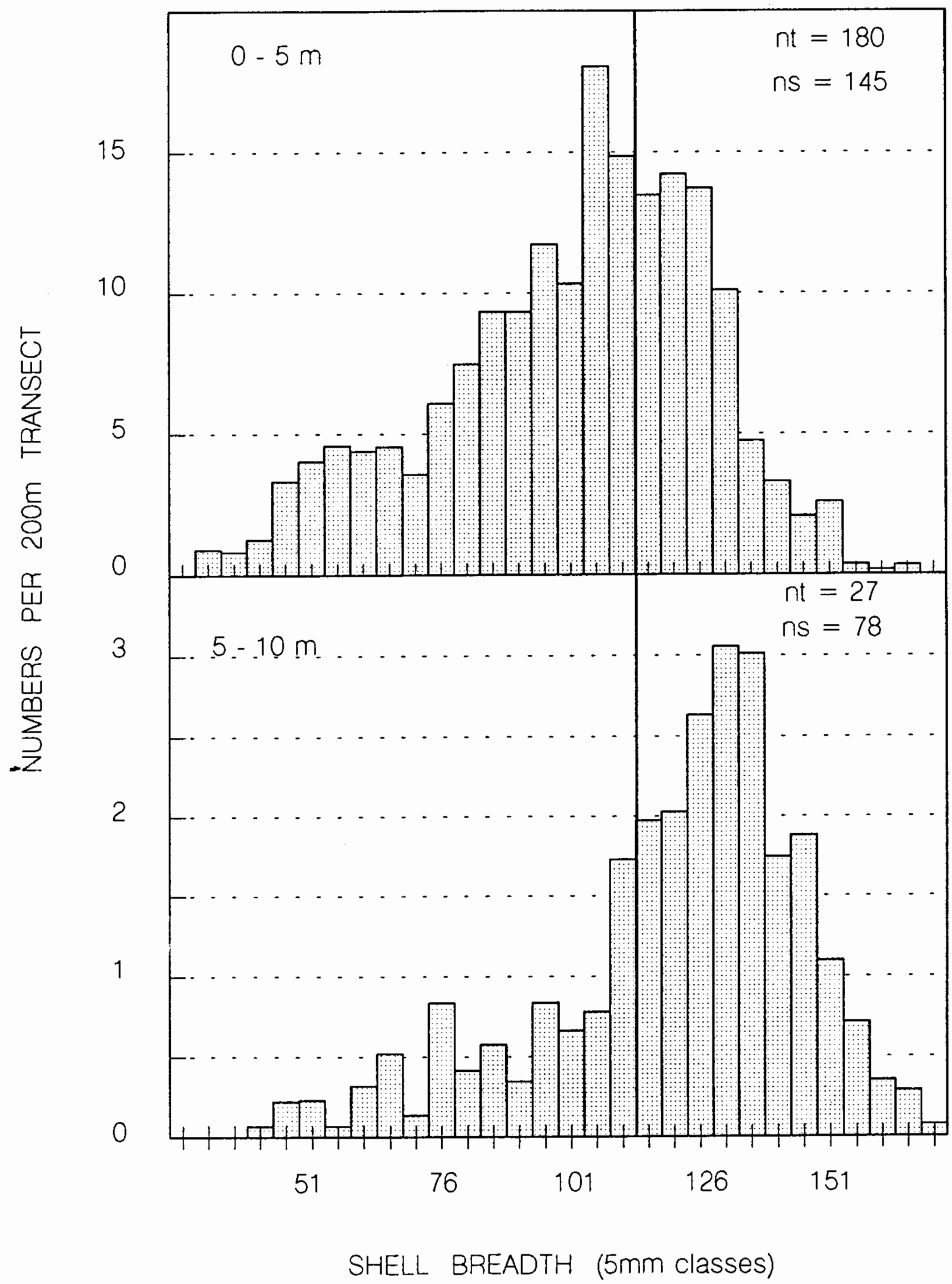

Figure 12: Pearly Beach (1987): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

Dyer Island 1990:

In order to assess the effect of the closure of this area since December 1983, it was resurveyed in March 1990. No attempt was made to duplicate the transect positions of the previous survey at Dyer Island. Instead the recently completed kelp forest map of the area was studied, and a smaller number of stations were identified in order to obtain representative coverage around the island.

Sixteen transects were swum in total, evenly distributed among the three areas 0 - 5 m, 5 - 10 m & Clyde. The increase in mean density (from 512 to 853 animals per transect in the 0 - 5 m depth range and from 177 to 407 animals per transect in the 5 - 10 m depth range) was immediately apparent. Dense abalone colonies were found on many of the transects, and there also appeared to have been a re-aggregation of previously scattered abalone into many large contiguous beds of adults. The average densities encountered are given in Table 1.

The overall increases in abundance as well as the increase in the proportion of legal sized abalone was marked, and it was clear that the area had improved significantly as a result of the closure. The graphs showing average length frequency per transect (Fig. 11) reflect the higher numbers encountered, and that a higher proportion of the population is legal-sized. However due to the very high variance around the means, the improvement could not be shown to be statistically significant.

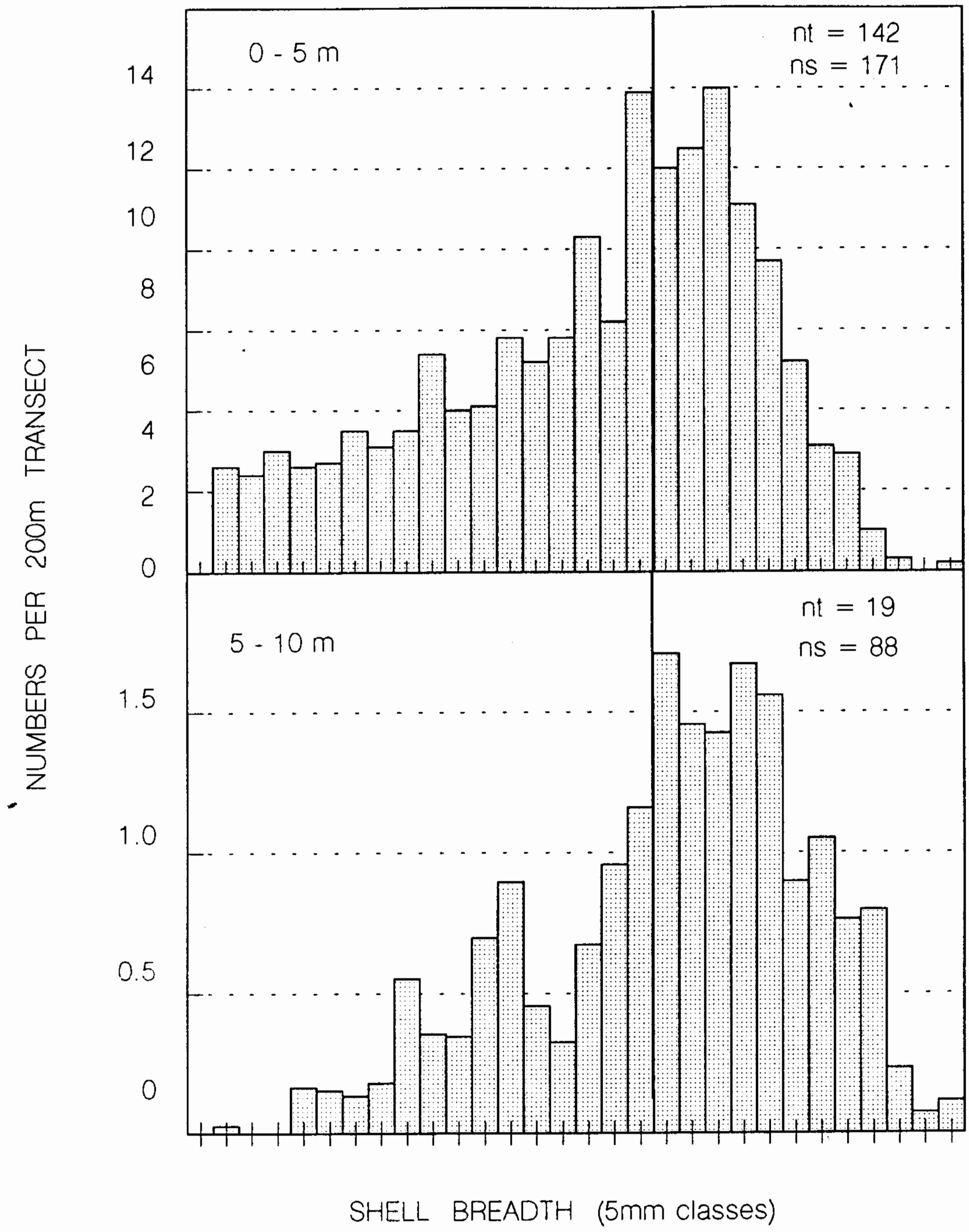

Figure 13: Buffeljags (1986): Mean abalone shell breadth distribution per transect. nt = number of abalone per transect; ns = number collected for size analysis.

Pearly Beach 1987:

This area was the most extensive of the fishing grounds, covering 24 km of coastline, and was also the last major fishing ground to be surveyed.

A total of ten transects was completed, all in less than 10 m depth range. Similarly to the adjacent Buffeljags area, this coastline was shallow, with a high sediment load, and frequent poor visibility. Most of the *E. maxima* canopy petered out at 6 to 7 m depth, but owing to the gently shelving seabed, the canopy extended hundreds of metres offshore in places. Dense colonies of the reef worm *Gunnarea* were encountered.

The average densities per transect are given in Table 1. These low densities were similar to those in the Buffeljags area (still to be discussed), to which it is ecologically most similar. The histograms showing average length frequency per transect are shown in Fig. 12. It can be seen that the mode for the 0 - 5 m range occurs below the size limit, indicating a possible effect of commercial fishing in this ground. However, only one of the five 0 - 5 m transects (situated opposite a popular holiday resort area), showed a mode below the size limit. Since this transect supported a far higher density of abalone (438) than the others, it had a major effect on the average. The mode of the 5 - 10 m range transects occurs well above the size limit, at 131mm, indicating a probable low effect of previous fishing on the population structure in this depth range.

Buffeljags 1986:

This area comprises the most easterly sector of the coastline fished by commercial divers. It is therefore of particular interest, comprising as it does the cut - off point beyond which no commercially fished abalone populations exist. Seven stations were occupied, and a total of 17 transects were swum during March 1986, of which two were deeper than 10 m. As these both yielded zero abalone, no more "deep" transects were attempted, and spot dives confirmed the absence of abalone in this depth range.

The most immediately apparent environmental factor evident in this area was that the *E. maxima* kelp canopy effectively stopped on the easternmost side of this area, namely at Quoin Point. This is presumably related to warmer water, although other factors such as nutrients and water clarity may also be involved (Velimirov *et al* 1977; Tegner and Dayton 1987). It was noted that the kelp plants at Quoin Point appeared "unhealthy", having few, if any, fronds, and with the stipes being abnormally brittle. In addition the plants did not extend far offshore, with few occurring deeper than 5 m (see Chapter 2), despite the availability of suitable reef. A result of this was that most of the 5 - 10 m transects were swum outside the kelp canopy, an event which seldom occurred in other areas. The survey area also had a notably high sediment load, with underwater visibility frequently a problem. Numerous large colonies of the tube - worm *Gunnarea* were also encountered, occupying a significant proportion of the seabed, and covering the shells of many of the abalone.

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The most notable feature of the abalone population in this area was that below 5 m depth very few abalone were found, reflecting an association with the kelp distribution. This survey produced the first record of a 200 m transect in the 5 - 10 m depth range yielding zero abalone.

The average densities encountered are given in Table 1.

This area appears to support a lower population density than the other commercial areas, and the population appears to be confined to shallower depths. It seems likely that this is associated with the decline in the kelp canopy. From the histograms of the average length frequency per transect (Fig. 13), it is apparent that the mode of the 0 - 5 m population occurs below the size limit, at 106 mm. The average length frequency for the 5 - 10 m range, however, does not reflect this rapid drop-off in sizes, such as found in areas such as Danger Point and Mudge Point, which is usually associated with intensive fishing pressure (Witherspoon 1975; Farlinger and Bates 1986). However the actual density in this depth range is extremely low.

DISCUSSION:

The purpose of this series of diving surveys was to determine the state of the abalone resource by direct observation, and to draw comparisons between the various fishing and non-fishing areas. Abalone stock assessment by direct means is both logistically difficult and time-consuming (Adkins and Stefanson 1977;

Clavier and Richard 1984; Petherick 1986; Gilberto and Mauricio 1992), and results are difficult to validate statistically due to the effects both of the clustering behaviour of abalone, and factors such as the natural topographical variation of their submarine habitat, which affects habitat selection. Past larval recruitment history may also play a significant role in this variability. The Canadian abalone fishery offers the best-documented series of abalone stock assessment diving surveys in the literature, dating from 1977 (reviewed in Sloan & Breen (1988)), yet they were never able to obtain an accurate estimate of stock size (Jamieson 1989). Farlinger (1992) recommended that their survey methodology be redesigned. Similarly, despite intensive surveys in Mexico covering more than 22 000m^2, problems with high variance led to the conclusion that the "... density data appear to be a poor measure of true abundance" (Guzmán del Próo 1992).

The series of surveys reported on here represent a considerable area of directly examined seabed, in that 81 0-5m transects and 74 5-10m transects were swum, covering a total of 93 000 m^2. Nonetheless few statistically significant conclusions can be drawn from the data, for reasons outlined already. Although there appeared to be a difference in abalone density, and in particular, depth-distribution, along the east-west gradient from Robben Island to Buffeljags, this was not supported statistically. In general, however, the patterns found in shallow water were well-echoed by the corresponding deeper water results. Only the Mudge Point 1985 means substantially broke this pattern - from second largest among shallow water means to sixth largest among the deepwater means (Tables 1a & b). The Betty's Bay and Robben Island (both unfished) densities were significantly different from each other (MW $p < 0.05$). However, it was not possible to establish statistically significant differences among any of the commercial areas.

Regarding temporal differences, the increases recorded for Mudge Point between 1981 and 1985 were significant (MW $p < 0.025$). Due to the magnitude of the increases in this area over a four year period despite continued fishing (albeit at a somewhat reduced level), it seems intuitively likely that these differences may have been caused at least in part by some difference in survey technique between the two years. For example it is possible that the 1985 transects may have been positioned on average closer inshore than those of 1981. This could have arisen due to calmer sea conditions, or the increased experience of the divers, and would result in an upward bias in densities being recorded. Should this have occurred, it would also go some way in explaining the exceptionally large increase in sublegal densities recorded between the two surveys (Table 2), since it would normally be expected that sublegal densities should fluctuate less with time.

The visually obvious increases at Dyer Island with time were not significant due to the high variability between transects. This high variability was primarily an artifact of the difficulty in maintaining depth separation in some of the transects. This fact can be confirmed by the smaller difference between the densities in the two respective depth ranges shown at Dyer Island when compared to other areas. The average Dyer Island abalone densities in the 5-10m depth range were from 34% to 48% of the abalone densities in the 0-5m depth range, whereas for the other areas these values varied from 12% to 25% of those in the 0-5m depth range.

The densities of *H. midae* found on these surveys can be compared with other abalone populations. Since the majority of the population occur within the 0-5m depth range, only data from this sector will be compared. It must also be emphasized that this survey technique only recorded non-cryptic "emergent" abalone, therefore the smaller size classes (< 50mm) are under-represented. These surveys showed average densities of *H. midae* in unfished grounds to range from 83/100m^2 to 142/100m^2 in the 0 - 5 m depth range. These densities appear considerably lower than figures reported for unfished *H. kamtschatkana* of 440 to 1000/100m^2 (Adkins and Stefanson 1977) (where very few animals smaller than 50mm shell length were recorded), and for *H. tuberculata* of 280 to 890/100m^2 (Clavier and Richard 1984), but are similar to figures reported for *H. tuberculata* in Guernsey, of 5 to 235/100m^2 (Peck and Culley 1990). However *H. tuberculata* is a cryptic, smaller species, sampled primarily from under-boulder habitats, therefore is likely to show different population densities from *H. midae*.

One survey of *H. midae* was carried out by Zoutendyk (1982), of the Robben Island population, and he reported similar variations (from 0 to 280/100m^2). His mean result of 70/100m^2 is similar to mine of 83/100m^2.

Due to varying average sizes between species however, biomass comparisons would be more meaningful, and accordingly the average transect results in terms of biomass were given in Table 2. Few reports giving biomass of unfished abalone populations are available for comparative purposes: Clavier and Richard (1984), sampling non-cryptic *H. tuberculata*, showed that almost 90% of the biomass was above the MLS. This is similar to the values of 85 to 97 % for Betty's Bay and 83 to 92 % for Robben Island.

Similarly comparisons can be drawn between commercially fished populations, although only the 0-5m depth range data will be considered. Table 1 shows commercially fished grounds (excluding Dyer Island) to have densities ranging from 23,7/100m^2 to 100,6/100m^2. These are higher than those for fished Mexican *H. corrugata* (11 to 44 per 100m^2) (Gilberto and Mauricio 1992), although the Mexican fishery is presently in a collapsed state. Similarly, these figures tend to be higher than the densities reported for *H. rufescens* populations in California of 2/100m^2 (Cooper *et al* 1977) and 16 - 18/100m^2 (Tegner *et al* 1989). Californian abalone populations are, however, like the Mexican fishery, currently extremely depressed in numbers due both to early heavy fishing pressure (Anon 1979; Tegner *et al* 1989), and more recently, to inroads made by an expanding population of sea otters (Hines and Pearse 1982; Tegner 1989). Our densities are similar to those reported for Canadian *H. kamtschatkana* of 47 to 130 per 100m^2 (Adkins and Stefanson 1977; Breen *et al* 1982; Carolsfeld *et al* 1988).

The low numbers of sublegals (<114,3 mm shell breadth) found deeper than 5 m (Table 2) is a feature of the recruitment ecology of *H. midae*. Like other haliotids, larval settlement appears to take place only on crustose coralline algae (Saito 1981; Morse and Morse 1984; Shepherd and Turner 1985). This occurs predominantly in the shallow (<3m) inshore area (Tarr unpublished data). Haliotid juveniles are cryptic in their behaviour (Burge and Schultz 1971; Shepherd 1973;

Breen *et al* 1978; Clavier and Richard 1984; Tegner *et al* 1989), only becoming emergent at approximately 5cm shell breadth. In consequence the inshore area supports higher numbers of newly-emergent abalone, which in the course of their growth and development disperse gradually into deeper water. An alternative cause of this observed distribution pattern could be changing larval survivorship with depth, given non-selective settlement, however larval settlement does not appear to occur in water deeper than approximately 4 m, since no new recruits (2 - 5 mm length) have been observed in this area (Tarr unpublished data). This is in contrast to the Canadian situation, where *H. kamtschatkana* juveniles are found in sea urchin "barrens" on the seaward edge of the kelp forests (Jamieson 1989). However, gradual dispersion of adults to deeper water from shallow settlement sites appears to be the norm for haliotids (Clavier and Richard 1982; Shepherd and Turner 1985; Moss 1986).

It is of interest to note that the lowest total densities, as well as sublegal densities, in both depth ranges were recorded at Buffeljags, which is the easternmost limit of commercially harvested *H. midae.* This may reflect environmentally induced lower reproductive success, or slower growth rates in this area.

Of the factors which initiated this series of surveys, one was a reported localised reduction in availability of abalone in areas which had traditionally yielded abalone. During the course of these surveys it became apparent that, as in other abalone fisheries (Parker *et al* 1992; Farlinger and Campbell 1992) localised reductions were occurring in areas which were easily accessible to recreational divers, such

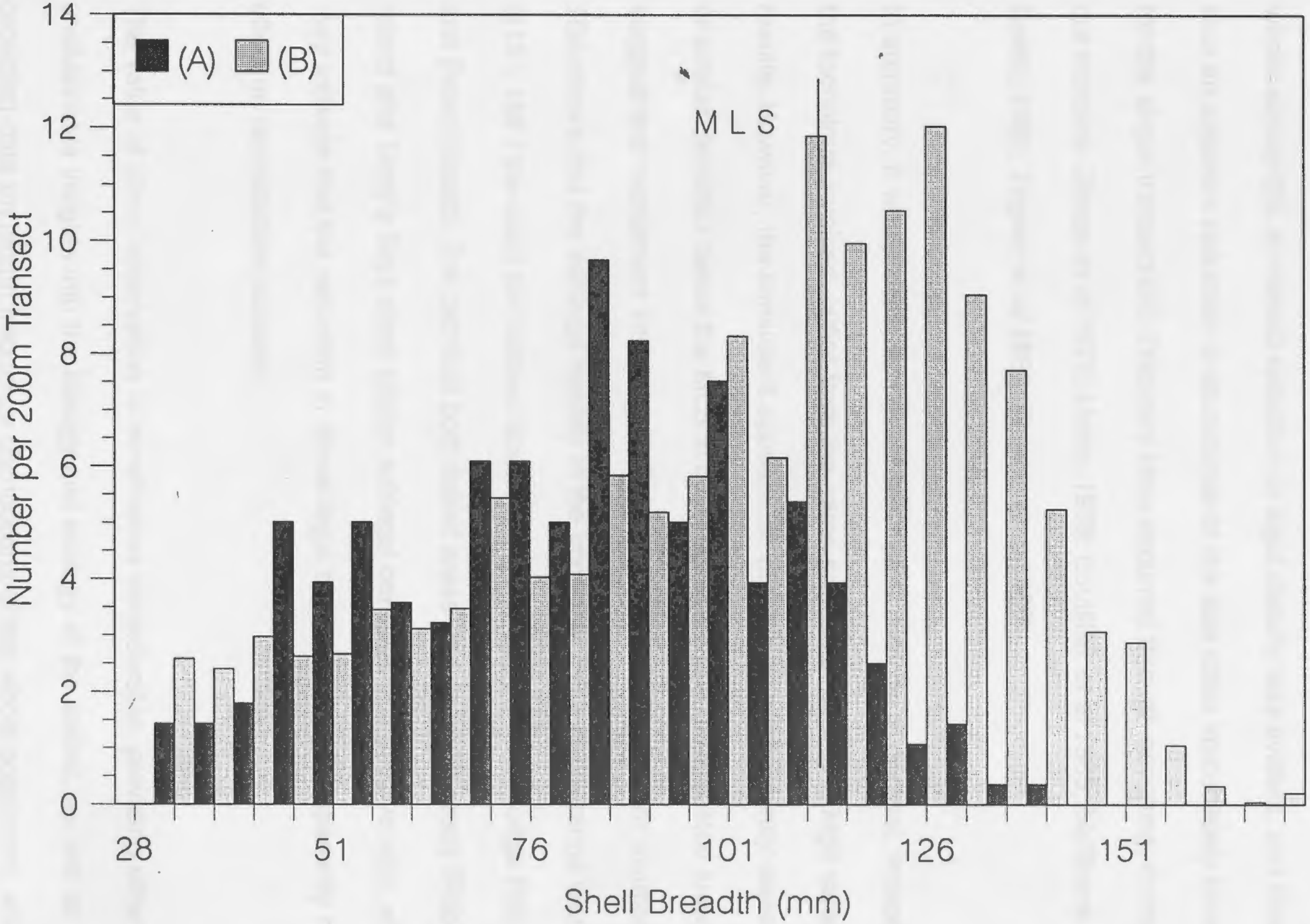

Figure 14: Shell breadth distribution per transect. (A) in an easily accessible site, (B) the average for all 5 sites in the region (Buffeljags).

as sheltered bays, or opposite public car parks. To illustrate this point, results from one transect swum in one of the most heavily fished areas in the Buffeljags region are shown in Fig. 14 (A), compared with the average of the 0 - 5m transects for the whole survey (B). A marked reduction in legal density was evident, and there was also an apparent reduction in abundance of the size class immediately below MLS for the single transect (A). This may have occurred through poaching, or from bar-cut mortality (Burge *et al* 1975; Mottet 1978; Boutillier *et al* 1985; McShane and Smith, 1986; Tegner *et al* 1989; Tegner *et al* 1989).

In summary, it would seem that direct surveys of abalone in general, irrespective of the technique involved, suffer from the same problems relating to high variance of results. However, the consistent appearance of abalone in apparently reasonable or similar densities below the MLS in both harvested and unharvested areas would suggest that recruitment into the population was still continuing. For example, Table 1(b) shows that the sublegal density in the important 0-5m depth range was similar (115 - 169 / transect) for Robben Island, Hangklip, Betty's Bay, Mudge Point ('81), and Pearly Beach. The fact that both fished areas and unfished areas (Robben Island and Betty's Bay) show similar sublegal densities is a positive sign, which may indicate that the reduction in above-legal biomass has not apparently had any effect on reproductive success.

The value of direct observation is nonetheless considerable, providing otherwise unobtainable insights into the biology and ecology of the animal, as well as providing data on length frequency distributions of the whole population, which can as sheltered bays, or opposite public car parks. To illustrate this point, results from one transect swum in one of the most heavily fished areas in the Buffeljags region are shown in Fig. 14 (A), compared with the average of the 0 - 5m transects for the whole survey (B). A marked reduction in legal density was evident, and there was also an apparent reduction in abundance of the size class immediately below MLS for the single transect (A). This may have occurred through poaching, or from bar-cut mortality (Burge *et al* 1975; Mottet 1978; Boutillier *et al* 1985; McShane and Smith, 1986; Tegner *et al* 1989; Tegner *et al* 1989).

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The value of direct observation is nonetheless considerable, providing otherwise unobtainable insights into the biology and ecology of the animal, as well as providing data on length frequency distributions of the whole population, which can be utilized in future modelling exercises. Since direct surveys would still appear to be a valuable stock assessment option, it is appropriate to consider an alternative survey strategy. It is the author's opinion that smaller-scale biennial surveys could be carried out in a series of sites selected from each coastal region. A suitable sampling technique can be determined, incorporating the depth variability, and it should then be possible to assess broad trends in the population over the long term, possibly using graphical methods rather than statistically rigorous methods to establish trends in the population status with time.

Given that knowledge of abalone density and biomass has been obtained, the next logical step in stock assessment and management was to determine the habitat area available in the various coastal regions. Since these diving surveys confirmed that the majority of *H. midae* occur within the inshore *E. maxima* forests, mapping of the extent of the kelp was carried out. This is reported on in the following chapter.

CHAPTER 3

HABITAT AREA ESTIMATION AND TOTAL STOCK CALCULATION

INTRODUCTION

The South African abalone *Haliotis midae* Linne, occurs from the Qora river mouth (32°25'S 28°40'E) to St Helena Bay (32°45'S 18°05'S) (Newman 1969). However the activities of the commercial sector of the fishery are centred on the most productive section of this coastline, namely from Cape Hangklip to Quoin Point (Fig. 1), which has yielded on average more than 80% of the annual commercial catch. This approximately 125 km section of the Southwestern Cape coastline is further subdivided by a series of sandy beach areas such that the available habitat for abalone, namely sublittoral rocky seabed, is naturally partitioned into a number of separate coastal regions.

Diving surveys along this coastline were carried out in order to obtain information on abalone population structure in the various fishing grounds (Chapter 1). A natural extension of this work was to determine the habitat area available, and then attempt to utilize the density data to make a direct estimate of the total abalone stock. This would clearly be useful in a fishery where landings are limited by annually revised total allowable catches (TAC's) (Tarr 1992). Total stock assessment of benthic inshore populations can usually be achieved by multiplying the density from randomly placed transects perpendicular to the shore, by the total distance of habitable coastline

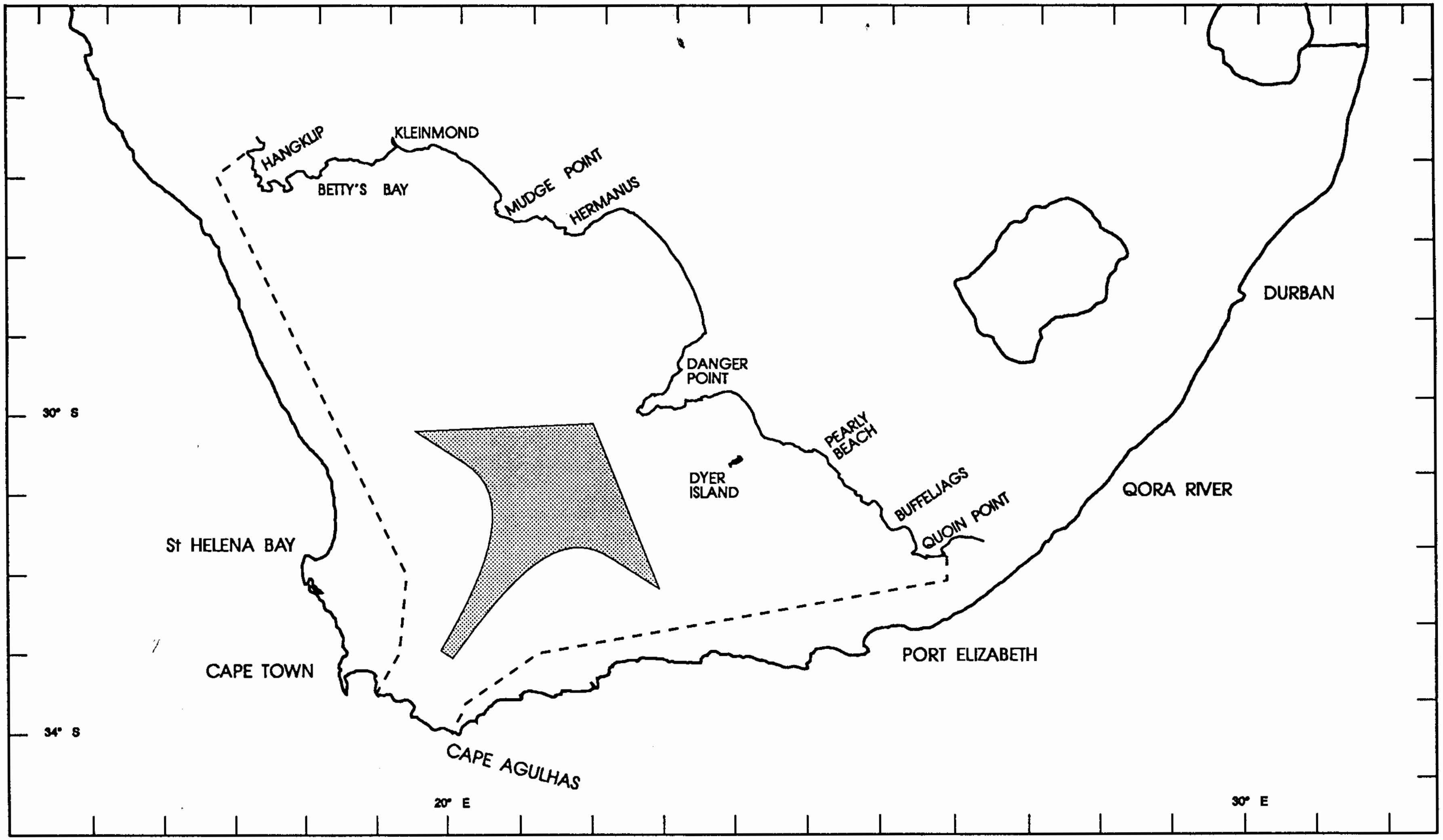

Figure 1: South African coastline, showing places mentioned in the text.

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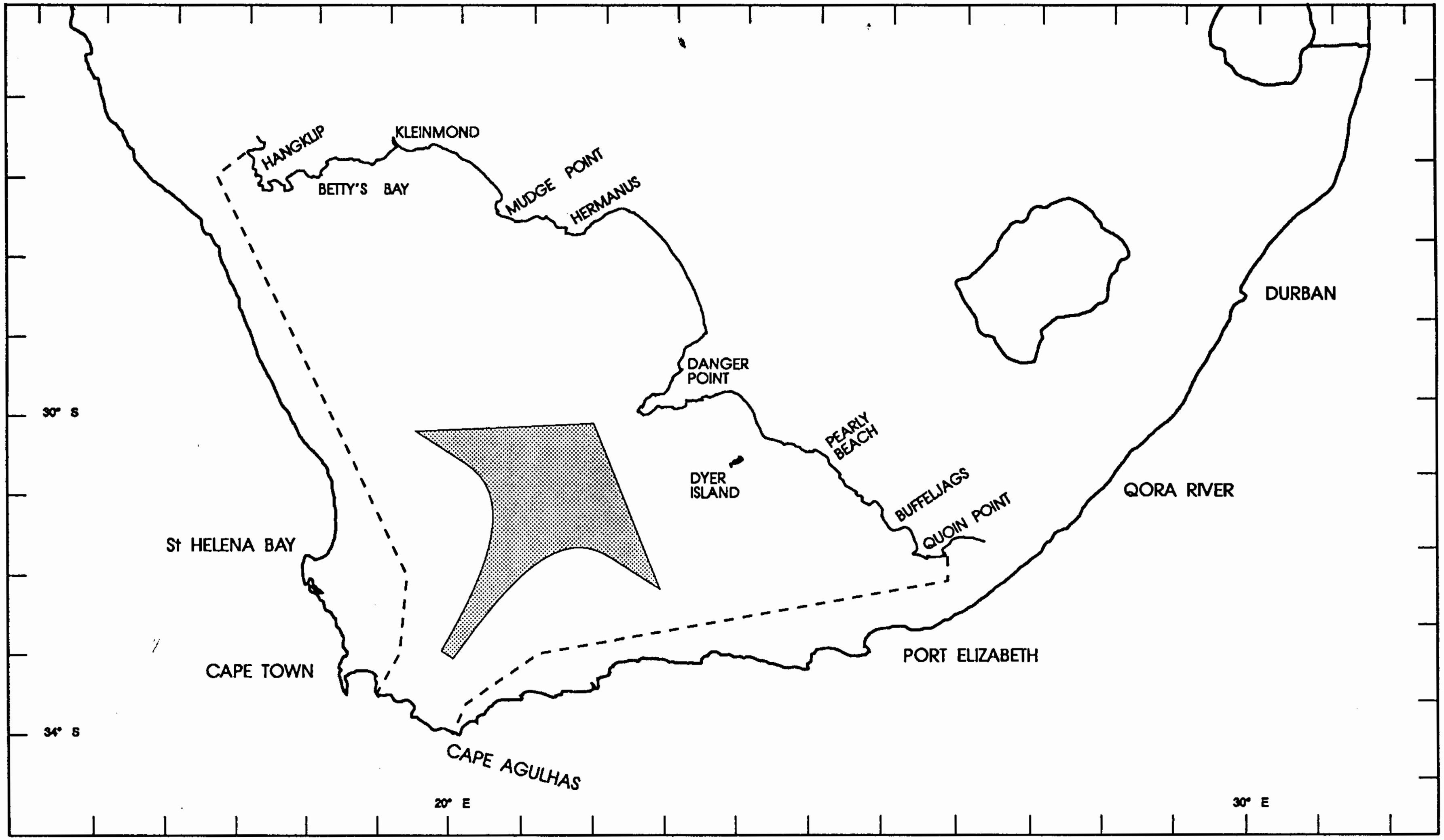


Figure 1: South African coastline, showing places mentioned in the text.

(Branden and Shepherd 1982; Sainsbury 1982; Petherick 1986). However for reasons outlined in Chapter 1, transects were swum parallel to the coastline, in 5 metre depth categories, so density data could not be related to linear coastline distance. Instead total habitat area data were necessary, such as that utilized by Forster (1962), Clavier and Richard (1984), McShane *et al* (1986) or Gilberto *et al* (1992).

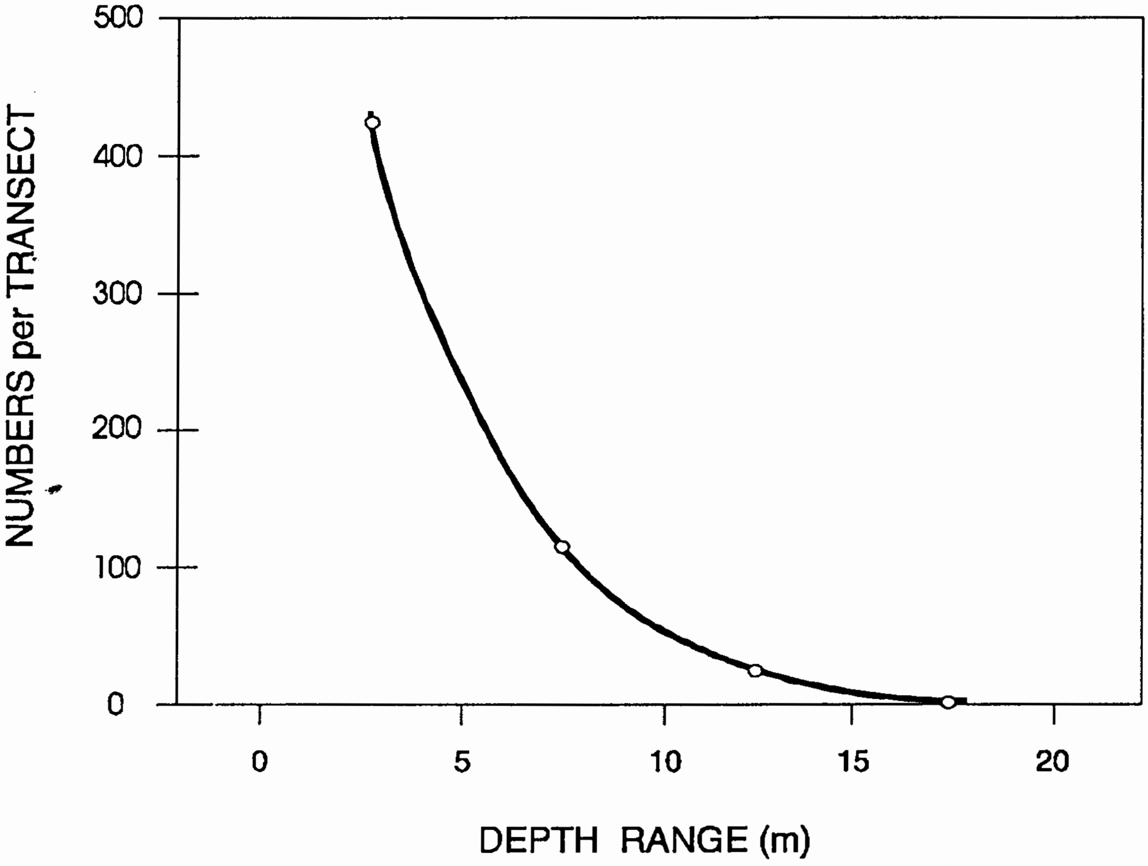


Figure 2: Average density per transect (data from Betty's Bay) declines with depth.

Knowledge of abalone distribution gained from early diving surveys in Betty's Bay (Chapter 1) showed that density was inversely related to depth (Fig. 2). These early field trips also showed that the great majority of the abalone population was to be found in the kelp (*Ecklonia maxima*) forests. Therefore determination of population size needed to take into account depth information as well as the area of kelp forest.

Major fluctuations in the extent of some Californian kelp forests have been reported, caused primarily by the *El Niño* phenomenon (Tegner and Dayton 1987; Tegner and Dayton 1991), but compounded by storm damage, and grazing by sea urchins and amphipods (North and Pearse 1970; Dayton and Tegner 1989). No such instability has been reported for *E. maxima* forests, therefore area data are likely to be a valid abalone habitat index for many years.

METHODS

Kelp area

The majority of *E. maxima* occurs in less than 10m water depth, although it can extend to a maximum of 15m, usually in areas of exceptional water clarity (Field *et al* 1980). The morphology of this alga is different from that of the Californian kelp *Macrocystis pyrifera*, in that all the fronds are borne on the crown of the plant, which is bulbous and gas-filled (Simons, 1976). Early growth is rapid (Jarman and Carter 1981), and the plant soon reaches the surface, where the long strap-like fronds are spread out by water movement, forming a surface canopy for maximum exposure to the sunlight. As a result of this, all areas of seabed supporting significant populations of *E. maxima* can be identified from the surface by the presence of the fronds. In particular at low spring tides the stipes and fronds frequently form a densely entangled surface mat of plant matter which can be virtually impenetrable to both man and boat. Aerial photography therefore lends itself as a tool for the determination of the extent of these kelp forests. However, not all plants towards the outer depth range of *E. maxima* reach the surface throughout the tidal cycle, so low spring tides were the most suitable period for photography. Because the amplitude of any given spring tidal movement can vary considerably during the course of a year only those periods with predicted low tide levels approaching Lowest Astronomical Tide (Anon 1988) were selected as suitable flight days. Other criteria which had to be satisfied in order for a flight to succeed were minimal oceanic swell and absence of low cloud over the survey area.

Different film types were tested, such as standard monochrome, infra-red-sensitive monochrome, standard colour transparencies, and colour infra-red transparencies. The most suitable result *ie.* maximum differentiation of the kelp canopy from the background, was obtained from colour infra-red transparencies (70mm Kodak Aerochrome colour infra-red film, utilized with colour-compensating & polarising filters). The camera used was a Pentax 645 SLR camera. The resultant transparencies at the correct exposure show bright red kelp contrasting against a deep blue sea colour, illustrated in Tarr (1992). With the film being sensitive to both infra-red and normal light spectra, a slight degree of depth penetration was achieved on the images, making interpretation of the transparencies easier. This also permitted the automatic exposure facility of the camera to be utilized after calibration of the film.

A Bell Jet Ranger helicopter proved a suitable aircraft, since photography was possible through a hole in the plexiglass canopy. It was not possible to mount the camera in gimbals, therefore manual vertical orientation of the camera was achieved with the aid of a circular spirit level mounted on the back of the camera. The period utilized for photography was limited to 1 hour before and after the predicted low tide time.

A suitable flying altitude was calculated to be 2440 m, which given the camera format with 75mm lens, provided sufficient surface area coverage to encompass the widest kelp forests in one frame. This altitude was maintained throughout the flight. An overlap of at least 10% was achieved on all successive frames.

A number of flights were aborted for various reasons such as malfunctioning camera, cloud cover, and rough seas. Finally a flight was successfully completed in February 1983, and data from those exposures are presented here.

The maps were hand-drawn in a dark-room by projecting the image through a photographic enlarger onto a 1:10 000 orthophoto. The orthophoto is a monochrome aerial photographic image overlain with cartographic details such as contours and latitude and longitude lines. By projecting the slides onto the orthophotos and superimposing features such as buildings and roads on the orthophotos, it was possible to project the images at a scale of exactly 1:10 000. The extent of the kelp forests could then be mapped. The outer (seaward) edge of the kelp was taken to occur where no further signs of kelp could be made out on the transparency. Some uncertainty was experienced in identifying the inner (landward) edge of the kelp. This arose from the problems in differentiating dense living kelp from algae-covered rocks or from gullies filled with kelp wrack. However with knowledge of the areas involved, and using the subtle differences in red tones it was possible to consistently arrive at a reliable estimate.

In places such as offshore reefs, promontories and exposed coastline, surface foam on the water obscured some detail, and these areas were marked "white water" on the map. Experience derived from diving surveys had shown that abalone frequently occur in "white water" areas, therefore these were included in habitat area calculations. Areas of "blue" water which had sandy bottoms, could on occasion be identified within the (red) kelp beds. These were marked as "blue water" on the maps, and excluded during habitat area calculations. Similarly, exposed offshore rocks could be identified within kelp beds, and were excluded from the total area calculations.

Depth contouring

Suitable depth contours were not available for the inshore area from standard SAN charts, since no depth survey work had previously been carried out inside kelp forests. It was therefore necessary to carry out independent depth contouring. Two components needed to be obtained: depth determination related to chart datum; and simultaneous accurate position fixing.

Depth determination was carried out using a Skipper 411 echo sounder with 200 Khz (9° beam) transducer. The transducer was mounted on a bracket on the transom of a 5m inflatable boat, such that the transducer pole could kick up backwards when encountering thick clumps of kelp. A strong but flexible braided nylon twine passed under the boat from the bow, and tensioned the transducer pole, acting as a return spring to bring the transducer back to vertical. Series of transects were carried out perpendicular to the coastline, spaced a few hundred metres apart.

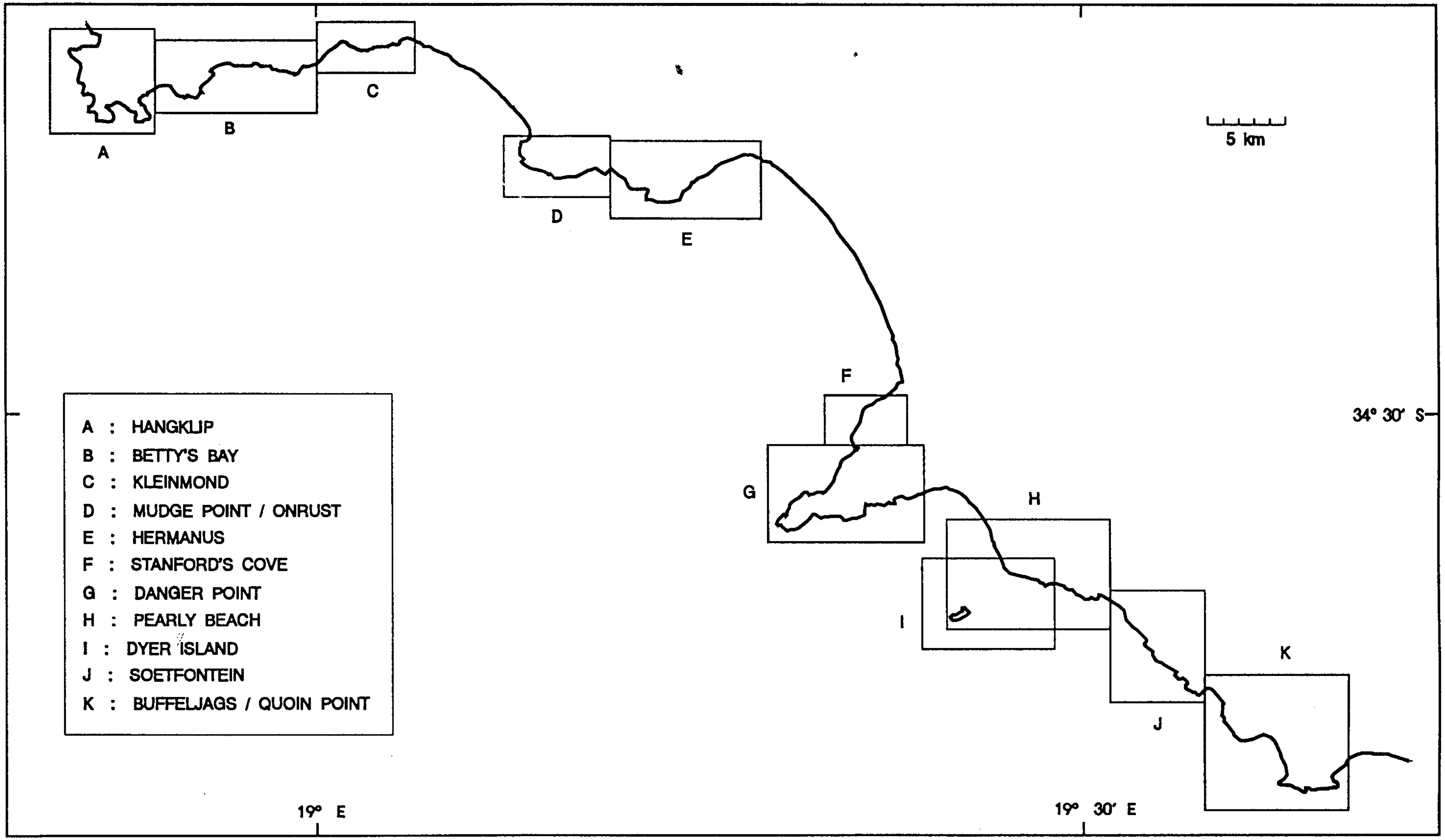


Figure 3: Index showing the positions and orientation of the kelp maps given as appendices A - K.

of the maps with *Corel Draw,* and enabled these areas to be differentiated on the basis of different fill colours. Where adjacent maps are contiguous, a dotted line indicates the common junction position. Each map shows numbered subdivisions of the kelp which correspond to the kelp area information given in the tabulated appendices 1 a & 1b. Note, however, that these subdivisions do not necessarily have the same grouping on the maps as in the tables.

The maps are available from the author in various standard export formats such as DXF, CGM etc.

Kelp area:

Calculated kelp areas (in square metres) for the various coastal regions from Hangklip to Quoin Point are summarised in Table 1. Kelp areas are given for the 0-5m, 5-10m and 10-15m depth ranges. Since kelp bed area data for specific sectors of coastline may have various research applications, each of the coastal regions was further subdivided to correspond to the diving surveys (Chapter 1). These detailed data on kelp areas per station are presented as appendices 1(a) and 1(b). The boundaries of these areas have been shown on the kelp maps in appendices A to K. Where no diving had been carried out in a coastal region supporting kelp (eg. Kleinmond), suitable sub-divisions of the coastline were made to provide area data on a more detailed scale.

COASTAL REGION	0 - 5 m AREA (m^2)	5 - 10 m AREA (m^2)	10 - 15 m AREA (m^2)	TOTAL AREA (m^2)
HANGKLIP	1716257	958314	244877	2919448
BETTY'S BAY	805800	218007	10197	1034004
*KLEINMOND	462889	58413	-	521302
MUDGE POINT	1493406	757664	38973	2290043
*HERMANUS	675490	97229	4257	776976
DANGER POINT	3390374	886499	-	4276873
DYER ISLAND	896921	673874	_	2016471
CLYDE (3-8M)	715909	-	-	-
PEARLY BEACH	2612513	173210	-	2785723
BUFFELJAGS	2335262	295715	-	2630977
TOTAL (ha.)	1483,46	411,89	29,83	1925,18

* Kelp areas not covered by diving surveys are marked with an asterisk.

Table 1: Kelp area per coastal region in square metres.

A small amount of surface-visible *E. maxima* occurred in the 10-15m depth range from Hangklip to Hermanus, but none east of Hermanus, indicating a possible reduction in the depth penetration of *E. maxima* in an eastward direction. This trend finds support in the observation (Chapter 1) that little kelp was found deeper than 5m depth in the eastern regions such as Buffeljags. This trend of reducing depth penetration of *E. maxima* has been illustrated in Fig. 4, where the percentage of kelp canopy which occurs within each of the three depth ranges has been plotted following an east-west direction.

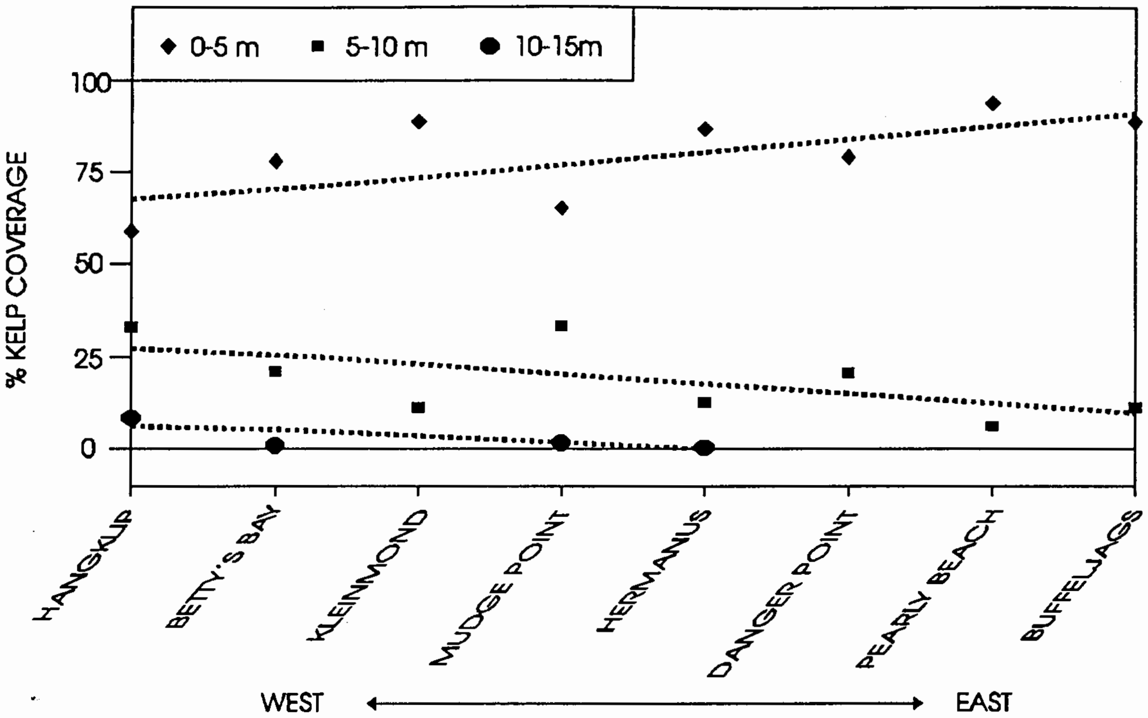


Figure 4: Trends in the proportion of the kelp canopy which occurs in different depth ranges.

COASTAL REGION	LEGALS	SUBLEGALS	TOTAL
HANGKLIP	179352	415125	594477
BETTY'S BAY	485036	202970	688006
*KLEINMOND	61352	191560	252912
MUDGE POINT 1981	115790	378781	494571
MUDGE POINT 1985	407247	1182710	1589957
*HERMANUS	94619	332087	426706
DANGER POINT	363399	1583545	1946944
DYER ISLAND 1984	306616	853067	1159683
DYER ISLAND 1990	852778	1302270	2155048
PEARLY BEACH	288322	501369	789691
BUFFELJAGS	247551	314897	562447
**TOTAL No.:	2979655	6026533	9006188

* Regions not covered by diving surveys are marked with an asterisk.
** Using most recent surveys only

Table 2A: Calculated abalone numbers per coastal region, both depth ranges combined.

Standing stock calculation:

Using the density data obtained from the diving surveys of the coastal regions (Chapter 1), it was then possible to estimate the total abalone stock per region (excluding Robben Island), by multiplying density figures by habitat (kelp) area. Due to the extremely low abalone densities encountered in the 10 to 15m depth range (Chapter 1), and the small amounts of kelp mapped outside the 10m depth contour, no stock calculations were made for the seabed deeper than 10m.

Two.methods can be used: density data per diving station can be applied to the kelp area for each station; or the average abalone density for each coastal region can be applied to the total kelp area for that region. For this report, the latter method was used, since there appears less potential for bias from individual stations, and the two methods yielded similar results. However, since diving surveys were not carried out in two small (fished) areas, namely Kleinmond and Hermanus, the average abalone density data from the regions geographically on either side were used (excluding the Betty's Bay marine reserve). Therefore density data from the Hangklip and the two Mudge Point surveys were applied to the Kleinmond area. For the Hermanus area, density data from the two Mudge Point surveys and the Danger Point survey were combined.

The calculated total abalone standing stock per coastal region is given in Table 2(A). This yielded a total stock estimate of 9 million abalone, of which approximately one third were of legal size.

These data are presented in Table 3. No commercial activity took place in Betty's Bay, a marine reserve. Dyer Island was closed to commercial harvesting in December 1983, therefore catch data for the previous 3 years are given, although the reporting accuracy for this particular region may not be as reliable as for other areas.

COASTAL REGION	CALCULATED LEGAL BIOMASS	5-YEAR COMMERCIAL LANDINGS	LANDINGS AS % OF CALCULATED BIOMASS
HANGKLIP	119264	97463	81,7
BETTY'S BAY	323123	-	-
*KLEINMOND	35431	38876	109,7
MUDGE POINT 1981	66921	130490	195,0
MUDGE POINT 1985	229302	113885	49,7
*HERMANUS	53536	33614	62,8
DANGER POINT	212693	187212	88,0
DYER ISLAND 1984	189152	27267	14,4
DYER ISLAND 1990	541598	-	-
PEARLY BEACH	185657	76273	41,1
BUFFELJAGS	168333	72253	42,9
**TOTAL Mass (kg):	1103368	646843	58,6

* Total excluding Betty' Bay, Mudge Point 1981, and Dyer Island 1990

** Using most recent surveys only

Table 3: Average commercial abalone landings (kg) per coastal region (5-year average) compared with the calculated legal-sized abalone biomass.

The reported annual landings would be expected to be significantly less than the calculated legal sized biomass from these areas, since 100% fishing efficiency is logistically impossible. However this was not reflected in the figures for Kleinmond and Mudge Point (1981), where reported landings were higher than the figure calculated for legal sized biomass. Furthermore, the average commercial landings recorded for Hangklip and Danger Point are more than 80% of the calculated legal biomass, which is still far higher than would intuitively be expected for a fishery for this slow growing species.

The stock calculations for Kleinmond are based on density data from Hangklip and Mudge Point, which may have been lower than the actual densities in these regions. However some bias must have occurred in the application of the various survey techniques in order to yield the above results, since the stock estimates appear to be lower than would be expected of an apparently stable fishery. These possibilities will be discussed later.

Fishery recruit biomass: For a fishery to be sustainable and maintain a stable population structure, the ideal annual fishing harvest would be equivalent in mass to the annual growth of abalone into the fishery across the size limit (fishery recruitment). In reality, however, this is not possible for practical reasons, (since an infinitely high level of fishing effort would be required), and an optimum harvesting strategy is therefore desirable to determine what proportion of the annual production should be taken. This is not known for the *H. midae* fishery which is managed by annual revision of primarily historically derived catch quotas. However Newman (1973) suggested that high yields could be maintained at relatively low rates of exploitation, and in general a strategy of $F_{0.1}$ is considered an appropriate target fishing mortality (Schiel and Breen 1991).

It is nonetheless of interest to compare existing fishing harvests with the calculated biomass of annually available fishery recruits. The actual level of the annual recruitment might vary inter-annually, dependent on a number of factors such as density-dependent effects on natural mortality or variable growth rates. However the assumption is that the abalone population in these regions is stable, with constant annual fishery recruitment. Notwithstanding the obvious negative bias in the legal size biomass calculations above, it is possible to calculate an estimate of the annual recruitment into the fishery for each coastal region. Growth data from Betty's Bay are available from this study (Chapter 3) and can be applied to all the coastal regions. The von Bertalanffy equation describing growth of *H. midae* (this study) is given below:

$$L_t = 172{,}76\ (1 - e^{-0{,}186\ t})$$

From this, the annual shell breadth increment of an abalone of legal size was calculated to be 5,5mm. Therefore, assuming a stable population structure in the presence of constant fishing pressure, the past year's fishery recruitment (after natural mortality) would be equivalent to roughly 1,1 times the number of abalone occurring in this first legal 5mm shell breadth size class. The total stock of abalone fishery recruits per coastal region can now be calculated using the habitat area data. Once again it is of interest to compare these amounts with the average commercial landings for these areas. Results are given in Table 4.

COASTAL REGION	CALCULATED RECRUIT BIOMASS (kg)	5-YEAR COMMERCIAL LANDINGS
HANGKLIP	23818	97463
BETTY'S BAY	35193	-
*KLEINMOND	13558	38876
MUDGE POINT 1981	23418	130490
MUDGE POINT 1985	96223	113885
*HERMANUS	23292	33614
DANGER POINT	86045	187212
DYER ISLAND 1984	45002	27267
DYER ISLAND 1990	99123	-
PEARLY BEACH	32470	76273
BUFFELJAGS	21724	72253
**TOTAL Mass:	342131	646843

* Coastal regions not covered by diving surveys

** Total excluding Betty' Bay, Mudge Point 1981, and Dyer Island 1990

Table 4: Average commercial abalone landings (kg) per coastal region (5-year average) compared with the calculated biomass of fishery recruits.

Clearly, the tabulated estimates of recruit biomass must have erred on the conservative side, being on average approximately 50% of the past five years' average annual commercial harvest from the respective areas. With the exception of data from Dyer Island, all the areas reflected far higher commercial landings than the estimated annual fishery recruitment. Reasons for the unexpectedly low biomass estimates are discussed below.

DISCUSSION

Use of habitat area to estimate the total abalone stock, where densities are known from diving surveys has seldom been used. Clavier and Richard (1984) studied available colour aerial survey plates of the unfished French coastline, and with the benefit of water clarity were able to map suitable reef habitat areas to a maximum depth of approximately 10m. They obtained a total stock assessment of some 400 tonnes, with a harvestable amount of 150t. They were not able to compare this calculation with any known landings.

Forster (1962) used standard large scale charts to determine the likely abalone habitat area available in a bay and an 800 metre section of Channel Islands coastline. He extrapolated from this and diving survey results to obtain a total population estimate for *H. tuberculata* around Guernsey of 20 million animals. Once again this estimate could not be validated against landings.

Tegner *et al* (1989) used the total area of their 36 ha study site off southern California to obtain a total population estimate of 51 552 abalone, which again could not be validated.

McShane *et al* (1986) prepared a comprehensive set of abalone reef maps of Victoria, Australia, principally by consultation with divers. He determined individual reef areas, and compared annual catch and CPUE per reef using diver catch-return statistics. However no standing stock estimates were available for comparison.

Gilberto (1992) reported a survey which utilized a series of $10m^2$ quadrats in various Mexican fishing grounds. The total area of fishing grounds covered 1241 ha. and his total stock estimate was 148,6t. This indicated an average density of about 120 $kg.ha^{-1}$ which is considerably less than the (conservative) result of this survey, at 1775 $kg.ha^{-1}$.

This study therefore represents the first attempt to carry out a dedicated habitat area assessment in order to provide data in a direct manner for total standing stock assessments. Furthermore it is the first study where a stock assessment was able to be compared to known fishery landings.

Reasons for negative bias

It is clear that the calculated stock estimates given above yielded figures which are less than the actual standing stock. There are a number of factors which may have been involved, mostly with regard to the actual diving survey technique, and these are considered below:

Overlooking cryptic abalone: Divers may have been missing abalone *ie* underestimated numbers. It was understood from the outset that the technique employed would underestimate cryptic juveniles. However, few mature or legal sized *H. midae* occupy cryptic habitat (pers. obs.), and caves or deep crevices suitable for sheltering large abalone are uncommon along this section of coastline. Therefore only small abalone are likely to have been significantly underestimated in the survey, which should have a minimal effect on calculations of biomass. It is possible that the survey divers missed recording some adult abalone due to their cryptic appearance, but this would not be expected to involve a factor of more than about 5%.

Transect length less than 200m: The actual two-dimensional (mapped) distance of seabed covered by the transect line would have been less than 200m. This would occur because of the three-dimensional nature of the seabed, with the transect line being weighted down onto the bottom. (It would be impossible to avoid this happening in practice). The nett result is again an underestimate of abalone abundance, since, although 600m^2 of 3-dimensional seabed may have been covered, somewhat less than the equivalent two-dimensional mapped area would have been covered. The degree of error is difficult to determine, and would be negligible on a flat boulder bed coast, but quite considerable where high profile reef was encountered. A "correction factor" could be determined by re-assessing the seabed profiles of the various areas concerned. However, the benefits of this exercise would be dubious. It is of interest that results from the generally shallow and low profile coasts of Pearly Beach and Buffeljags appear more reasonable (Table 3) than those from more high profile coasts (eg. Hangklip and Danger Point). A similar problem was reported by Clavier (1984) when attempting to relate transect lengths to mapped distances.

Total transect width was less than 3m: Transect width was principally measured using the divers' outstretched double arm-span, which was occasionally "checked" against a 1,5m length of line. This method was essential for diver efficiency in order to permit 200m to be covered in the available time. However, it is more likely that abalone at the edge of the distance were excluded, than that extra abalone from outside the distance were included.

Habitat area estimates may be lower than actual area: The kelp area maps may underestimate the actual area. This could occur due either to i) technical reasons such as insufficient clarity/definition of outlying kelp on the transparencies, or ii) some arithmetic error associated with the calculations. The former error is possible, and would always result in an under-estimate, however it was not expected to be a significant factor since the clarity and definition of the transparencies for most coastal regions was very good. The latter error is unlikely, since frequent cross-checking of area calculations was possible.

Biomass conversion formula is inaccurate: The biomass conversion formula used was based on an abalone sample from one coastal region at one time of the year. As such, despite a highly significant fit to the data it is open to error for the following reasons: i) The gonad bulk or animal condition may vary significantly through the year, affecting the length:weight relationship, therefore sampling for morphometric conversions should be based on a representative coverage of the seasons. (This database will be improved in the future). ii) The conversion was derived from abalone from which all extraneous growths had been removed ie. the shells were "clean". Fouling growths such as seaweeds, ascidians (*Pyura stolonifera*) and colonial tube worms (*Gunnarea sp.*) are known to comprise a significant proportion of the mass of live *H. midae*, and the degree varies between coastal regions.

It is possible to quantify this variation since data are available from commercial abalone samples, where a known mass of abalone were measured for length frequency. Comparison of the calculated weight of the sampled abalone with the actual recorded weight of the sample was done for a number of regions and years. Results indicated that the actual weight was on average 7% more than the calculated weight based on morphometric data.

Abalone occur outside kelp beds: It is possible that significant populations of abalone occur outside the visible kelp beds, and that these are also being included in the annual landings, but not in the total biomass estimates. This does occur in certain areas, notably one area near Danger Point. However this is unlikely to be a significant source of abalone, since the commercial divers routinely spend most of their diving time within the kelp.

Transects do not sample the average density: In general, density declines with depth (Fig. 2), therefore if transects on average sample the deeper part of the range, densities will be greatly underestimated. Examination of the depths recorded in the raw data indicate that depths of 3 and 4 metres were recorded more frequently than depth of 1 and 2 metres.

The seabed profile is not even: Application of kelp area to density data assumes that the seabed slopes evenly from 0 to 10 metres. However this is unlikely to occur, and there may be, for example, extensive shelf areas of similar depth, which would in turn support depth-related abalone population structures. Bias of this nature could however be negative or positive, and can be ignored.

Conclusions:

It is clear from the above that there were numerous potential sources of error, and nearly all would have the effect of reducing the calculated total stock estimate. However few of the factors are able to be quantified in such a way as to enable revised calculations to be made. A need nonetheless clearly exists for a more extensive morphometrics database, due to the importance of deriving accurate whole-mass data from length frequency data.

The extent of the underestimate of the total biomass is made even more apparent by recent unpublished information indicating that the recreational fishery accounts for abalone landings in excess of 60% of the commercial TAC, meaning that total landings are in excess of 1.5 times those reported here. The purpose of these surveys was to assess the total abalone stock and relate this to known landings. Clearly the total stock estimates are too low. Given this continued uncertainty over the total abalone population biomass, and the possibility that combined recreational and commercial landings closely approximate total annual recruitment into the fishery, future management procedures should adopt an extremely cautious approach. It is nonetheless also true that the average length frequency distributions given in Chapter 1 show many age classes present above the MLS, which would not be likely in the event of excessively high fishing pressure. In addition, calculations of natural mortality and fishing mortality derived from length frequency data (Tarr, *in prep.*) indicate reasonable levels of F.

The kelp area data alone are nonetheless of great value, since they reflect the area of the primary habitat of *H. midae*. Since these data are now available for specific coastal regions which correspond to fishery TAC management areas, they can be utilized for fishery management purposes. These data were in fact originally utilized together with data on historical fishing effort and abalone density when TAC's were first set for the fishery in 1986 (Tarr 1992).

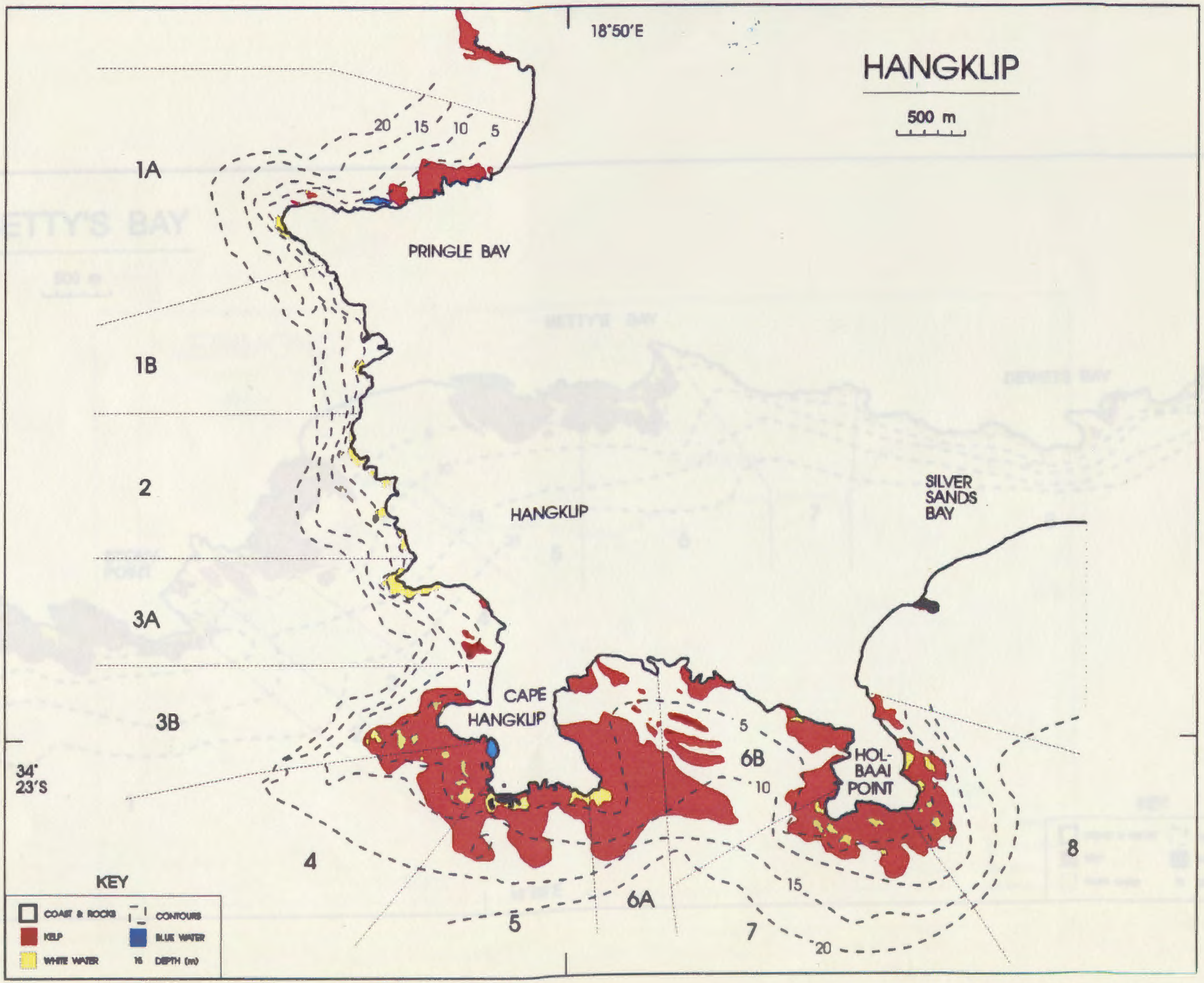
The trend of reducing depth penetration of the *E. maxima* canopy in an eastward direction may explain at least one of the reasons for the cut-off of *E. maxima* distribution which occurs in the Quoin Point - Cape Agulhas area. Various factors have been mentioned, of which the most likely appear to be temperature, water clarity or nutrients (Foster and Schiel 1985). During the course of the diving surveys in these eastern coastal regions (Pearly Beach & Buffeljags) poor visibility was a consistent problem. It seems likely therefore that water clarity could be a significant element in limiting the eastward kelp distribution, since factors such as temperature or nutrient availability are unlikely to be related to depth on such a fine scale. Pollock and Beyers (1981) suggested a relationship between depth penetration of the kelp *Laminaria pallida* and water clarity, and Branch & Griffiths (1988) illustrated an increase in depth penetration of *E. maxima* from north to south along the west coast, also suggesting that it was associated with water clarity. The exception to their trend was Betty's Bay, which is east of Cape Point. From these results it would appear that the western side of Cape Point constitutes the maximum depth penetration of *E. maxima* and that a decline then occurs from west to east, similar to the northward decline illustrated by Branch & Griffiths (1988).

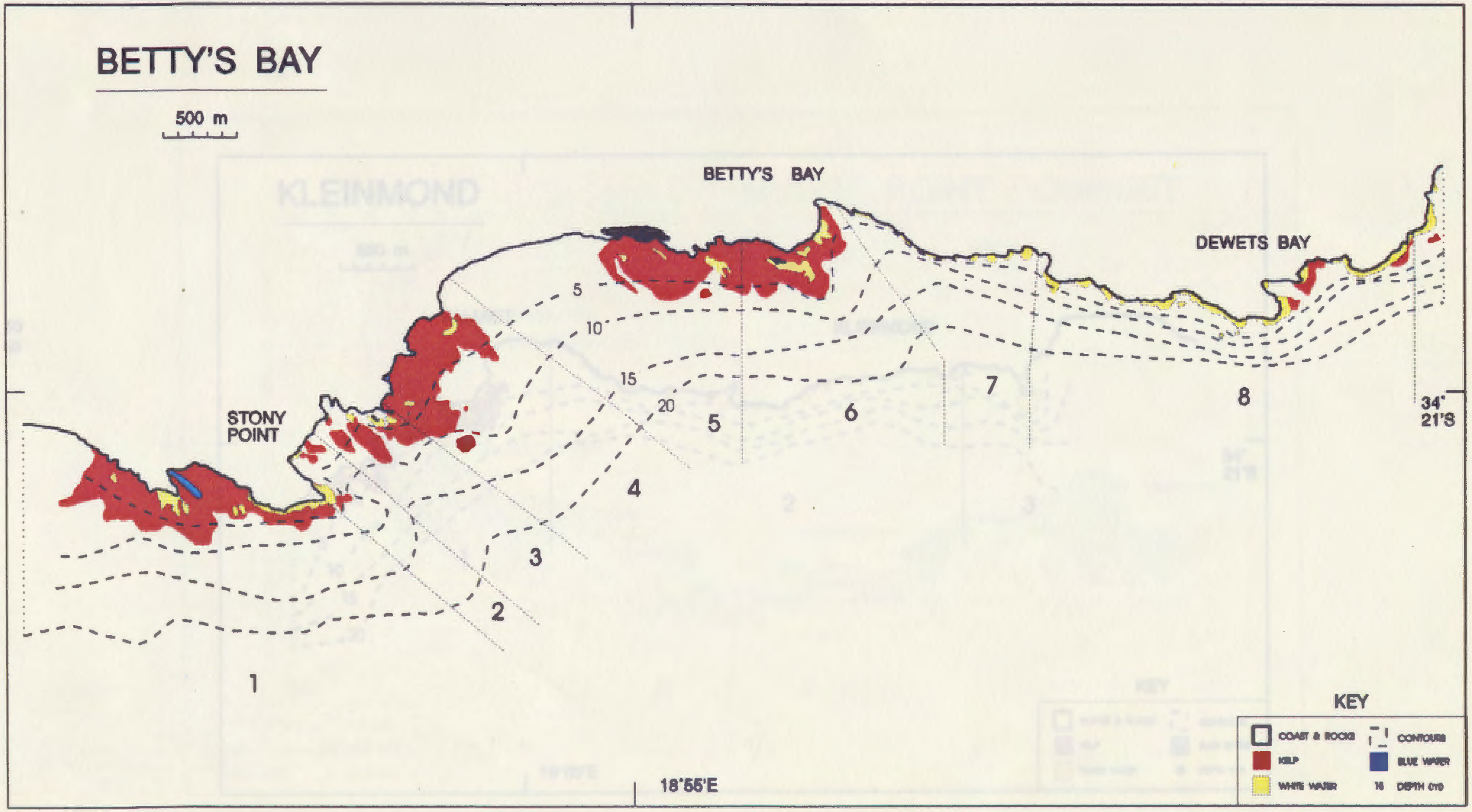
PLACE NAME	Station Number	0-5m depth kelp area (m^2)	5-10m depth kelp area (m^2)	10-15m depth kelp area (m^2)
HANGKLIP	1a	101 776	9 406	-
	1b	5 061	669	-
	2	30 885	-	-
	3a	43 715	12 078	-
	3b	165 036	50 199	-
	4	148 970	84 526	4 693
	5	86 522	127 223	112 973
	6a	223 225	273 948	42 828
	6b	200 566	139 005	84 383
	7	21 258	95 414	-
	8	162 240	32 268	-
	9*	338 003	133 578	-
	Total:	**1 769 182**	**958 314**	**244 877**
BETTY'S BAY	1	29 114	2 664	-
	2	40 525	72 318	-
	3	256 631	72 235	10 197
	4	233 328	49 596	-
	5	215 288	21 194	-
	6	30 914	-	-
	Total:	**805 800**	**218 007**	**10 197**
KLEINMOND	1*	156 745	-	-
	2*	214 804	58 413	-
	3*	65 126	-	-
	4*	26 214	-	-
	Total:	**462 889**	**58 413**	**-**
MUDGE POINT	1	118 676	45 216	-
	2	85 737	75 860	-
	3	231 707	119 642	25 823
	4	233 000	184 567	4 294
	5	141 410	108 571	6 026
	6	150 729	29 156	-
	7	110 656	52 979	-
	8	351 071	91 649	730
	9	70 420	50 024	2 100
	Total:	**1 493 406**	**757 664**	**38 973**
HERMANUS	1*	182 719	5 523	-
	2*	238 212	74 110	4 257
	3*	98 519	10 104	-
	4*	63 954	3 090	-
	5*	22 966	-	-
	6*	29 793	4 402	-
	7*	39 327	-	-
	Total:	**675 490**	**97 229**	**4 257**

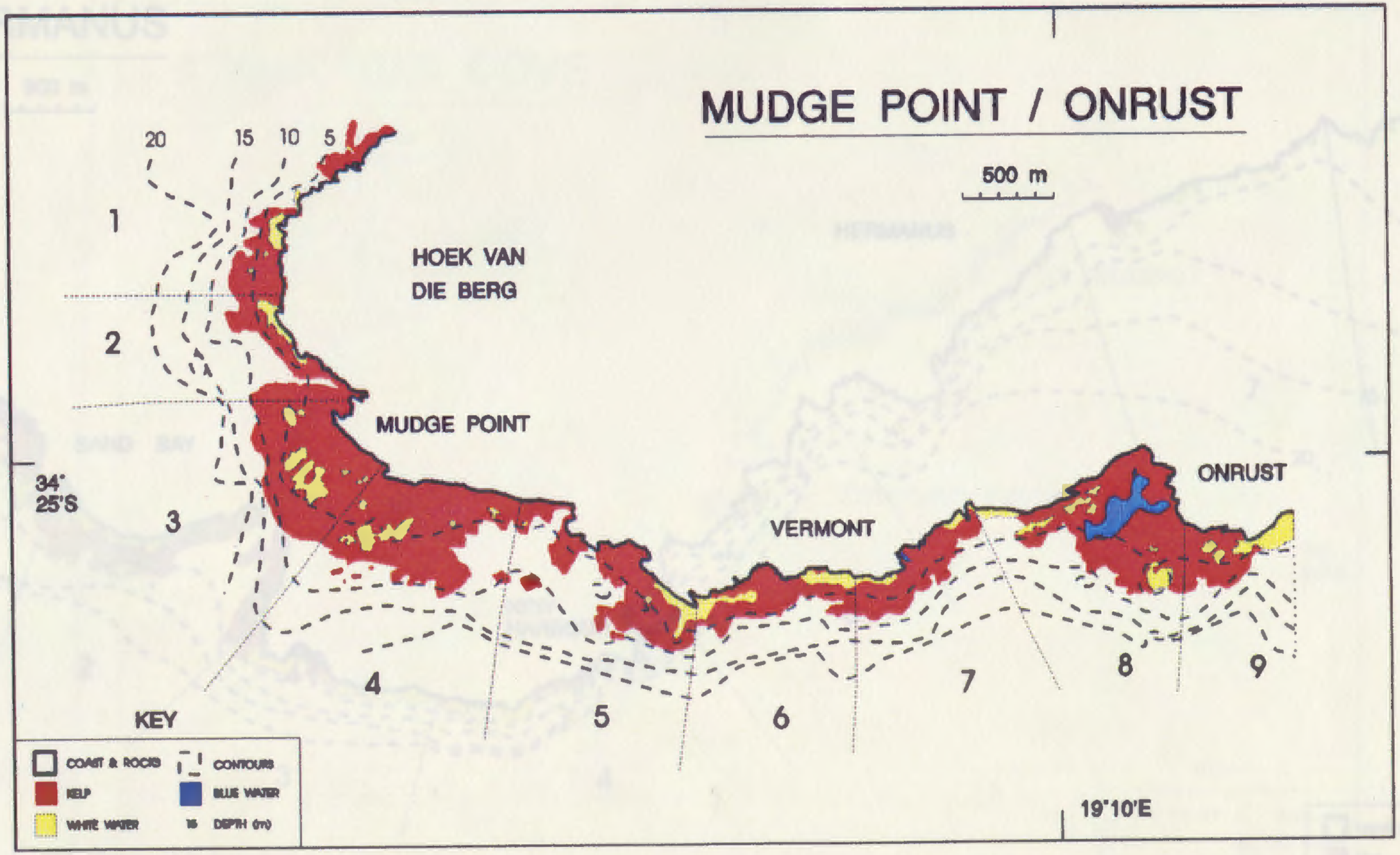
Appendix 1a: Kelp area in square metres per diving survey area. (Those areas not included in diving surveys are marked with an asterisk).

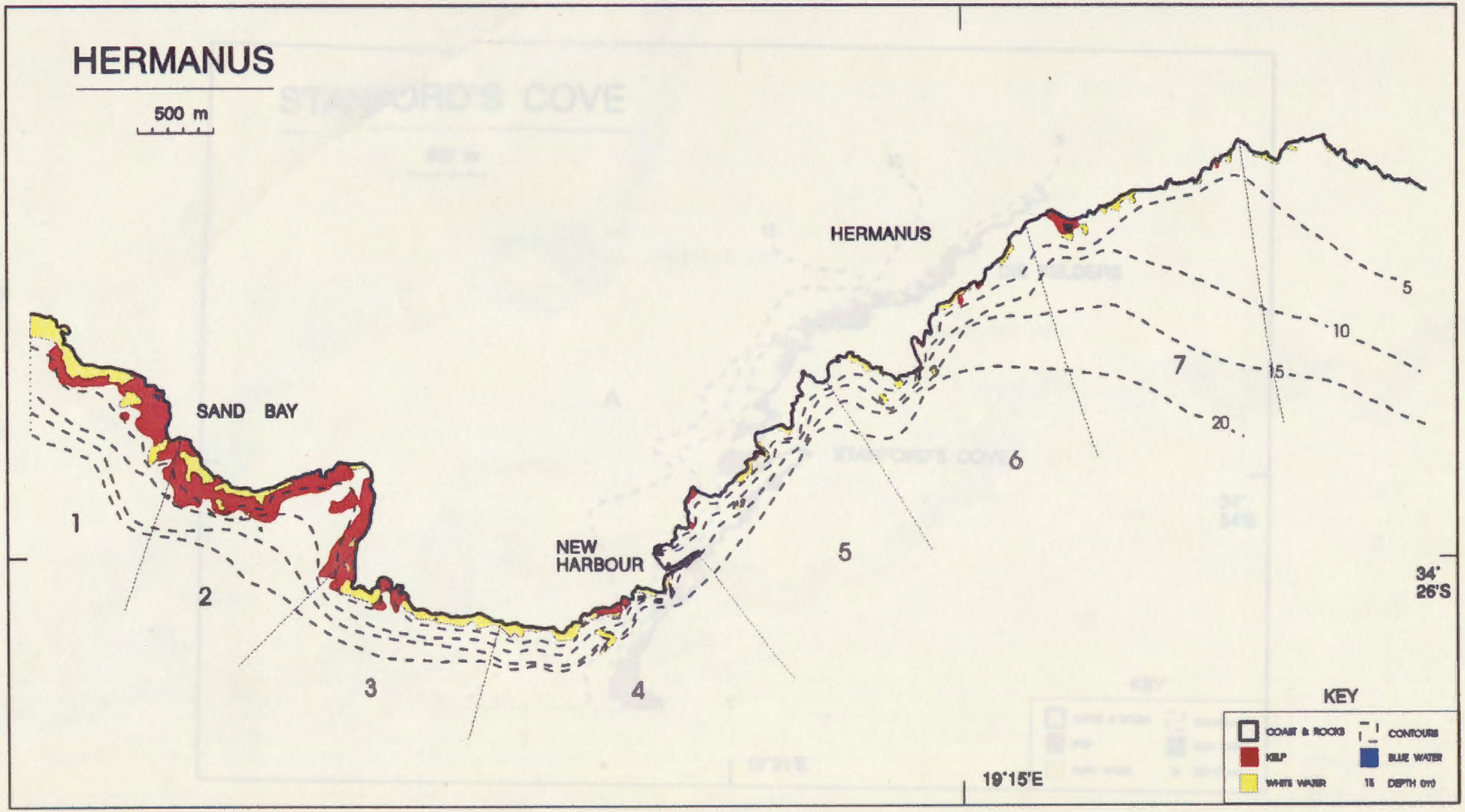
PLACE NAME	Station number	0-5m depth kelp area (m^2)	5-10m depth kelp area (m^2)
DANGER POINT	A*	361 714	30 342
	1	454 927	5 690
	2	136 510	2 123
	3	146 881	46 056
	4	236 663	52 209
	5	317 958	186 672
	6 & 7	478 426	329 865
	8	188 413	94 176
	9	196 345	87 365
	10	358 214	46 502
	B*	514 323	5 499
	Total	**3 390 374**	**886 499**
DYER ISLAND	A	417 924	232 329
	B	177 305	96 285
	C	87 211	46 180
	D	214 481	28 847
	Total:	**896 921**	**403 641**
"Clyde"	E	445 676	270 233
(3-8m)	**Total:**	**715 909^**	
PEARLY BEACH	A*	105 448	-
	B*	74 634	-
	C*	87 263	-
	1	449 533	1 577
	2	541 824	53 485
	3	478 940	23 703
Donkergat	4a	336 759	26 591
Soetfontein	4b	223 766	7 570
	5	314 346	60 284
	Total	**2 612 513**	**173 210**
BUFFELJAGS	1	356 734	105 163
	2	356 211	6 984
	3	294 274	15 423
	4	128 275	-
	5	288 854	103 325
Quoin Point	6	543 460	55 966
	7	367 454	8 854
	Total:	**2 335 262**	**295 715**

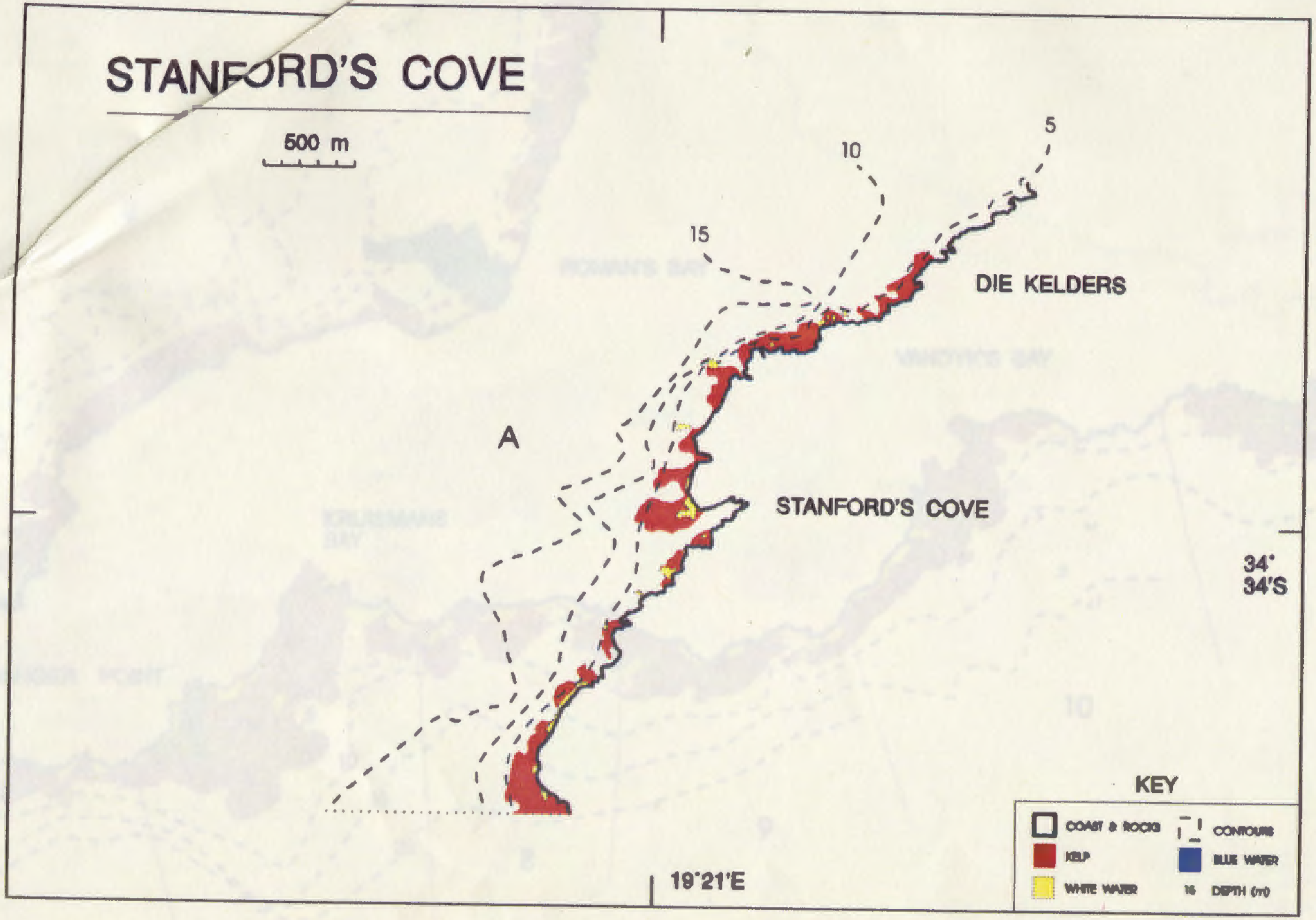
Appendix 1b: Kelp area in square metres per diving survey area. (* = Those areas not included in diving surveys; ^ = Clyde total = both depth ranges).

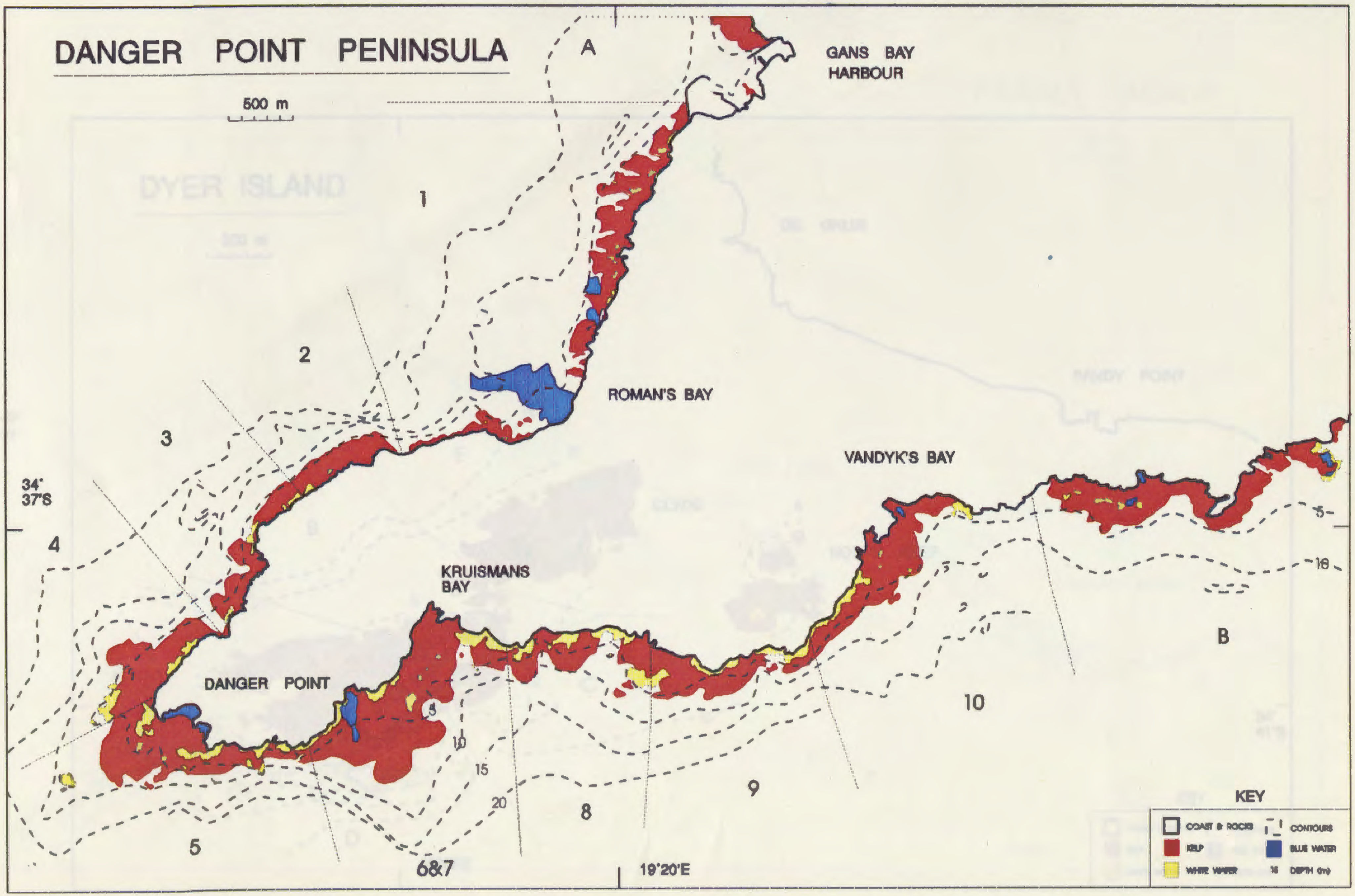

HANGKLIP
500 m
18°50'E
20
15
10
5
1A
1B
2
3A
3B
4
5
6A
6B
7
8
PRINGLE BAY
HANGKLIP
SILVER SANDS BAY
CAPE HANGKLIP
HOL-BAAI POINT
5
10
15
20
34° 23'S
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15 DEPTH (m)

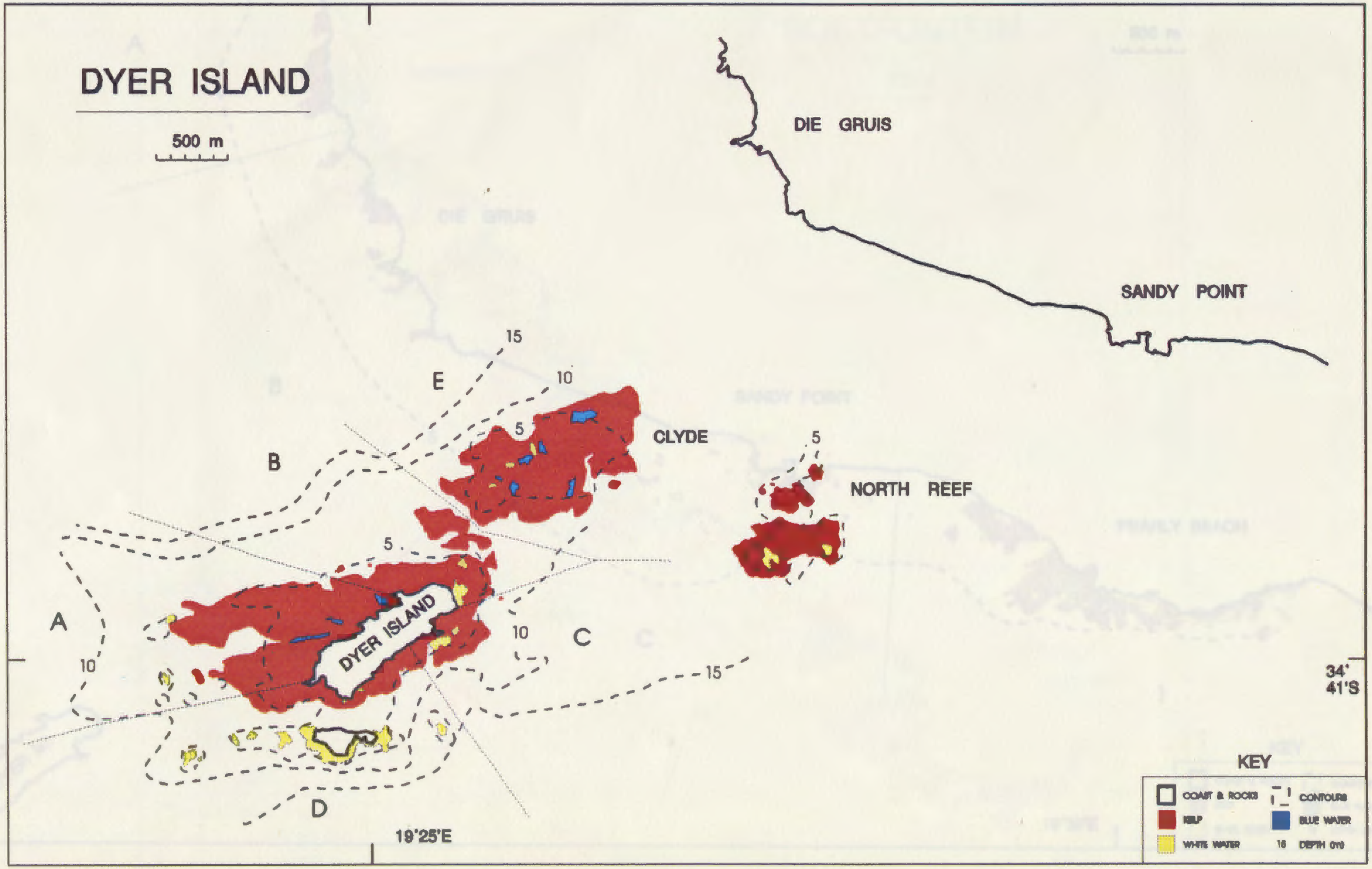

BETTY'S BAY
500 m
BETTY'S BAY
DEWETS BAY
STONY POINT
5
10
15
20
1
2
3
4
5
6
7
8
34°
21'S
18°55'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
10 DEPTH (m)


MUDGE POINT / ONRUST
500 m
20
15
10
5
1
2
3
4
5
6
7
8
9
HOEK VAN
DIE BERG
MUDGE POINT
VERMONT
ONRUST
34°
25'S
19°10'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15 DEPTH (m)

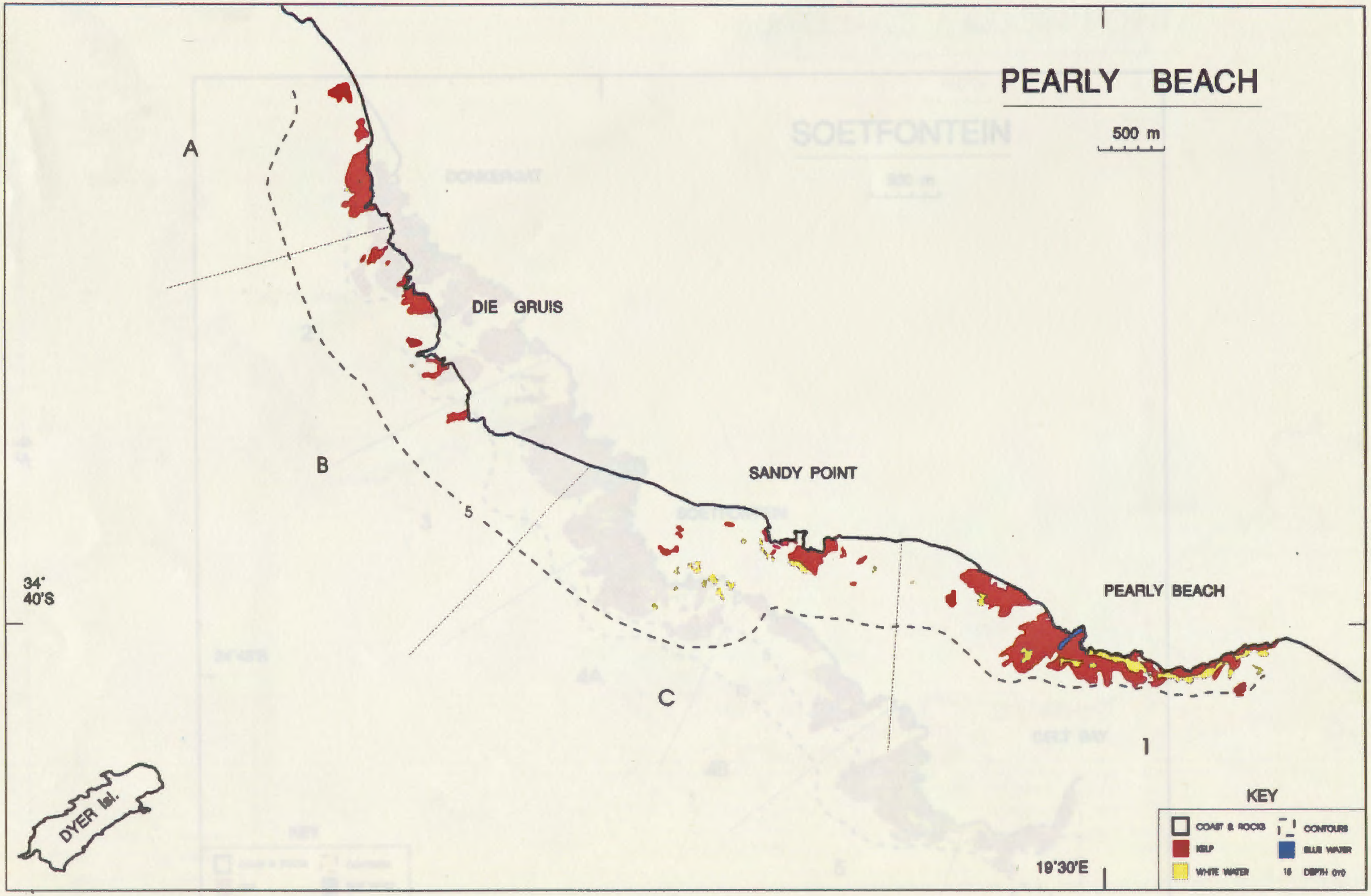

HERMANUS
500 m
SAND BAY
NEW
HARBOUR
HERMANUS
1
2
3
4
5
6
7
5
10
15
20
34°
26'S
19°15'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15
DEPTH (m)

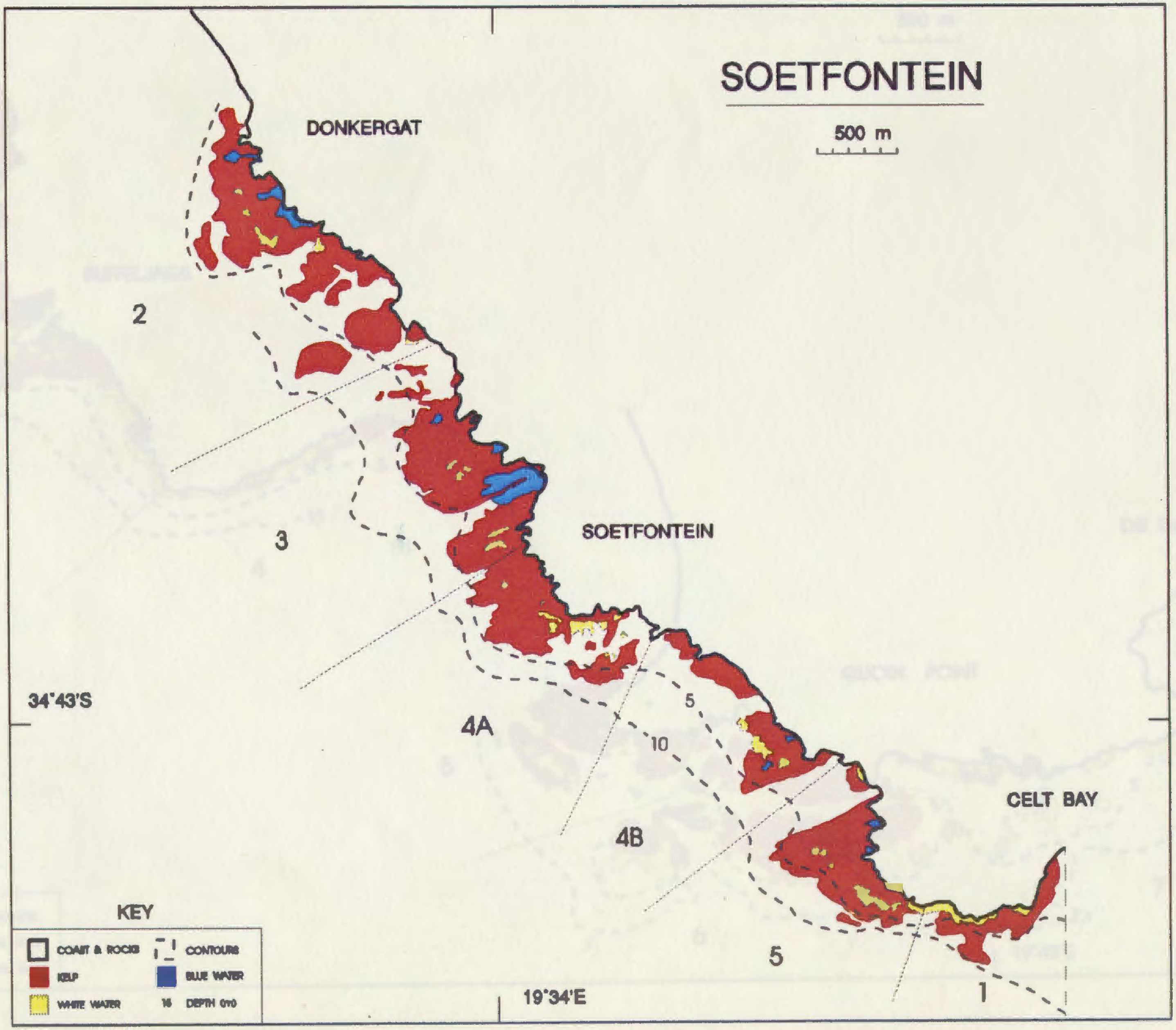

STANFORD'S COVE
500 m
10
5
15
DIE KELDERS
A
STANFORD'S COVE
34°
34'S
19°21'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
16 DEPTH (m)

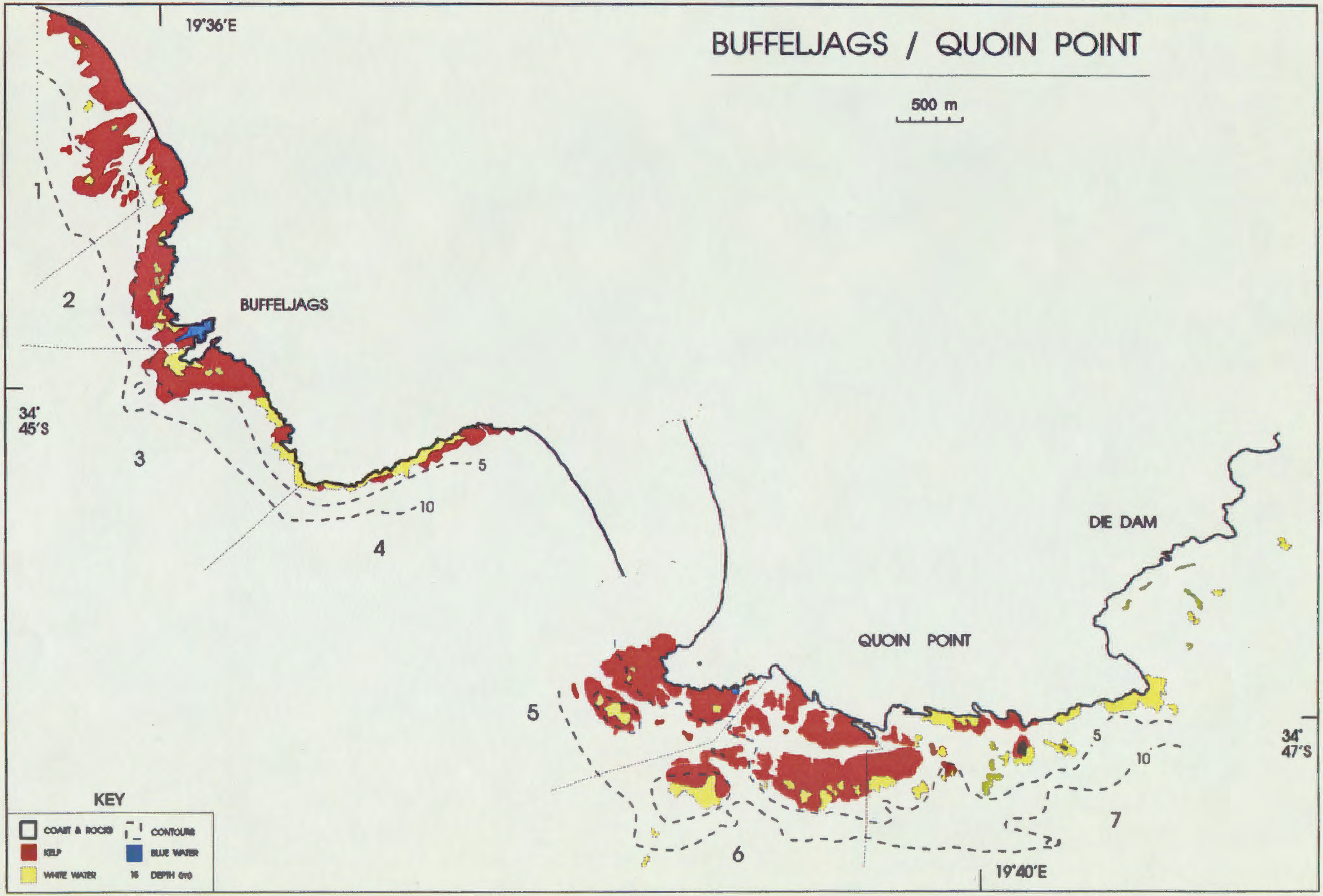

DANGER POINT PENINSULA
500 m
A
GANS BAY
HARBOUR
1
2
3
34°
37'S
4
ROMAN'S BAY
VANDYK'S BAY
KRUISMANS
BAY
DANGER POINT
5
6&7
8
9
10
B
5
10
15
20
5
10
19°20'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15 DEPTH (m)



DYER ISLAND
500 m
DIE GRUIS
SANDY POINT
CLYDE
NORTH REEF
DYER ISLAND
A
B
C
D
E
15
10
5
5
5
10
10
15
34'
41'S
19'25'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15 DEPTH (m)


PEARLY BEACH
500 m
A
DIE GRUIS
B
5
SANDY POINT
PEARLY BEACH
34°
40'S
C
1
DYER Isl.
19°30'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
18 DEPTH (m)


SOETFONTEIN
500 m
DONKERGAT
SOETFONTEIN
CELT BAY
2
3
4A
4B
5
1
5
10
34°43'S
19°34'E
KEY
COAST & ROCKS
CONTOURS
KELP
BLUE WATER
WHITE WATER
15 DEPTH (m)



BUFFELJAGS / QUOIN POINT

CHAPTER 4

REASSESSMENT OF GROWTH RATES OF *Haliotis midae*

INTRODUCTION

Knowledge of the growth rate of commercially exploited species is an important factor in their management. Growth rate data can provide an indication of the probable age of animals, and be utilized in various ways in estimating sustainable yields. Furthermore growth rates may vary from area to area for the same species, and knowledge of this will facilitate optimal management of that species.

Three methods are commonly used to estimate growth rates of abalone: 1) Mark-release-recapture, which provides data on length increments associated with known times at liberty, (Schiel 1993; Prince *et al* 1988; Tutschulte and Connell 1988; Keesing and Wells 1989; Tegner 1989; Prince 1991; Schiel and Breen 1991; Blecha *et al* 1992; Morales and Ortiz 1992). 2) Study of modal shift in population length-frequencies with time (Poore 1972; Prince *et al* 1988; Sainsbury 1982; Prince *et al* 1988; Shepherd 1988; Shepherd *et al* 1988; Tutschulte and Connell 1988). 3) Direct study of age and length by analyzing growth checks or rings visible in the shell (Forster 1967; Poore 1972; Munoz-Lopez 1976; Kojima *et al* 1977; Kim and Cheung 1985; Prince *et al* 1988; Morales and Ortiz 1992).

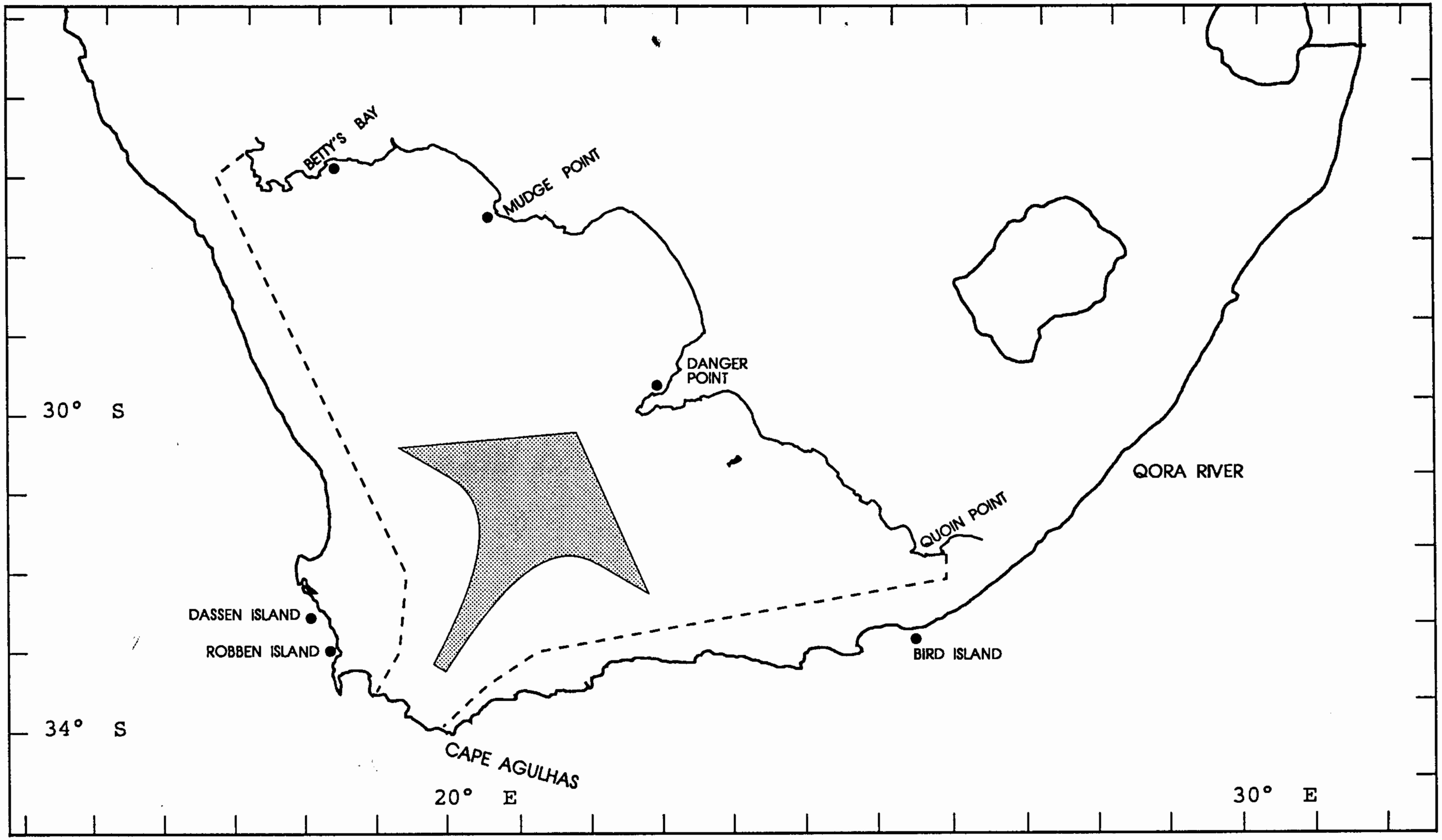


Figure 1: South African coastline, showing the tagging sites (●) and other places mentioned in the text.

boring organisms (*Cliona* sp.) frequently obscures any patterns. Modal studies are only useful for the first few years of abalone growth because wide individual variations in growth rates (Hayashi 1988; Sainsbury 1982; Murray 1986; Genade *et al* 1988; Day and Fleming 1992)) result in a loss of distinction between individual cohorts within a few years.

The following factors were taken into account in designing the new experiments in order to afford greater confidence in the results: 1) As wide as possible a range of sizes were desirable, because if only smaller sizes were sampled, K would be overestimated and L∞ underestimated. Conversely, if only large abalone were sampled, K would be underestimated, and L∞ overestimated (Keesing and Wells 1989). 2) The tagging method should cause minimal disturbance to the animal, both during and after tagging (Forster 1967; Harrison and Grant 1971; Poore 1972; Shepherd and Hearn 1983; McShane *et al* 1988; Prince 1991). 3) Growth studies should take place in a variety of representative localities in order to determine whether local differences occur (Murray 1982; Prince *et al* 1987). 4) In order to avoid complicating seasonal effects (Shepherd and Hearn 1983), the major tag recovery effort should be timed to occur at least one full year after tagging (Keesing and Wells 1989). Possible inter-annual variability in growth, as discussed by Day and Fleming (1992), was not accounted for in this experimental design. This possible bias is most likely to occur as a result of variable food availability.

Significant movements of *H. midae* were recorded by Newman (1966), and he also cited commercial abalone divers as claiming that heavily fished areas appeared to recover rapidly after fishing due to migration of adults into the area. However, observation of natural undisturbed populations such as exist in marine reserves show aggregations of several hundred large mature individuals, which appear to be stable. Tagging of such a population is one means of gaining insight into the movement dynamics of such aggregations. This also has relevance in the interpretation of catch per unit effort statistics, since the potential for replenishment of fished aggregations from adjacent more scattered abalone populations has a bearing on the often debated relationship between diver catch per unit effort indices and abalone stock size (Harrison, 1983; Day and Leorke, 1986; Breen, 1992).

METHODS

Six study sites around the South African coastline were identified (Fig. 1) in order to adequately cover the differing environmental conditions inhabited by *H. midae*, *viz.* Dassen Island and Robben Island on the cold West Coast; Betty's Bay (a marine reserve), Mudge Point and Danger Point within the optimum environmental area of *H. midae*, and Bird Island in the warmer waters of the Eastern Cape, where a dense, but non-exploited population of *H. midae* exists.

After various tagging methods had been tested, the most suitable proved to be copper disc tags cemented to the shell. These were manufactured from 0,6mm thick copper sheeting, with alphanumeric sequences stamped onto them. Two tag sizes were used, the smaller tags being ovoid in shape (5mm x 15mm), and suitable for abalone in the smaller size range. The larger tags were circular and 19mm in diameter. Both sizes had one or more holes which acted as a key for the putty. Whenever possible, tagging and measuring was done *in situ* on the seabed in order to minimise tagging disturbance. When *in situ* tagging was not possible, limited numbers of abalone (<20) were held on site over the side of a boat in buckets with perforated bases until tagged. These were then returned by divers to the seabed near the point of removal, usually within 15 minutes of collection. It was not necessary to dry the shells, and the abalone were therefore out of the water for only a few minutes during tagging.

The centre of the shell was lightly scrubbed free of epibionts, and a small lump of epoxy putty (Pratley's Standard set) was pressed onto the shell. A tag was then embedded in the putty. In particular with smaller abalone, the profile of the putty and tag was kept as low as possible in order to minimise both water drag and interference to abalone movement under rocks and ledges. This method proved slow, but very suitable, since tagging-induced mortality was negligible (as evidenced from shell searches carried out during and soon after tagging trips). The tags remained in position for many years, permitting multiple recoveries of the same animal. Measuring accuracy was checked at all sites by remeasuring randomly selected abalone, and no significant errors were recorded. Shell length was recorded for growth studies instead of shell breadth, (which was used for stock assessment surveys), as this can be measured with greater accuracy.

The copper resisted fouling by epibionts, enabling tags to be readily identified by divers. In contrast the epoxy putty soon became indistinguishable from shell material due to fouling (Plate 1). With the continuous flushing experienced in an open-water marine system, no negative physiological effect of copper on the abalone would be expected.

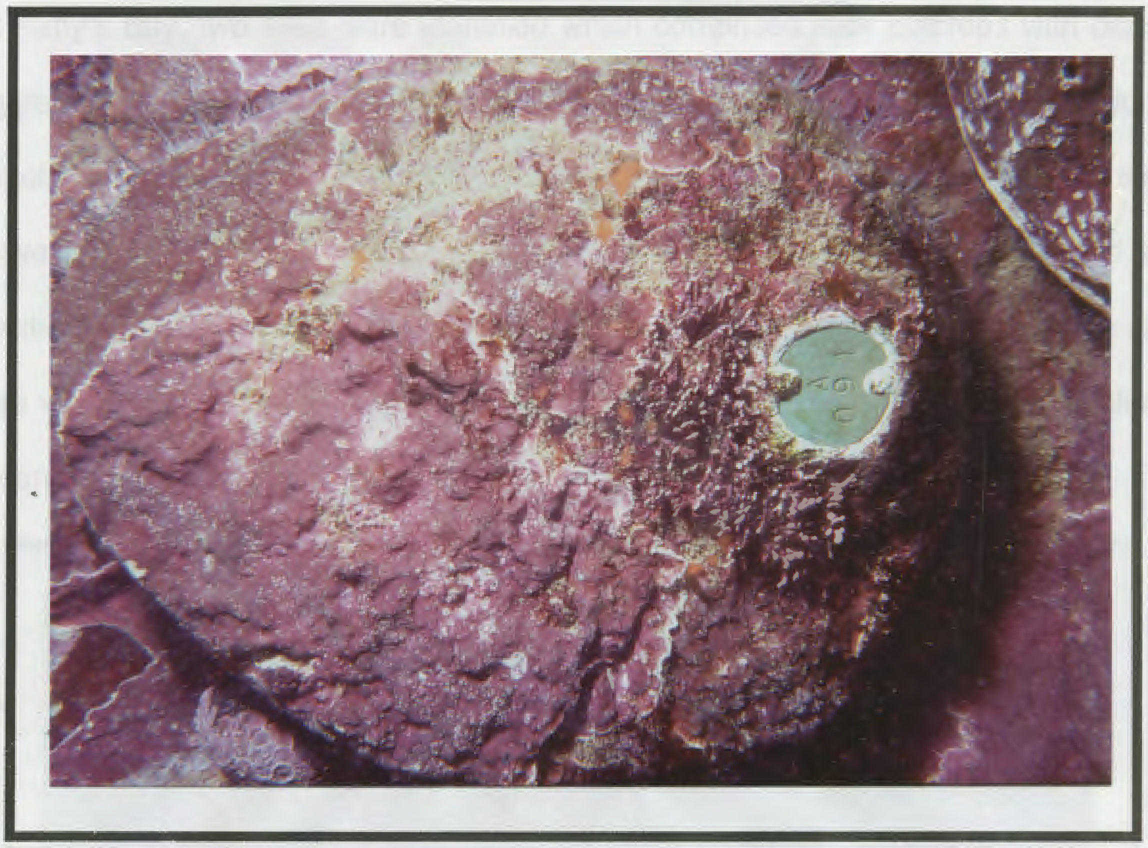


Plate 1: Tagged abalone showing complete encrustation of epoxy putty, and the readily visible non-fouled copper tag.

The length range of abalone tagged covered as wide a range as possible, and shell length was recorded to 0,1mm. Recoveries were usually carried out within a few days (maximum 4 weeks) of a full calender year from the tagging date, and all recoveries were measured and released again. In commercial areas, a tag-reward system was employed to aid recoveries. However, few of these data could be used, due to unsuitable release intervals, which would have required allowances for seasonal effects. In addition, at most localities multiple recoveries could be made, as well as recoveries with release periods of up to 5 years.

Movement study:

At Betty's Bay, two sites were identified which comprised rock outcrops with dense aggregations of adults (Plate 2). Abalone on these rocks were tagged *in situ* in October and November 1985. In order to allow for immediate tagging-induced movement, site sketches were made the day after the final tagging exercise, and the positions of the 58 large tagged abalone which occupied it were recorded. The site was visited annually until November 1988, and the positions of the tagged abalone recorded.

Plate 2: Tagged large abalone occupying one of the large rocks used in the movement study.

RESULTS

A total of 6393 abalone were tagged at the six sites, with useable recovery success ranging from 42% at Dassen Island to 4% at Danger Point, with an average return rate of 18%. Danger Point and Mudge Point were the only two sites which were fished by commercial and/or recreational divers, and it is possible that these poor return rates may have been due to loss of tagged abalone to divers.

The majority of unusable recoveries were rejected because of illegible (eroded) tag numbers, commercial returns where the recovery date was uncertain, or because the release period was not within 4 weeks of one year. A very small number (~8) were rejected due to clearly erroneous growth increments which probably arose from incorrect recording of initial shell length data.

TAGGING RESULTS: These are summarized below on a per area basis:

Dassen Island supports a significant abalone population, which has been commercially fished on an intermittent basis since the inception of the industry. However during February 1988 no abalone below 105 mm shell length could be found despite intensive searching (Fig. 2). In addition it was noted that many of the shells were in poor (eroded) condition, exhibiting a high incidence of shell damage caused presumably by the boring sponge *Cliona* (Forster 1967; Breen 1980; Tegner *et al* 1989; Clavier 1992). Frequently, the outer crystalline calcium carbonate layer was completely eroded away on the dorsum, leaving only the nacreous layer. In addition, severe erosion of the anterior edge of the shell was noted in some cases, and a few specimens were even found with ribbed mussel (*Aulacomya ater*) attached to the inner nacreous edge on the anterior end of the shell, indicative of animals in poor condition. Many shells consequently appeared very old despite their small size.

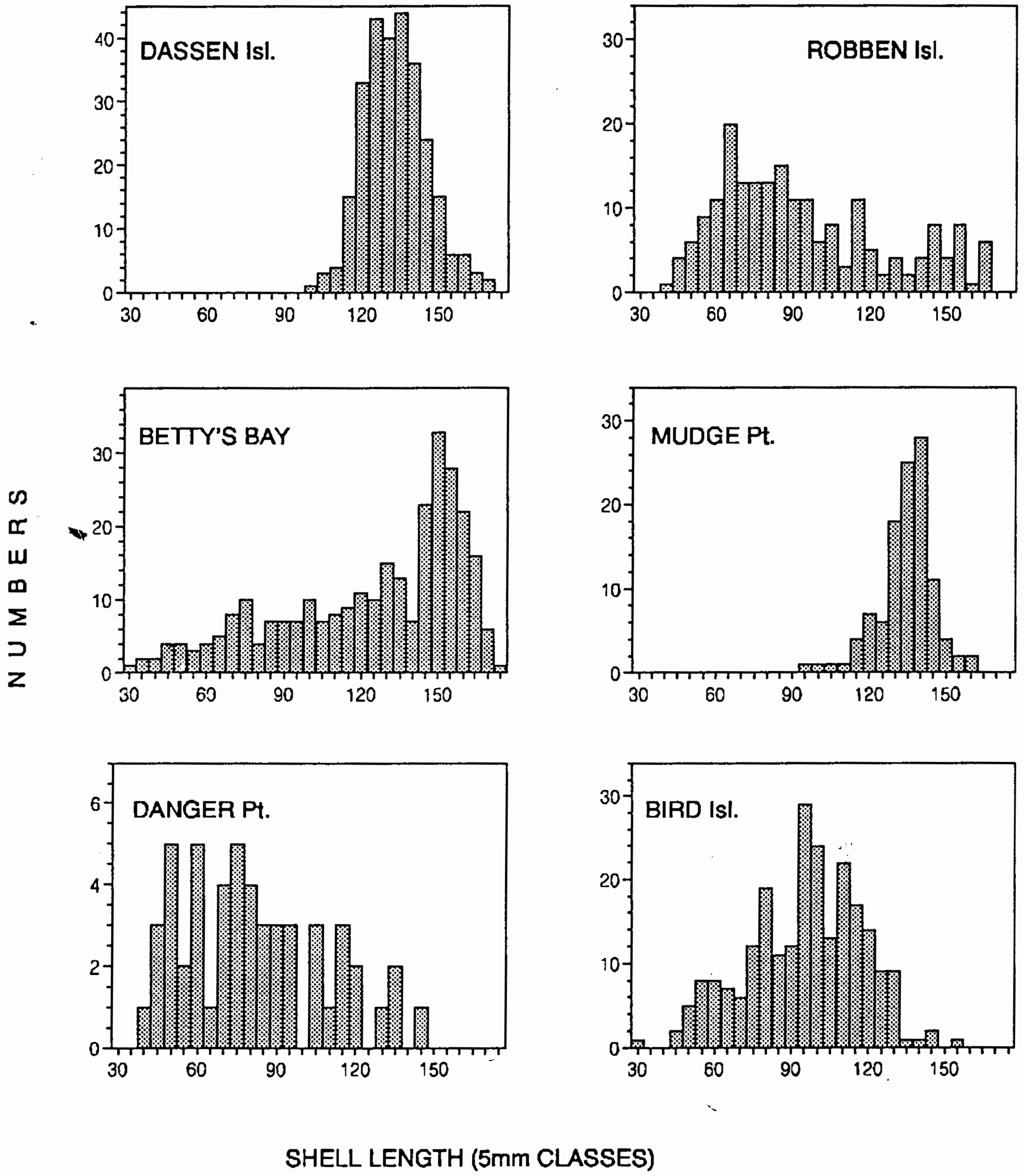


Figure 2: Shell length frequency (L_t) of abalone recovered during tagging operations.

Of the 658 abalone tagged in House Bay, Dassen Island, 275 useable recoveries were made within five days of one year. A high proportion (35,6 %) of the abalone recovered showed negative growth, which was presumably related to the frequent poor shell condition. This, combined with the unsatisfactory length frequency tagged (L_t = 105 - 173mm), made the data unsuitable for producing a meaningful growth curve. However, it was clear that growth was abnormally slow, and the population appeared stunted.

Robben Island is approximately 70 km south of Dassen Island, also on the colder West coast. The abalone population here appeared more viable, with all size ranges present. A total of 675 abalone were tagged at two sites during June 1988. Of these, 199 useable recoveries were made within 4 weeks of a one-year release period (Fig. 2).

Betty's Bay, a marine reserve, was chosen as the initial area for tagging trials, and after development of the technique, 1767 abalone were tagged during October/November 1985 and 1986. Of these, 242 useable recoveries were made within 4 weeks of a one-year release period (Fig. 2).

Mudge Point was the first commercial area in which tagging was carried out, and a total of 1198 abalone were tagged at a number of sites. Very few recoveries could be achieved by research divers, and a tag-reward scheme provided the majority of the returns. One factor contributing to the poor recovery rate may have been that tagging was carried out at a number of localities (due to the low densities of abalone encountered). In consequence, searching efficiency was greatly hampered, due to the greater area of seabed which had to be covered. Only 57 returns were useable, and because the majority of these were from commercial fishermen, the smallest size recovered was L_t = 100mm shell length (Fig. 2). In consequence the data were considered unsuitable for determination of a meaningful growth curve.

Danger Point: a total of 1207 abalone were tagged at two localities on either side of the peninsula in November 1987. Despite a tag-reward incentive, as well as directed searches being made, only 52 useable recoveries were made, within a few days of a full calender year. However, because the size range recovered appeared reasonably representative of the population (L_t = 42 - 149mm: Fig. 2), the data appeared suitable for calculation of a growth curve.

Bird Island, in the Eastern Cape, was the subject of an intensive abalone survey during August 1986 when 888 abalone were tagged. One year later (± 2 days) 244 useable recoveries were made, over the size range L_t = 30 - 155mm.

COMPARISON OF REGRESSIONS: With two sites being rejected for growth rate comparisons (Dassen Island and Mudge Point), the data for the four remaining sites were compared as follows: Shell length increments were all corrected to represent exactly one year's growth. Then the four regressions of original shell length (L_t) against corrected annual growth increment (L_{t+1}-L_t) were compared using analysis of covariance. Scatter plots of the growth increments are shown in Figure 3. Results of the calculations are given in Table 1, and the null hypothesis that all slopes were equal was rejected : $F_{0.05(1),3,718} = 2{,}61$.

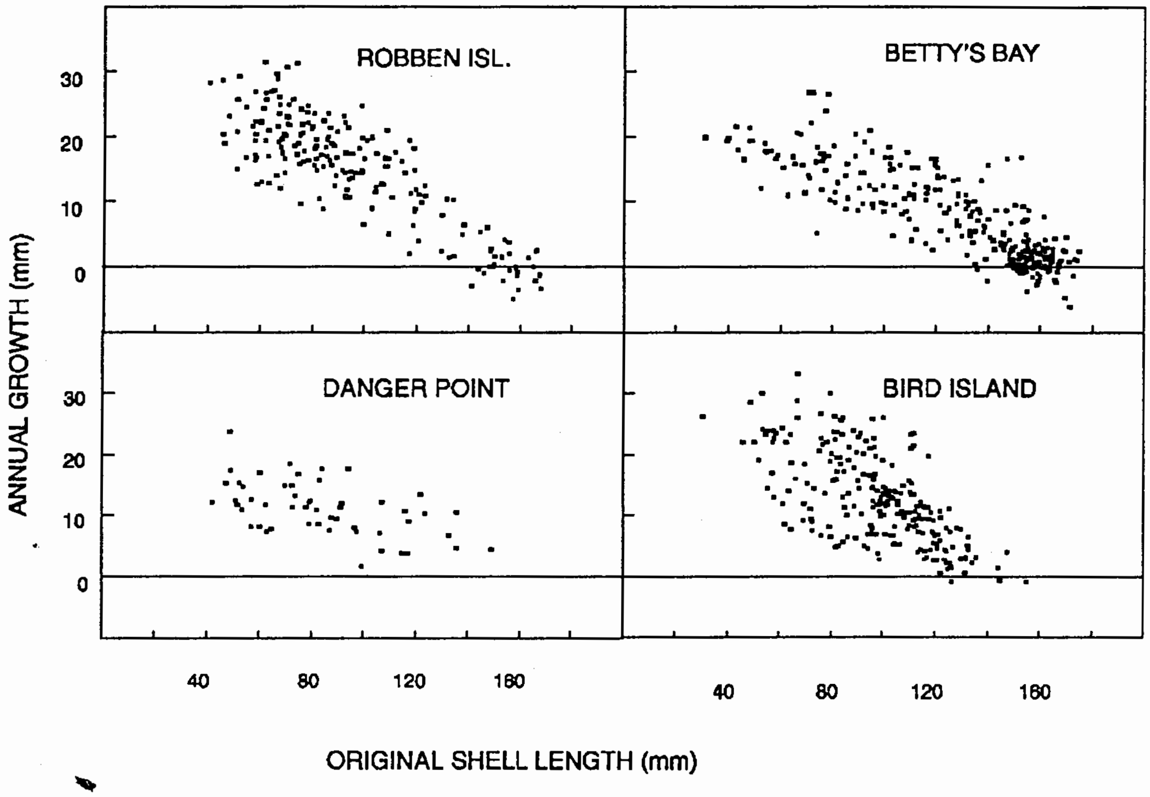


Figure 3: Annual shell length increments suitable for growth curve calculations.

The Tukey multiple range test was then applied to all possible comparisons of slopes. Results of these tests are given in Table 2. No significant difference was found between the Bird Island and Robben Island slopes, and comparison of the elevations of this pair also showed no difference. However, all the other pairs of slopes were significantly different from each other. Therefore for purposes of calculation of growth curves, data from Bird Island and Robben Island could be combined, but given that sufficient data points exist for each, and the geographical separation of the two sites, independent growth curves were calculated.

TEST	n	b	Residual sum of squares	Residual degrees of freedom
Robben Island	199	-0,221	3796,04	197
Betty's Bay	242	-0,170	3458,36	240
Danger Point	52	-0,088	706,48	50
Bird Island	233	-0,219	7057,58	231

Table 1: Analysis of covariance parameters for the simultaneous comparison of four regression slopes.

TEST	S.E.	Residual degrees of freedom	q
Betty's Bay / Bird Isl.	0,007	471	7,25
Betty's Bay / Robben Isl	0.006	437	8,96
Betty's Bay / Danger Pt.	0.007	290	11,40
Bird Isl. / Robben Isl.	0.011	428	0,18 *
Bird Isl. / Danger Pt.	0.012	281	10,75
Robben Isl. / Danger Pt.	0.008	247	15,81

Table 2: Multiple range test parameters for comparison of pairs of regression slopes (* No significant difference).

There is no consensus among workers on the "best" model or method for producing a growth curve for haliotids. An exhaustive investigation of this subject is beyond the scope of this report, and is currently being carried out by a colleague (C. Raubenheimer *pers. comm.*). However a brief background regarding the various growth models and procedures used in the past is given in the Discussion. For the purposes of this report, the standard von Bertalanffy model was applied to the length increment data using the maximum likelihood procedure as outlined by Hampton (1991), but excluding model error. This model was chosen due to the convenience of the maximum likelihood fitting procedure outlined by Hampton, and the persistence throughout the literature of the standard von Bertalanffy curve as an adequate descriptor of growth.

The format of the formula is given below:

$$\delta l_i = (L_\infty - l_i)(1 - e^{-Kt_i})$$

An estimation of t_0 is required for many applications of the von Bertalanffy model, but is not available from length increment data alone. To estimate t_0, age-at-length observations are required, such as from studies of annual growth checks in the shell. Such data are not available for *H. midae*, therefore t_0 is assumed to be zero.

Many workers report linear growth in juvenile haliotids (Forster, 1967; Newman, 1968; Tutschulte and Connell, 1988; Shepherd, 1988; Shepherd *et al* 1988; Greenier and Takekawa, 1992), although the age/size at which this changes to a declining von Bertalanffy type of curve varies between species. Analysis of recruitment cohorts in the size range from 2mm to 45 mm shell length (Tarr, *in prep.*) confirms this linear pattern in juvenile *H. midae*. It will therefore soon be possible to incorporate these data into a growth model which will therefore have data points more closely approximating t_0.

Growth curves for the four sites are given in Fig. 4, and the relevant von Bertalanffy growth parameters are given in Table 3. It is apparent from observation of the

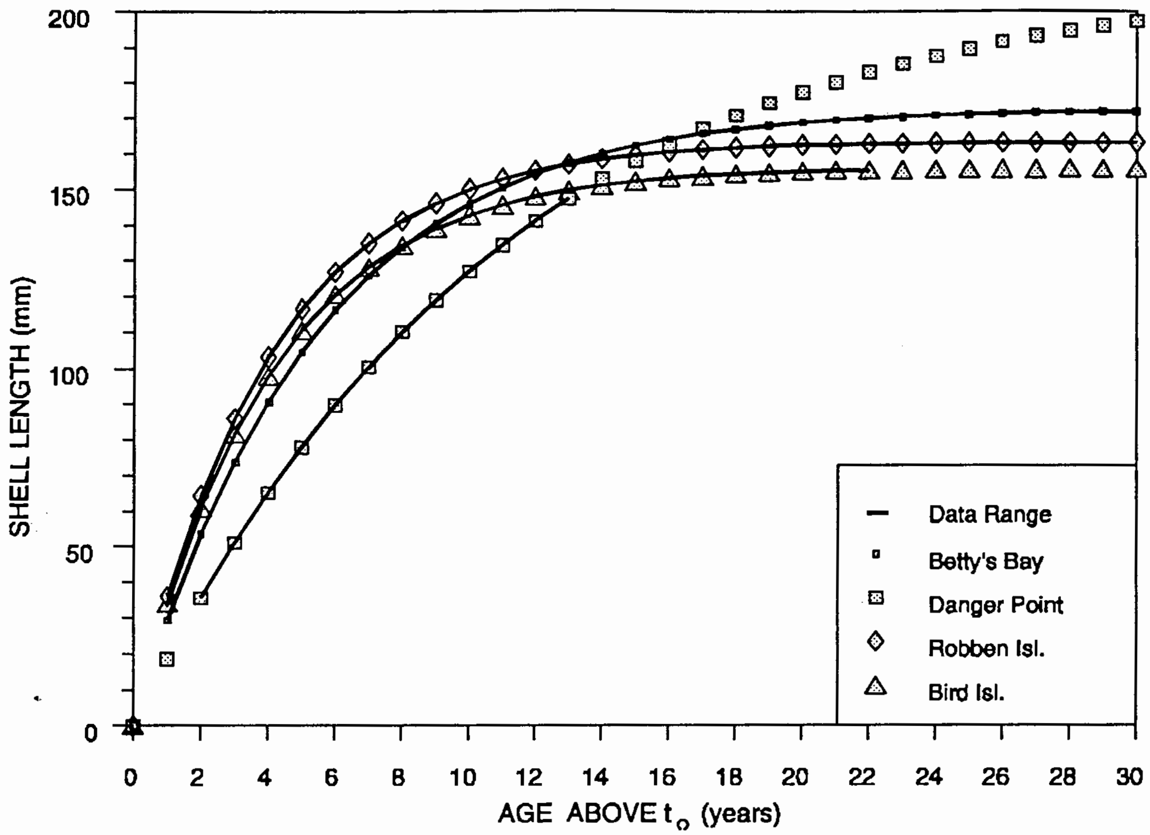


Figure 4: von Bertalanffy growth curves for *H. midae* from four sites.

resultant growth curve for the Danger Point area that the results from this area should be treated with caution. The exceptionally low value for K and the high L∞ are unlikely to be representative of this entire commercial fishing ground, which has been intensively fished since the inception of the industry in the 1950's. There are a number of reasons why this result may be misleading: 1) A very small proportion (4%) of the abalone tagged were recovered, and it is possible, therefore that those animals recovered may have represented an atypical proportion of the population. A more likely source of error however, is the location of the site. For the duration of this tagging exercise, sea conditions were not particularly favourable, being unseasonably rough, and in consequence the most sheltered site available was selected for the tagging operation. While the site appeared typical of other kelp forests in the area, it is possible that generally lower swell-induced water movement may have affected food availability (drift kelp), which can result in lower growth rates (Leighton and Boolootian 1963; Poore 1972; Tutschulte and Connell 1988). It would seem that further work could be done to investigate this possibility further.

TEST	n	K	L_∞
Robben Island	199	0.2495	163.294
Betty's Bay	242	0.1859	172.76
Danger Point	52	0.0927	210.32
Bird Island	233	0.2469	155.88

Table 3: von Bertalanffy growth parameters derived from a maximum-likelihood analysis of growth increment data.

Movement study: Results are summarised in Table 4, which shows that of the original 58 abalone whose positions were recorded on two rocks in 1985, three years later 46,6 % were still present on the same rocks. Of these, 81,5% still occupied the exact same position on the rock. Length increment data are not available for each year, since measuring was not always carried out (in heavy seas) due to the possibility of disturbing the abalone. Original lengths of the abalone present each year have been plotted on Fig. 5 showing the large mean size of the abalone tagged, and the fact that it was in general the larger abalone that remained on the site. Loss of abalone from the site could be due either to migration or mortality, although the fact that mostly smaller animals disappeared may indicate that migration was the primary factor.

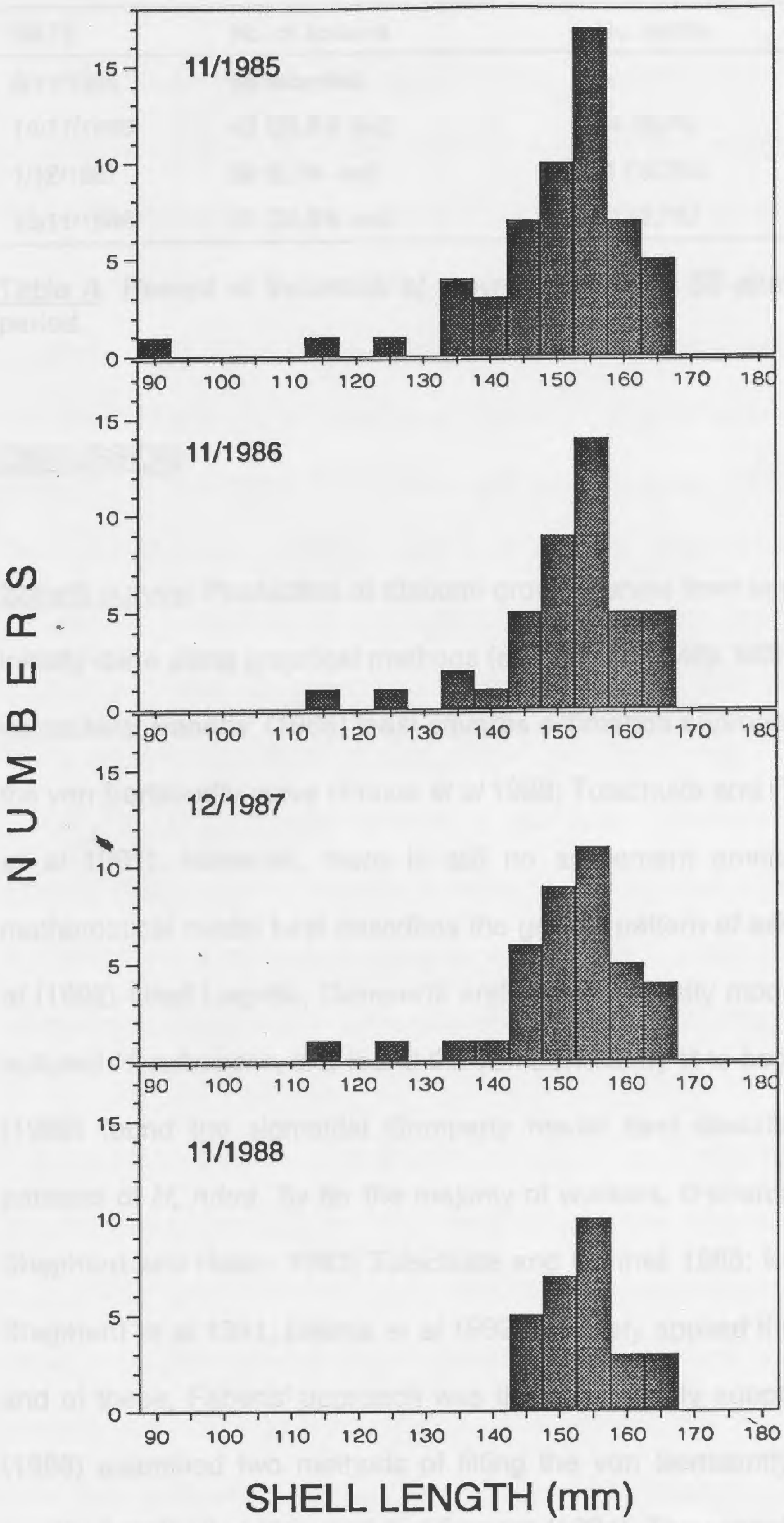


Figure 5: Changes in length frequency (L_t) of abalone in movement study over the period 1985 - 1988.

DATE	No. of abalone	No. mobile	No. stationary
6/11/1985	58 recorded	-	-
18/11/1986	43 (25,6% lost)	4 (9,3%)	39 (90,7%)
1/12/1987	39 (9,3% lost)	4 (10,3%)	35 (89,7%)
13/11/1988	27 (30,8% lost)	1 (3,7%)	26 (96,3%)

Table 4: Record of incidence of movement among 58 abalone over a three year period.

DISCUSSION:

Growth curves: Production of abalone growth curves from length increment data was initially done using graphical methods (eg Walford 1946). With the extensive usage of computers, Fabens' (1965) least squares estimation approach was widely used to fit the von Bertalanffy curve (Prince *et al* 1988; Tutschulte and Connell, 1988; Shepherd *et al* 1991). However, there is still no agreement among workers as to what mathematical model best describes the growth pattern of adult abalone. Greenier *et al* (1992) fitted Logistic, Gompertz and von Bertalanffy models to growth data from cultured *H. rufescens*, and found the von Bertalanffy fit to be the best. However Nash (1992) found the sigmoidal Gompertz model best described the varying growth patterns of *H. rubra*. By far the majority of workers, (Fabens 1965; Sainsbury 1982; Shepherd and Hearn 1983; Tutschulte and Connell 1988; Keesing and Wells 1989; Shepherd *et al* 1991; Blecha *et al* 1992) routinely applied the von Bertalanffy curve, and of these, Fabens' approach was the most widely adopted. Maller and de Boer (1988) examined two methods of fitting the von Bertalanffy curve: Fabens' and a modified method of Kirkwood and Somers (1984). They concluded: "... it remains true that, provided the data support estimation of an asymptotic length, the von Bertalanffy is one of the simplest curves giving such a description, and variability of the order of magnitude which we have observed in actual data sets makes the distinction between the von Bertalanffy and other descriptions of asymptotic growth somewhat academic." However, James (1991) persisted, suggesting that the least squares approach had the potential to produce biased estimators, and he concluded that further work was required. Attention has also been directed at incorporation of individual growth variability (Sainsbury, 1980; Kirkwood and Somers, 1984) into growth models. Recently Hampton (1991) described several von Bertalanffy growth models incorporating individual growth variation as well as model error (some animals may not grow exactly according to the von Bertalanffy model), and using maximum likelihood fitting procedures. He concluded that a modified model of Kirkwood and Somers (1984) including individual variation in growth as represented by variation in L_∞, and incorporating model error was the most appropriate to his Tuna data set. It was due to this lack of a clearly identifiable "best" model for animal (or abalone) growth that the standard von Bertalanffy curve was applied to the *H. midae* data.

It is generally accepted that growth rates within poikilothermic species will vary with temperature within their normal environmental tolerances: faster in warmer conditions and slower in colder waters. Therefore the similarity of growth rates between the Bird Island population and those of Robben Island was not expected, and should be investigated further. Newman (1969) calculated that growth of juvenile abalone cohorts from Port Elizabeth (near Bird Island) was 33% faster than those from Betty's Bay. Recently T. Hecht (*pers. comm.*) reported faster growth of artificially fed *H. midae* at raised temperatures. Similarly, faster growth in warmer temperatures have been reported for haliotids by other workers (Leighton *et al* 1981; Lee *et al* 1988).

The high individual variability in growth rates which produced the wide scatter of growth increments was undoubtedly a major factor complicating statistical comparisons. Huge differences in growth were shown for similarly sized individuals. For example at Bird Island annual growth of individuals of ± 68mm varied from 9 to 33 mm shell length, and for individuals of ± 82mm, growth varied from 5 to 24 mm shell length. Similar scatter in growth increment data has been reported for other species (Sainsbury 1982; Murray 1986; Tutschulte and Connell 1988; Morales and Ortiz 1992). However, despite the scatter, visual examination of the data (Fig. 3) still indicates that the two populations show similar growth patterns.

There are other factors which may cause abalone growth at Bird Island to be lower than expected, the most significant being food availability. A relationship between abalone growth rate and food availability has been demonstrated by other workers (McShane *et al* 1988; Morales and Ortiz 1992; Tegner *et al* 1992), and has been discussed by Day and Fleming (1992). Shepherd and Hearn (1983) demonstrated that growth rate could be correlated with an index of crop fullness. It is therefore possible that either food availability, or the energetic suitability of Bird Island seaweeds are not optimal. *Plocamium* spp. are likely to be the major food of *H. midae* at Bird Island (R. Anderson *pers. comm.*). Algal availability during the August study period however appeared abundant. This may change seasonally, because seasonal mass washups of red algae (mainly *Plocamium* spp.) are reported to occur in the area (C. Heinecken, *pers. comm.*), which are correlated to local sea conditions. Barkai and Griffiths (1987) found that *Plocamium* had a higher calorific value than *Ecklonia maxima*, the dominant food of *H. midae* in the SW Cape. However relative absorption efficiencies for the two algal species are not available, and further work on feeding at Bird Island could be done.

Competition for food may also cause reduced growth in high density climax populations such as exist in places at Bird Island. However, abalone appear well-adapted to survival at high densities, using trap-feeding to obtain drifting algae. It is more likely that a shortage of food *per se* would limit growth, rather than intra-specific competition for food, although the two are clearly linked.

A further potential cause of lower growth at Bird Island could be related to the species approaching the northward limits (upper temperature range) of its distribution. Stunted populations of *H. rubra* were reported by Prince *et al* (1987), and related to warmer temperatures.

The von Bertalanffy growth curve from Newman (1968) (converted to shell length), is shown together with the growth curve from this study for Betty's Bay in Fig. 6. It can be seen that concerns that growth rates were underestimated for *H. midae* appear to be justified, since these results indicate a faster initial growth rate, and smaller L_∞. This shows that *H. midae* may be attaining the present MLS at 8+ years instead of 13+ years. The implications of such a large discrepancy for future modelling approaches are highly significant, since *H. midae* are also attaining sexual maturity at an earlier age than was previously considered: Newman (1967) reported 100% sexual maturity to occur at 127mm shell length, which corresponded to an age of approx. 11,2 years. This study shows that 100% sexual maturity may occur at around 7,2 years, some 4 years earlier. This information is essential to meaningful modelling approaches to *H. midae* management, which are currently underway (C. Raubenheimer, *in prep.*.

It is of interest to compare the von Bertalanffy growth parameters from this study (excluding those from Danger Point) with those from comparable studies. Table 5 shows parameters derived from Day and Fleming (1992), where only results from tagging studies and from large species (L∞ > 150mm) were extracted. Two of the

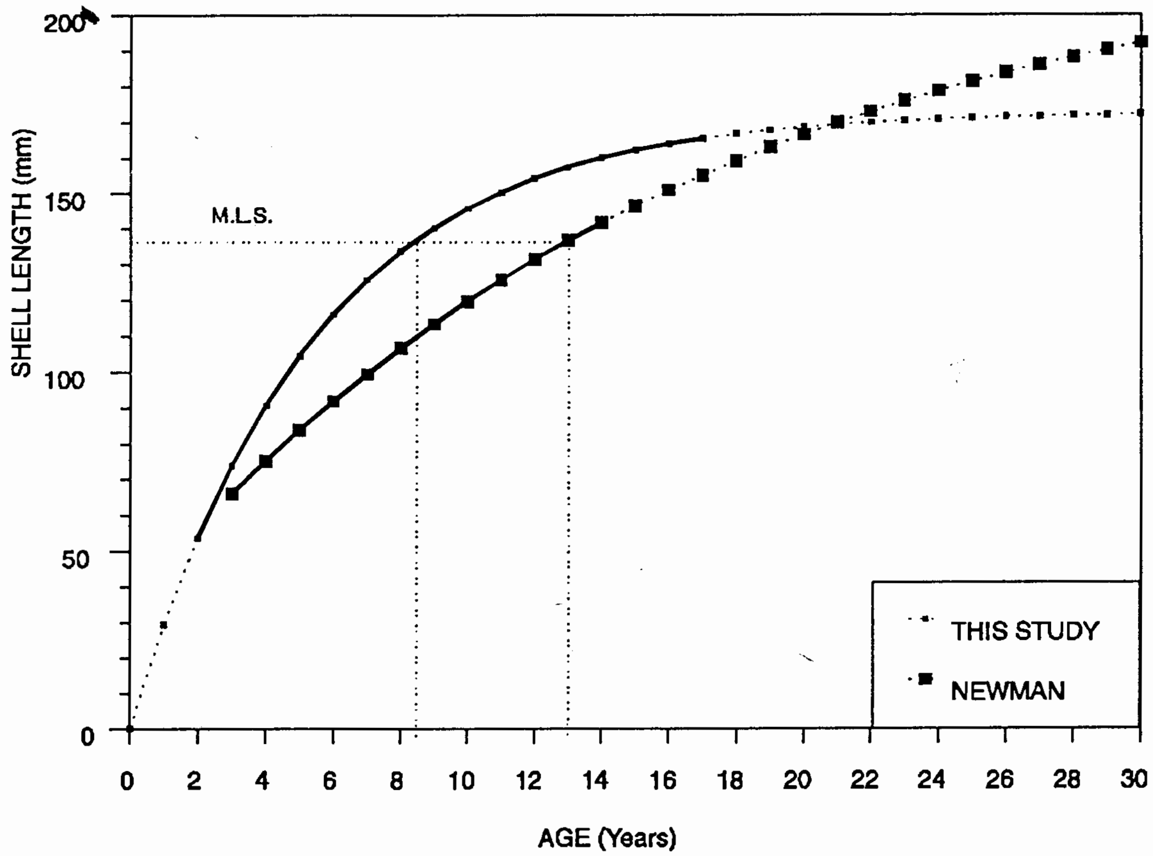


Figure 6: Growth curves for Betty's Bay abalone from this study and from Newman (1968).

species (*H. gigantea* & *H. rufescens*) attain a larger size than *H. midae*, which is reflected in their high L∞ values, but *H. gigantea* appears to have a faster growth rate. *H. fulgens* has an exceptionally high growth rate, reported by Shepherd *et al* (1991) to be among the fastest in the world. It would appear that *H. midae* has a growth curve most similar to the Australian *H. rubra*. The value for K reported by Newman is also clearly very low by comparison.

SPECIES	AUTHORS	K	L ∞
H. fulgens	Guzmán del Próo 1992	0,34	189
H. fulgens	Shepherd *et al* 1991	0,38	183
H. gigantea	Kurogane *et al* 1974	0,41	205
H. midae	this study	0,19-0,25	156-173
H. midae	Newman 1968	0,06	205
H. rubra	Harrison and Grant 1971	0,12-0,22	160-175
H. rufescens	Tegner *et al* 1992	0,27	200

Table 5: Comparison of *H. midae* growth parameters with those from comparable studies on other species.

Movement: Newman (1966) studied movement in *H. midae* at Stony Point in Betty's Bay, a few hundred metres from the study site reported on here. He removed the abalone from the seabed, tagged them ashore and replaced the abalone near the site of collection. He concluded: "The incidence of movement was found to be high". A number of studies have shown, however that disturbance of abalone by tagging induces abnormal movement (Sinclair, 1963; Forster, 1967; Poore, 1972; Ault and DeMartini, 1987). Newman (1966) cited a sample of 23 abalone which showed a mean annual movement of more than 900 metres. However the annual movement calculations were usually extrapolations from shorter release periods. Given that the movement may have been initiated by the disturbance associated by the tagging event, and that when recovered the abalone may have ceased movement after having found a suitable habitat, annual movement extrapolations of this nature are probably misleading. It should also be noted that the size range studied by Newman involved relatively small abalone, with most of the animals in the 70 to 130 mm (shell length) range. His observations therefore would not necessarily apply to larger abalone.

H. midae larvae settle preferentially on shallow-water crustose corallines (pers. obs.), and juveniles shelter under sea urchins, in crevices and under boulders in shallow water. Mean size of "emergent" (*ie* non-cryptic) abalone increases with depth (Chapter 1), therefore a gradual offshore movement of abalone must occur as individuals disperse in search of favourable reef areas, and aggregations of adults develop. Movement of other abalone species has been reported to be oriented into the oncoming swell direction (Clavier and Richard, 1984; Shepherd, 1986; Shepherd *et al* 1991). My observation of great inertia in large abalone therefore confirms the overall pattern of haliotid movement behaviour, which is size-dependent, with little movement occurring among large individuals (Clavier and Richard 1982; Shepherd 1986; Shepherd 1991; Blecha *et al* 1992).

It would appear that in pristine populations, movement occurs until an "ideal" position has been located. With *H. midae* this appears to be an outcrop of reef extending from 0,5 to 2 m above the seabed, facing incoming swell, in the midst of dense *E. maxima*. Such a position may have selective advantages with regard to breeding success (aggregation), food availability, or shelter from storm-tossed boulders. It is apparent from many hours of underwater observation that once a favourable site has been occupied, adult abalone will defend this territorially against other abalone, with violent rotation of the shell, thereby ensuring an even spacing of adults over prime reef areas. (It is this rotation of the shell against other abalone which may have accounted for the tag damage and scratches reported by Newman (1966) and attributed by him to attack by fishes.) Another result of the non-migration of adults is the development of "home sites", or clean scars on the rock corresponding to the foot attachment site of the adult abalone. These are apparent whenever adult abalone are removed from optimum habitats, *ie* where aggregations have formed. Similar formation of home sites has been reported for other species (Poore, 1972; Beinssen and Powell, 1979; Ault and DeMartini, 1987; Tutschulte and Connell, 1988). Loss of these home sites may have induced the migratory results reported by Newman.

Management of the South African abalone fishery relies to a large measure on interpretation of trends in CPUE indices for discrete fishing grounds (Tarr 1992). If extensive migration of adults were continually occurring from non-optimum habitats to optimum habitats, resulting in aggregations of easily collected abalone which were then removed intermittently by commercial divers, then CPUE indices would not be accurately reflecting the decline in abalone abundance caused by fishing. For this reason Australian fishery managers do not rely extensively on CPUE indices for management information. This study shows that movement of adult *H. midae* does not appear to be as extensive as previously reported (Newman 1966), although it is sufficient to produce aggregations, which have the potential to bias CPUE data. A further difference between the fisheries lies in the absence of dense kelp stands in the Australian fishery: divers are free to move about extensively, searching only for suitable aggregations of abalone (Day and Leorke

1986; McShane and Smith 1989; Prince 1992). It is the hindering effect of the dense *E. maxima* beds on diver search efficiency (absent in Australian waters) that makes handling time low relative to searching/swimming time. The South African abalone diver collects whatever abalone he finds during searching, with minimal effect by handling time, therefore his catch rate should reflect the average abundance of above-MLS abalone.

Tutschulte and Connell (1988) suggested that the generalisation "... the processes of growth, maintenance and reproduction compete for the organism's limited energy resources" applied to abalone as well. Growth of the largest abalone in pristine populations such as Betty's Bay appears to be negligible, and it is likely that nearly all available energy is being channelled into reproductive output. Barkai and Griffiths (1988) determined the available energy for reproduction and growth to be 5% of energy intake. The importance of creating harvest refugia such as at Betty's Bay, within commercially fished areas, where adult abalone can form stable aggregations, is therefore clear in terms of their potential for gonadal output.

CHAPTER 5

THE ABALONE OF BIRD ISLAND, EASTERN CAPE

INTRODUCTION

The distribution of *H. midae* extends from Cape Columbine to Transkei (Fig. 1), however the only commercially exploited area lies between Robben Island and Quoin Point, in the SW Cape. East of this the population is apparently discontinuous. Long sections of coastline have virtually no abalone present, and are interspersed with localised high density areas fished by recreational divers.

A particularly dense abalone population exists around Bird Island, Eastern Cape, (Fig. 1), which due to its remote position is not subject to either commercial or recreational exploitation. Study of such a population would provide a unique opportunity to quantify the effect of a warmer water environment (see Christensen (1980)) on the population dynamics of *H. midae*. This investigation was carried out in order to study the density, size structure, reproductive success, size at maturity and growth rates of the natural abalone population. The last of these aspects has already been reported on in Chapter 3.

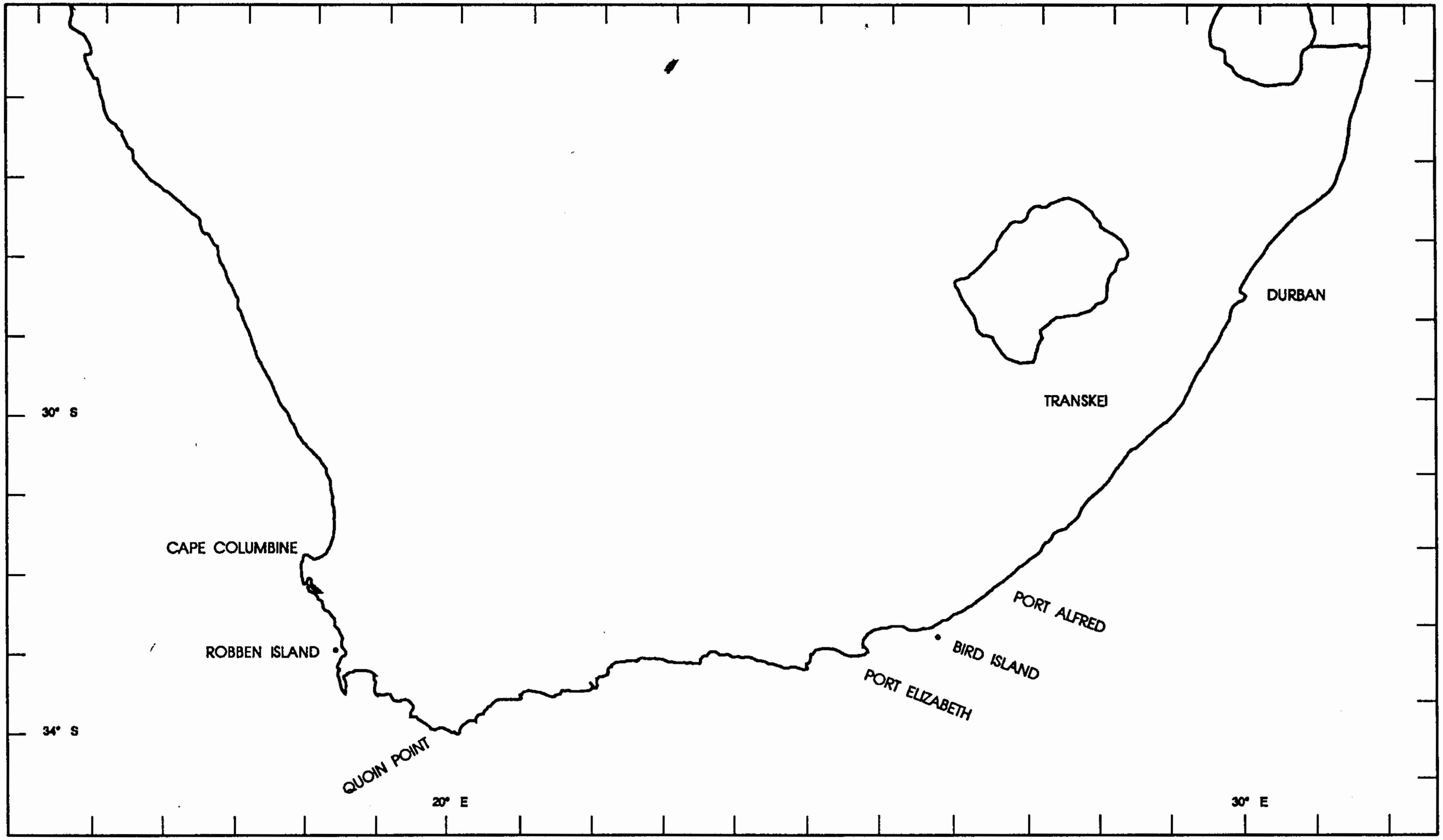


Figure 1: South African coastline, showing places mentioned in the text.

METHODS

Population Structure: In contrast to the typical abalone habitat of the SW Cape, the seabed around Bird Island does not support significant kelp beds, and the macroalgal coverage comprises primarily *Plocamium* spp. and articulated corallines. The biomass of these is high, being approximately 260 g.m^{-2} (R. Anderson *pers. comm.*). The biomass of *Plocamium corallorhiza* alone is approximately ten times that reported for total understorey algae in a west coast kelp forest (Velimirov *et al* 1977). This dense macroalgal cover obscured many "emergent" abalone, and resulted in considerable searching time being required for abalone density estimates from transects. In consequence a relatively short transect length of 50m was utilized, and "emergent" abalone within 1,5 m on either side of the line were counted, giving a coverage of 150 m^2 per transect. Simultaneously, a second dive-pair collected a sample of abalone in the near vicinity of the transect. These were measured in order to determine the length - frequency distribution of the population.

Ten transects were swum, at sites selected as representative of the area (Fig. 2). Depths ranged from 0,5 m to 9 m, although the majority of transects lay in the optimum abalone depth range of 2 - 5 m.

Size at Maturity: Gonad maturity was assessed for a total of 286 abalone over the size range 30 - 175 mm shell length during August 1986. Sex was recorded for all abalone with visible gonad material (green for females; cream for males).

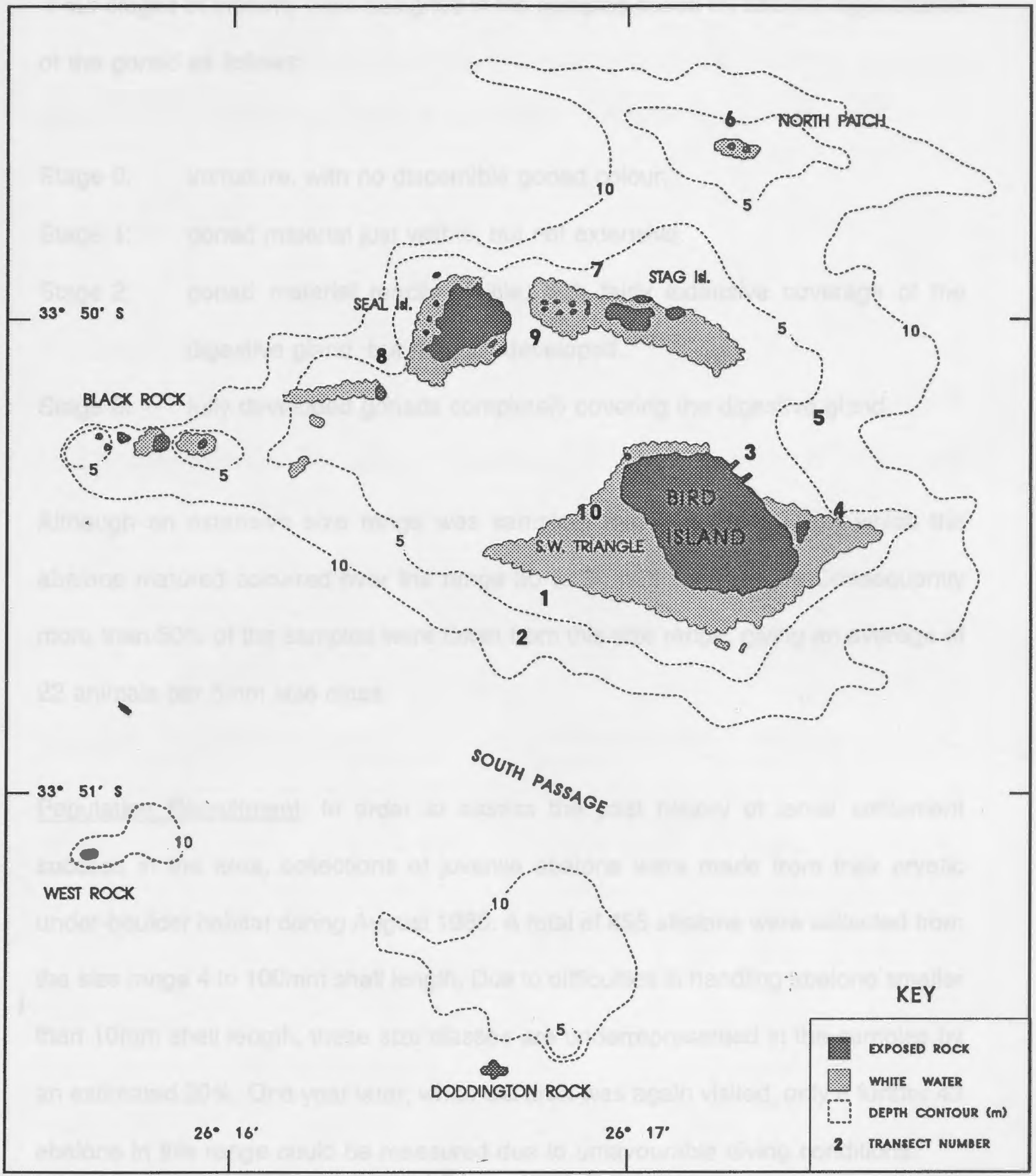


Figure 2: Bird Island and surrounding reefs showing depth contours and positions of the transects.

Four stages of maturity were assigned to the samples based on external appearance of the gonad as follows:

Stage 0:	immature, with no discernible gonad colour.
Stage 1:	gonad material just visible, but not extensive.
Stage 2:	gonad material readily visible, with fairly extensive coverage of the digestive gland, but not fully developed.
Stage 3:	fully developed gonads completely covering the digestive gland.

Although an extensive size range was sampled, the critical area over which the abalone matured occurred over the range 30 to 64 mm shell length. Consequently more than 50% of the samples were taken from this size range, giving an average of 22 animals per 5mm size class.

Population Recruitment: In order to assess the past history of larval settlement success in the area, collections of juvenile abalone were made from their cryptic under-boulder habitat during August 1986. A total of 455 abalone were collected from the size range 4 to 100mm shell length. Due to difficulties in handling abalone smaller than 10mm shell length, these size classes are underrepresented in the samples by an estimated 30%. One year later, when the area was again visited, only a further 43 abalone in this range could be measured due to unfavourable diving conditions.

Separation of the modes into their component distributions was achieved through the use of the interactive computer program MIX (Macdonald and Pitcher 1979;

Macdonald and Green 1985). This program fits a unique series of curves to a multimodal length-frequency distribution, and estimates the mean and standard error of each curve, and the proportion of the sample contained within each curve.

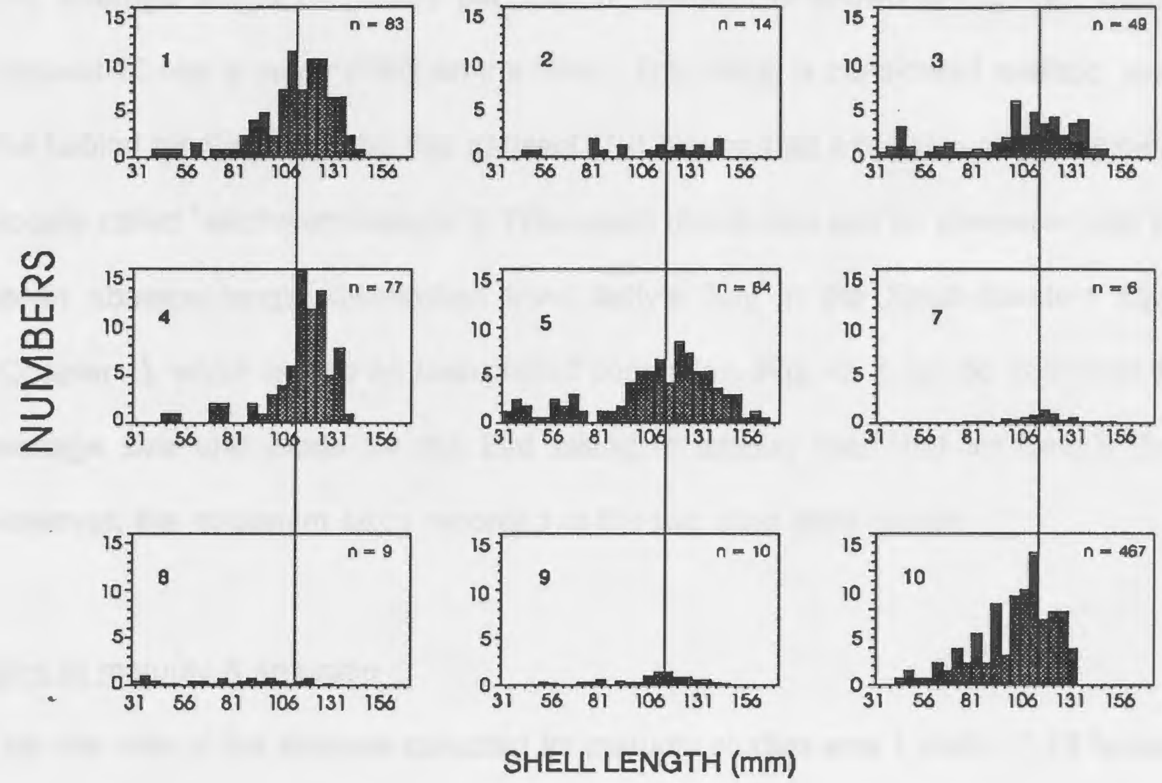
RESULTS

Population Structure

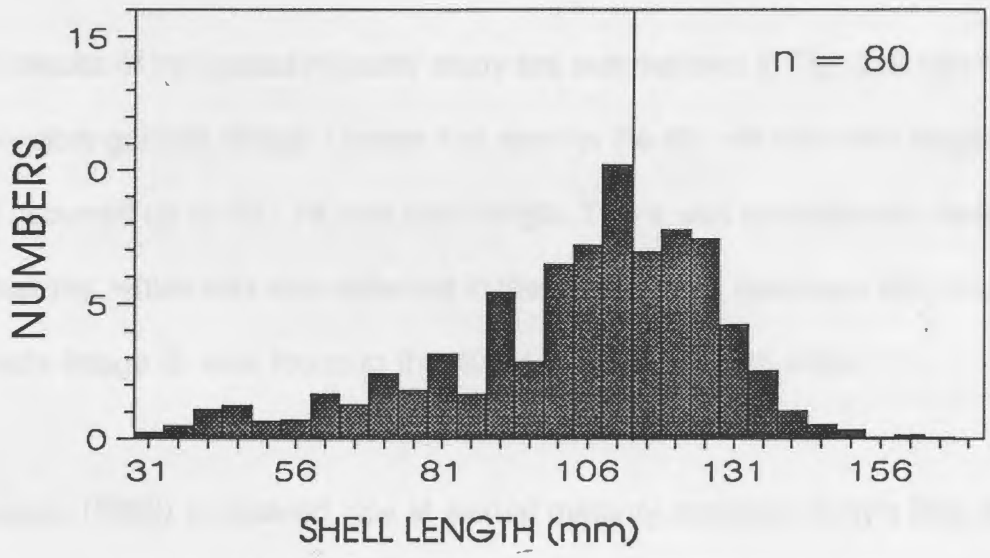
High variability in density was found between the ten transects, with counts varying from 1 to 467 abalone per transect. Densities are given in Table 1, and the length frequencies encountered are shown in Fig. 3A. Transect 6 is not shown because only one abalone was found. Transect 10 (note the different scale) was swum in an extensive area supporting an exceptionally high abalone density.

Transect	Depth (m)	Number	% above M.L.S.
1	3 - 4	83	53,4
2	7 - 9	14	45,5
3	3 - 6	49	40,1
4	5 - 6	77	71,8
5	5 - 6	84	50,7
6	4 - 6	1	85,7
7	4 - 5	6	59,5
8	4 - 5	9	15,8
9	2 - 4	10	45,8
10	1 - 3	467	28,3
Mean:	3,8 - 5,4	80,0	38,9

Table 1: Abalone numbers for Bird Island per 150m^2 transect. Transect positions are shown in Fig. 2.



A.) Abalone length frequency distribution for each of the 50m transects shown in Fig. 2.



B.) Mean abalone length frequency for all transects from Bird Island.

Figure 3: Abalone length frequency distribution per transect, and the mean for all transects.

The average length frequency per 150 m² transect is shown in Fig. 3B. Clearly transect 10 had a major effect on the mean. This result is considered realistic, since the habitat type sampled by this transect (10) covered an extensive area of seabed (locally called "southwest triangle"). This length distribution can be compared with the mean abalone length distribution from Betty's Bay in the South-Western Cape (Chapter 1), which is also an unexploited population (Fig. 4). It can be seen that the average size and mode for the Bird Island is smaller than that for Betty's Bay. However, the maximum sizes recorded at the two sites were similar.

Size at maturity & sex ratio

The sex ratio of the abalone collected for maturity studies was 1 male : 1,19 female. The null hypothesis that this sample did not differ from the expected 1 : 1 ratio was tested and accepted (0,25 < P < 0,1).

The results of the gonad maturity study are summarised in Fig. 5. It can be seen that just-visible gonads (stage 1) were first seen in the 40 - 44 mm shell length size class, and occurred up to 70 - 74 mm shell length. There was considerable variation in size at maturity, which was also reflected in the fact that one specimen with fully developed gonads (stage 3) was found in the 40-44 mm shell length class.

Newman (1969) compared size at sexual maturity between Betty's Bay abalone and a combined Eastern Cape sample (from Port Alfred and Port Elizabeth). He used the presence of visible gonads as the criterion for sexual maturity, which corresponds to my stage 1. His results (Newman 1969, Fig. 4) were converted from body weight to

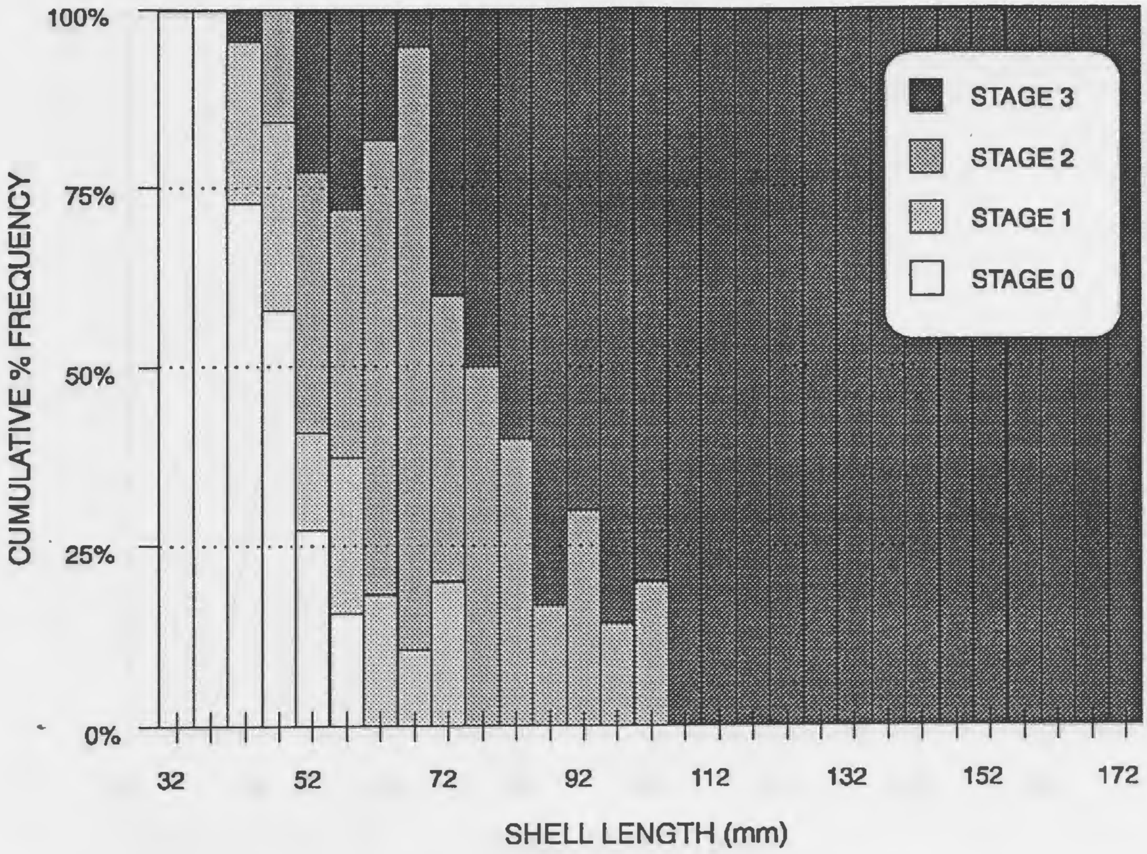


Figure 5: *H. midae* gonad development stages with size at Bird Island, stage) (immature) to stage 3 (fully mature).

shell length, and the percentage of abalone with gonads at different shell lengths are shown in Fig. 6 together with those from Bird Island and a comparative curve from Betty's Bay. The Bird Island curve shows the percentage of the population with gonad material visible (*ie* stages 1, 2 & 3 combined), and thus can be compared directly with Newman's figure. It would appear that Bird Island abalone mature at a smaller size than other Eastern Cape abalone, and at a considerably smaller size than those from Betty's Bay.

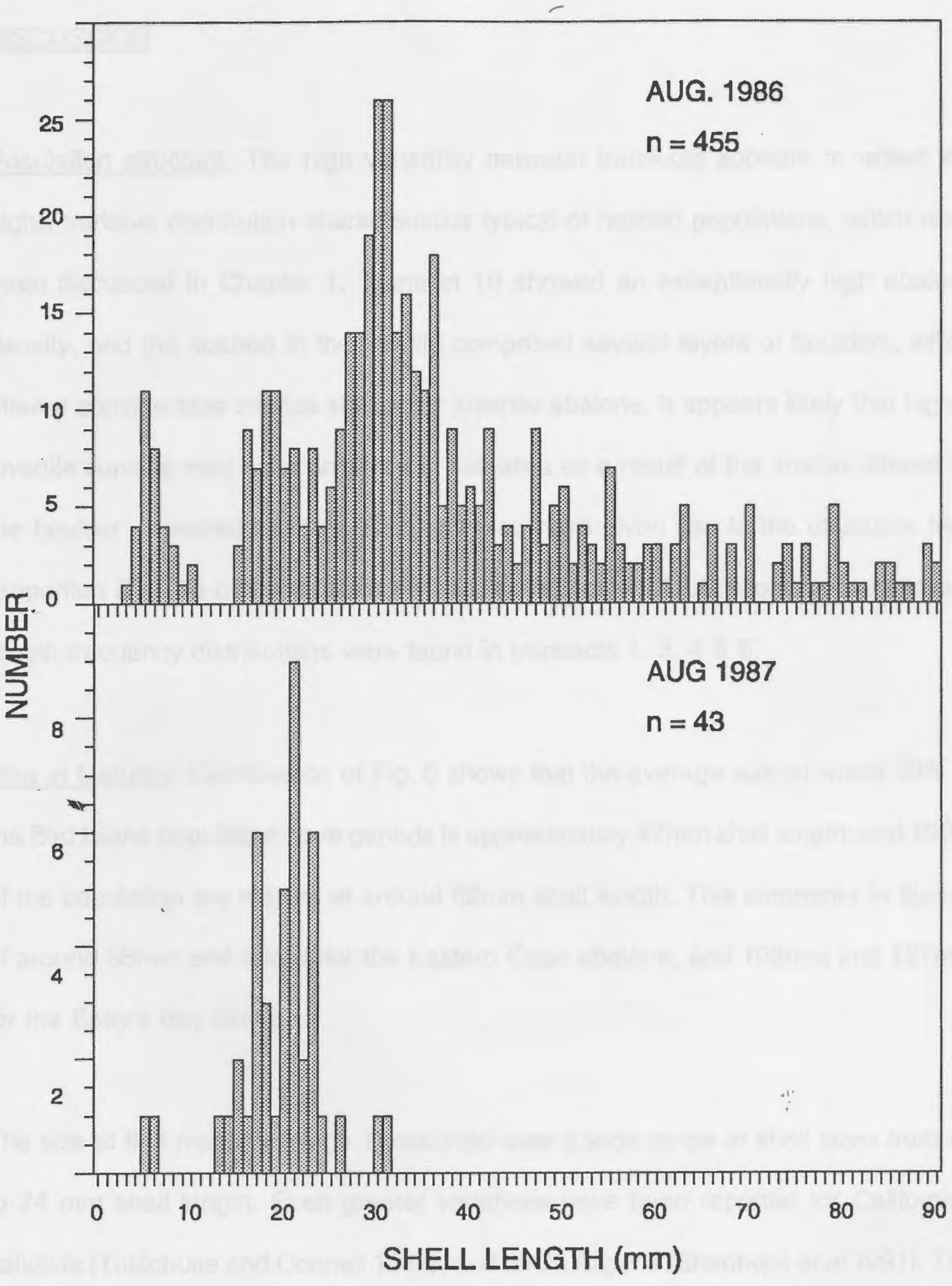


Figure 7: Juvenile abalone length frequencies at Bird Island in 1986 and 1987.

DISCUSSION

Population structure: The high variability between transects appears to reflect the highly variable distribution characteristics typical of haliotid populations, which have been discussed in Chapter 1. Transect 10 showed an exceptionally high abalone density, and the seabed in the vicinity comprised several layers of boulders, which offered considerable crevice shelter for juvenile abalone. It appears likely that higher juvenile survival may have occurred in this area as a result of the shelter offered by the boulder - covered seabed. This may also have given rise to the unusually high proportion (71,7%) of the abalone counted being below M.L.S. More typical abalone length frequency distributions were found in transects 1, 3, 4 & 5.

Size at Maturity: Examination of Fig. 6 shows that the average size at which 50% of the Bird Island population have gonads is approximately 47mm shell length; and 100% of the population are mature at around 62mm shell length. This compares to figures of around 56mm and 98mm for the Eastern Cape abalone, and 108mm and 127mm for the Betty's Bay sample.

The size at first maturity (stage 1) occurred over a wide range of shell sizes from 40 to 74 mm shell length. Even greater variations have been reported for Californian haliotids (Tutschulte and Connell 1981), and for *H. fulgens* (Shepherd *et al* 1991). The Bird Island results confirm those of Newman, showing smaller size at maturity in the warmer waters of the Eastern Cape. However, in the absence of good ageing data for *H. midae*, it is still not possible to determine whether maturity is age-determined or

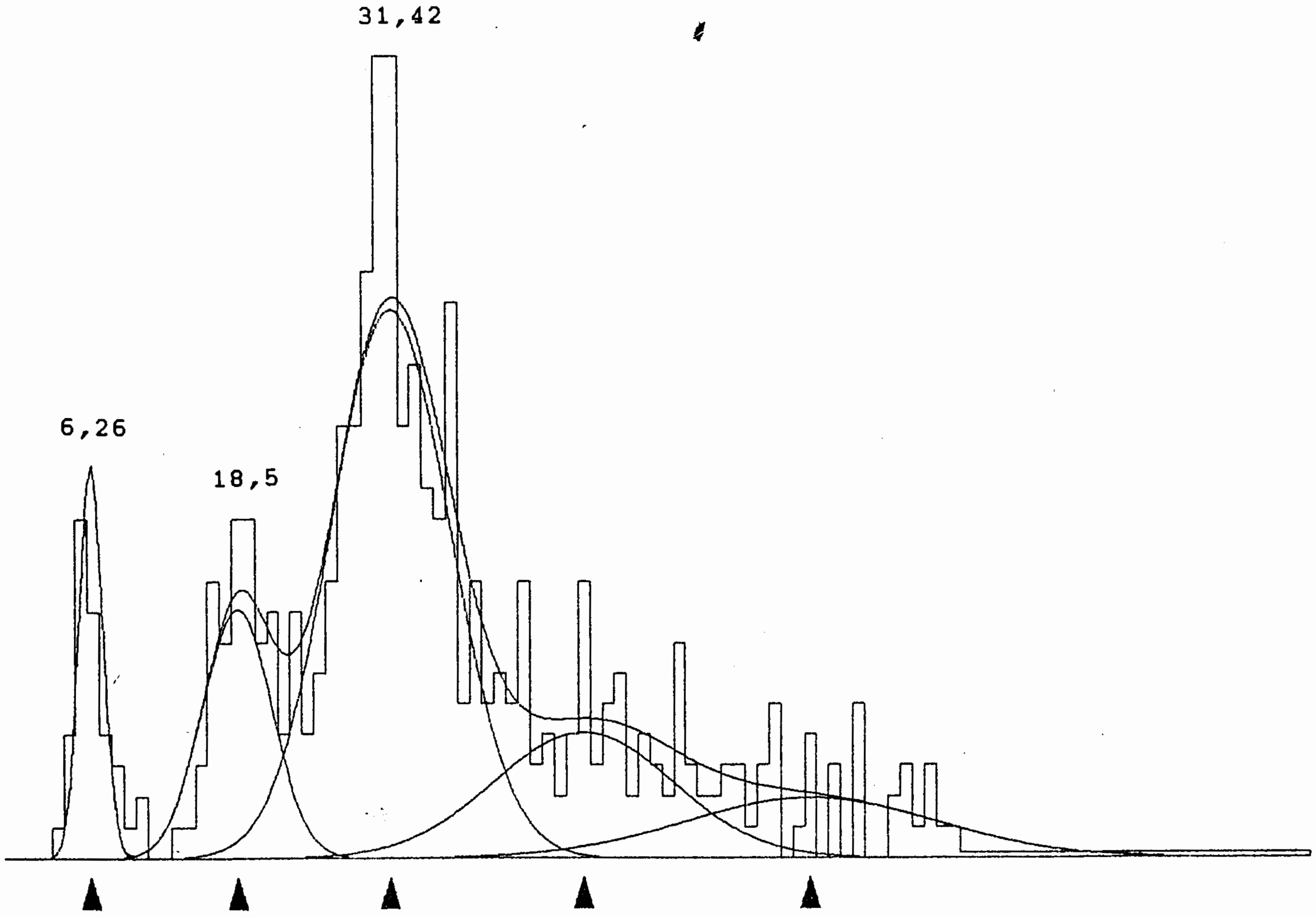


Figure 8: Mix plot fitting normal distributions to Bird Island 1986 recruit length frequency distribution.

size-determined, although indications from other *Haliotis* species are that it is age-based (Nash 1992). The minimum legal size for *H. midae* was set in 1953 at 114mm shell breadth, which is still applicable today. Subsequent studies (Tarr, unpublished information) have shown this size to be adequate for the protection of the Western Cape *H. midae* population. However should commercial harvesting be considered for Bird Island, a smaller M.L.S. would be appropriate. Relevant yield-per-recruit and egg-per-recruit modelling would then be required, bearing in mind that a cautious approach is required, since many of the assumptions on which these models are based do not necessarily hold for haliotids (Shepherd *et al* 1991; Breen 1992; McShane 1992; Nash 1992; Prince and Shepherd 1992).

Population Recruitment

On the assumption that each mode represents a distinct spawning event, it is necessary to determine whether these resulted from annual or biannual spawnings. The assumption is made that the difference between the means of adjacent modes represents the average growth of the members of that cohort during the relevant period (6 months or 1 year). Should the cohorts found in 1986 have resulted from annual spawnings, the two intermode distances would represent an average annual growth of approximately 12,6 mm p.a. This would appear an unrealistically low growth rate, since the growth curve produced from a tagging study at Bird Island (Chapter 3) indicates growth of approximately 30mm p.a. over the first two years. (However this curve is open to some error due to the lack of tagging data from very small abalone). Should spawning occur twice per annum, however, the difference in the modes would be equivalent to approximately 6 months' growth. This would then yield an annual

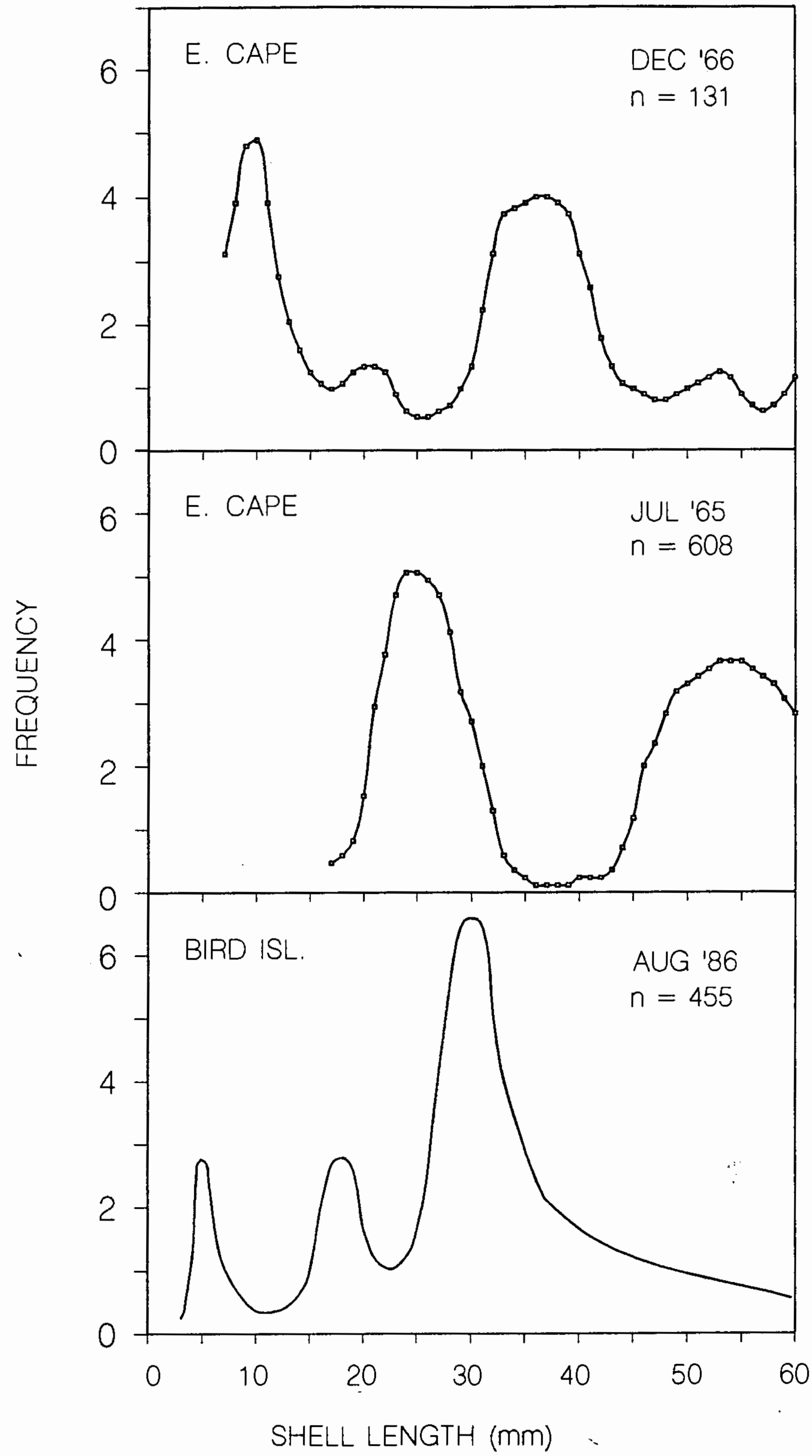


Figure 9: Length frequency of juvenile abalone from Bird Island and Eastern Cape. 1966 and 1965 data derived from Newman (1969). 1986 data from this study.

growth rate of approximately 25,2 mm p.a. This is similar to Newman's (1969) reported rate of 28,8 mm p.a. Unpublished data on *H. midae* recruitment cycles monitored for several years in the SW Cape (pers. obs.) indicate annual growth of approximately 20mm p.a. Shepherd (1988) and Prince (1988) found growth of approximately 20mm p.a. for *H. laevigata* and *H. rubra*, and Tegner (1985) reported growth of 30 mm p.a. for reseeded *H. rufescens*.

It appears more likely therefore that the Bird Island modes resulted from biannual spawnings, with an annual growth rate of approximately 25 mm p.a.

Data from Newman's (1969) graphs of recruitment modes for the Eastern Cape were extracted and compared with similarly presented results from this survey, as shown in Fig. 9. One unimodal graph of Newman's was not included (January 1966) due to the small sample size (n=39).

If the assumption made by Newman (1969), namely that "... size frequencies are representative of the population composition in the months of collection, irrespective of the year in which the observations were made ..." then one would expect my August 1986 results to be very similar to those of Newman's from July 1965 for the Eastern Cape. Clearly, however, this is not the case, although the dominant modes of each are similar, being within approximately 5mm shell length. Two conclusions can be drawn from this: 1) The reproductive cycle is not the same every year (*ie* Newman's assumption was not valid). 2) The Bird Island spawning and/or settlement patterns are different from those of the rest of the Eastern Cape. These possibilities could be clarified by further monitoring of settlement success in both environments. However, it would also be necessary to monitor the adult reproductive cycle in order to assess whether differences in observed settlement patterns arise from differences in the reproductive cycles of the adult populations, or whether these are due to variable settlement success of larvae.

It is of interest to study Newman's (1969) December 1966 graph, since he described this as having only two modes, representing annual spawning events. However evidence of two smaller modes can be seen which would correspond to biannual spawning events of variable success. In addition, if my August 1986 modes were shifted to the right to correspond to an expected growth of 4 months (approximately 8mm), they would coincide very closely with Newman's December 1966 modes. It is therefore suggested that Bird Island abalone have the potential to breed twice per annum, but that this does not always occur. In addition, when settlement does occur, it is of varying success.

Irregular recruitment of *H. midae* has also been observed to occur at Robben Island and Dassen Island, on the West coast (pers. obs.). Highly variable recruitment can be the result of many factors such as environmental effects on adults, local hydrodynamics and differential mortality (Keough and Downes 1982; McShane 1992). Variability in recruitment has also been reported for *H. rubra* (McShane *et al* 1988; McShane and Smith 1991), and causes of recruitment variability are discussed by Keough and Downes (1982).

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