

**POPULATION BIOLOGY AND ECOLOGY OF OCTOPUSES
IN THE SOUTHWESTERN CAPE: A STUDY TOWARDS THE
ESTABLISHMENT OF A SMALL-SCALE OCTOPUS FISHERY**

by

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Thesis submitted for the degree of

Master of Science

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June 1999

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DECLARATION

I hereby declare that the data collected, analysis and write-up of this thesis, except where the help of various other people is acknowledged in the text, are all my own work. This work has not been submitted for a degree at any other university.

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ABSTRACT

Many conventional fish stocks are on the decline and as a result fishers are increasingly redirecting their attention to non-conventional fish stocks, including octopus. Although octopus have been harvested since classical times and been the subject of many studies in other parts of the world, little information is available on octopus species inhabiting the waters of the southwestern Cape. Hence, the aim of this study is to fill this void by documenting the geographic range, depth range, biology and diets of octopus species commonly found in this region. This information, together with the marketability of octopus species was used to identify the most suitable candidate for exploitation by small-scale fisheries in the southwestern Cape. The spatial distribution, population dynamics and ecology of this species were investigated in more detail.

Geographic and depth ranges of *Aphrodoctopus schultzei*, *Octopus vulgaris* and *Octopus magnificus* were obtained from South African Museum (SAM) records. Biological and dietary data of *A. schultzei* were obtained by collecting specimens in the intertidal zone at Granger Bay. In contrast, *O. vulgaris* were collected in kelp beds of False Bay using SCUBA and *O. magnificus* were obtained from trawling and lobster trap vessels. Sampling was conducted between February 1997 and March 1998.

A total of 64 *A. schultzei*, 353 *O. vulgaris* and 48 *O. magnificus* were collected. *A. schultzei* is a small species (max mass 350 g) with limited depth (intertidal zone - 18 m) and geographic distribution (predominately west of Cape Point). *O. vulgaris* is a large species (max. mass 4 625 g) with large depth (intertidal zone - 290 m) and geographic distribution (common throughout South African waters). *O. magnificus* is also a large species (max. mass 8 625 g) and is common in the deep (100-560 m) temperate waters of southern Africa (Luderitz - Port Alfred). The diet of *A. schultzei* was largely comprised of winkles (68.8% of the total IRI). In contrast, both *O. vulgaris* and *O. magnificus* had more varied diets. *O. vulgaris* mainly consumed small crustaceans (45.5%), large crustaceans (28.1%) and abalone (17.1%). Similarly, *O. magnificus* consumed a high proportion of small crustaceans (31.8%) and large crustaceans (30.1%), but teleosts were more important (34%). Suitable depth range, wide geographic distribution, large size and potential threat to abalone fisheries make *O. vulgaris* the most suitable candidate for small-scale commercial fisheries to target in the southwestern Cape. This is further supported by it being the most sought after octopus species in the world. Moreover, the demand for imported *O. vulgaris* in Japan and Spain is increasing.

Further information on the population dynamics of *O. vulgaris* revealed seasonal fluctuations in mean size of octopuses. Mean octopus size was high in summer (1 161 g) and autumn (1 193 g) and low in winter (766 g). Fluctuations in octopus mean size were positively correlated with water temperature. Mating and spawning probably occurs throughout the year. However, spawning peaks were found in spring and summer in association with warmer water. This was also supported by the high number of recruits caught in summer, autumn and winter. Furthermore, medium and large females were particularly underrepresented in summer and spring. Hence, the overall sex ratio was biased towards males (0.6F:1.0M). This information, which is useful for fisheries and management, suggests the onshore - offshore migration of *O. vulgaris*, which appears to be driven by fluctuations in water temperature.

The best method for octopus diet assessment was also determined. The diet of *O. vulgaris* was then further investigated to determine the effects of octopus size and season on diet. Furthermore, important predators of *O. vulgaris* in False Bay were identified and special attention was given to the possible consequences of non-fatal attacks on octopus.

In conclusion, the need for an experimental fishery was identified to establish the economic feasibility of, and management strategies for, a small-scale southwestern Cape *O. vulgaris* fishery. Pot fishing was chosen as the most suitable fishing method to be used by this fishery because it is relatively inexpensive, efficient at catching octopus, has a low by-catch and is compatible with primary fisheries.

ACKNOWLEDGEMENTS

I am grateful to the Foundation for Research and Development for funding the project and to the University of Cape town for use of their facilities. Although this project did not adhere to the original proposal, I still would like to thank Marcel Kroese for the conception of the project, references and assistance. A special thanks to the committee of the Cape of Good Hope Nature Reserve for allowing me to conduct research at Buffels Bay, and to Dave Japp (Sea Fisheries Research Institute), Earl Moor (Primier Fishing) and Barry Rose (Irvin & Johnson) for providing *O. magnificus* specimens. Thanks also to Martina Roeleveld and Shannon Du Plessis for providing access to museum and fishing records respectively.

I am deeply indebted to Derek (eager beaver) Padiachee for his enthusiastic diving and lab assistance. Other people who bravely assisted with sampling were Adam West, Paul Williams and Yves Lechanteur. Liesl (ever-willing) Campbell also assisted with lab analysis. Thanks also to Neville Eden and Cameron Smith for their photographic expertise, and to the SFRI Seaweed Research Unit for allowing me to use their temperature data.

Thanks to the critics, Yves Lechanteur, Steve Mayfield, Anthony Richardson, Charles Griffiths, George Branch, Malcolm Smale, Ronel Nel and Cameron Smith, who commented on rough drafts of chapters included in this thesis. Special mention must be made of Anthony (stats boffin) Richardson and Barry Clark for greatly improving my statistical knowledge. Sincere thanks to my supervisors, Charles Griffiths, George Branch and Malcolm Smale, for their support.

Thanks go to my family and friends, especially Calvin Smith for the loan of his machinery while constructing octopus pots and to the Philander family for tolerating the mess of octopus pots in their yard. I am also grateful to Mandy Smith for financial support. Finally, I would like to thank Liesl Campbell for her patience, encouragement and support.

GENERAL INTRODUCTION

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GENERAL INTRODUCTION

Octopus, like cuttlefish and squid, are cephalopods belonging to the phylum Mollusca. Cephalopods are regarded as being among the most advanced invertebrates, having many anatomical features and behavioural traits similar to those of vertebrates (Augustyn & Smale 1989). Hence, initial studies of cephalopods, excluding taxonomy, have largely focused on the nervous system, physiology, learning and behaviour of octopus, especially *Octopus vulgaris* (Mangold 1983). However, the taxonomy of *O. vulgaris* is presently in a state of flux. This species is now believed to have a more restricted geographic range than previously thought; occurring only in the Mediterranean Sea and the eastern Atlantic. "*O. vulgaris*" from other regions are now considered as close relatives of the Mediterranean neotype, but probably represent distinct species (Mangold 1997). Since the taxonomy of these "*O. vulgaris*" species have not as yet been resolved I will retain the name *O. vulgaris* for the rest of this thesis.

Over the last two decades many field studies have been conducted, providing substantial information on the biology, ecology and population dynamics of various octopus species, including *O. vulgaris* (Nigmatullin & Ostapenko 1976; Hatanaka 1979a,b; Guerra 1981; Smale & Buchan 1981; Ambrose & Nelson 1983; Mather 1991; Mather & O'Dor 1991; Whitaker *et al.* 1991; Sanchez & Obarti 1993; Quetglas *et al.* 1998), *Octopus dofleini* (Hartwick *et al.* 1978; Hartwick *et al.* 1984; Robinson & Hartwick 1986; Hartwick *et al.* 1988), *Octopus bimaculatus* (Ambrose 1982, 1984, 1988), *Octopus tehuilchus* (Iribarne 1991) and *Octopus digueti* (Voight 1992). These studies, amongst others, have shown that

octopus as a group have wide depth and geographic distributions, occurring in the intertidal zone to depths of over 5 000 m, and found in all temperate, sub-tropical and tropical oceans. Octopuses in general are also fast-growing animals with short lifespans, ranging from six months in small species to three years in large ones (Mangold 1987). Furthermore, octopuses are semelparous (females breed once and die) (Calow 1987). Two different life history strategies occur in octopus: either direct (paralarvae stage absent) or indirect development (paralarvae stage present) (Stranks 1996). In addition, octopuses are opportunistic predators throughout their lives, despite having various life-history stages, with adults capable of feeding on a multitude of prey items, including crustaceans, molluscs, fish and polychaetes (Nixon 1987).

Furthermore, octopuses have a number of characteristics making them an attractive food source for humans (Paust 1985 cited in Paust 1988): white meat, firm texture and flavour similar to squid, lack of hard parts except for the beak, 80-85% meat recovery, relatively large size, and fast growth. Hence, octopuses have been caught since classical times in the Mediterranean Sea and western Pacific, traditionally by means of pot-fishing (Rathjen & Voss 1987). Because of the global decline in many conventional fish stocks, for example fin-fish, many countries are increasingly redirecting their attention to more non-conventional stocks, including cephalopods (Voss 1983, Amaratunga 1987). Consequently, the potential for commercial octopus fisheries has been investigated for several new fishing grounds, including the northwest coast of Africa, which has become the largest global octopus trawl fishery (Rathjen *et al.* 1987). Furthermore, the potential for commercial small-scale octopus fisheries have been investigated for several regions, including Australia (Kimura *et al.* 1978; Kimura 1980; Kimura & Isomae 1981), Alaska (Paust 1988), South Carolina (Whitaker *et al.* 1991)

and California (Lang & Hochberg 1997). In general these investigations showed a potential for commercial small-scale octopus fisheries, provided that suitable species were targeted, the biology and population dynamics of the species were known and appropriate fishing gear was employed. Despite octopuses being a suitable food resource and being fished in various regions they are still considered to be a grossly underexploited resource in many countries, including South Africa.

In South Africa, particularly the southwestern Cape, many poor marginalized fishing communities exist that largely depend upon the sea for their livelihood (McGrath *et al.* 1997). However, many of the fish stocks upon which these communities depend are on the decline (Penney *et al.* 1989). Given this scenario, a small-scale octopus fishery, if found to be viable, could supplement the income of these communities. However, little information is available on the biology and ecology of octopus species from this region and such information is a prerequisite to providing effective guidelines for fishery operations and management.

Hence, the aim of this thesis was to answer the following questions:

Chapter 1

What is the depth and geographic distributions, fisheries biology and diets of the common octopus species of the southwestern Cape?

Chapter 2

How does South Africa compare to the world in terms of octopus catches and marketability of octopus species? Hence, which species is most suitable for exploitation by small-scale fisheries in the southwestern Cape, based on global market demand, marketability of

octopus species, and biology and distribution of local species? Consequently, the following chapters asked specific questions related to this targeted species only.

Chapter 3

What is the spatial distribution of this octopus? Moreover, how do the population size structure and maturity of this species change with season?

Chapter 4

What is the best method to assess the diet of octopuses? How is the diet of the targeted species influenced by octopus size and season? Do octopuses show prey size selectivity?

Chapter 5

What are the important predators of this species? What predators are responsible for non-fatal attacks on octopus, and what are the possible consequences of non-fatal attacks on octopus?

Chapter 6

What guidelines are pertinent to future octopus fisheries in the southwestern Cape?

CHAPTER 1

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POPULATION BIOLOGY AND DIETS OF OCTOPUSES IN THE SOUTHWESTERN CAPE

INTRODUCTION

Approximately 200 octopus species have been described worldwide, of which 40 species have been identified from South African waters (Cephalopod International Advisory Council Symposium Workshop 1997). Although South Africa has a rich diversity of octopus species, very little information is available on the taxonomy, biology and ecology of these species. Only Smale and Buchan (1981) have investigated the biology of *Octopus vulgaris* and their work was restricted to the east coast of South Africa. The diet and mandibular growth of *Octopus magnificus* have been determined by Villanueva (1993). Other South African studies of octopus have focused on taxonomy (Roper & Mangold 1991; Villanueva *et al.* 1991). In addition, an identification key to South African octopus beaks has also been published (Smale *et al.* 1993).

In the southwestern Cape there is little information on octopuses, except for depth and geographic distributions (South African Museum (SAM) records). The common octopus species in this region are the brush-tip octopus *Aphrodoctopus schultzei* (Fig. 1.1), the giant octopus *O. magnificus* (Fig. 1.2) and the common octopus *O. vulgaris* (Fig. 1.3). *A. schultzei* ranges from Lüderitz (Namibia) to Tsitsikamma (Fig. 1.4), but is more common west of Cape Point. It is a shallow-water species, often abundant in the intertidal zone. The maximum recorded depth of this species is 18 m. *O. magnificus* has been documented from Lüderitz to Port Alfred (Fig. 1.4). It is predominantly a deep-water species which, although recorded from as shallow as 2 m, is more abundant at depths exceeding 100 m. The maximum



Fig. 1.1 *Aphrodoctopus schultzei* is uniformly red with minute papillae on mantle and no skin folds.

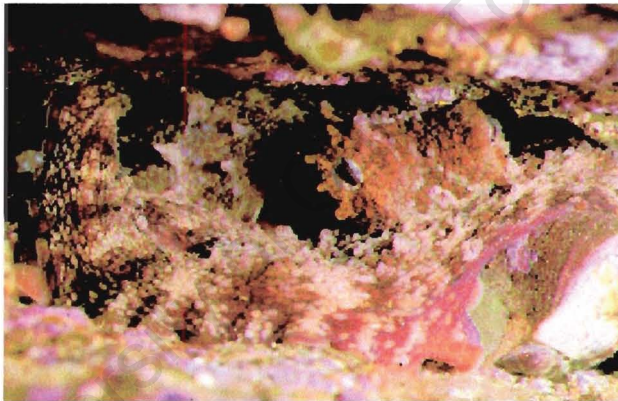


Fig. 1.2 *Octopus vulgaris* is mottled brown with distinct papillae and no skin folds.



Fig. 1.3 *Octopus magnificus* is mottled red with distinct papillae and longitudinal skin folds on the mantle. This species like *O. vulgaris*, has two rows of parallel suckers, whereas *A. schultzei* has two alternate rows of suckers. Photo from Villanueva *et al.* 1991, in Branch *et al.* 1994.

recorded depth for this species is 560 m. *O. vulgaris* is the most commonly recorded octopus in this region. It has a wide geographic range, occurring along the entire South African coastline (Fig. 1.4). This species has been recorded from the intertidal zone to a depth of 290 m, although its abundance appears to decrease with depth.

Octopuses consume a wide variety of prey items, including molluscs, crustaceans, polychaetes and fish (Hatanaka 1979a; Ambrose & Nelson 1983; Ambrose 1984; Nixon & Budelmann 1984) and when abundant they have the potential to deplete prey populations, including rock lobsters, crabs and shellfish (Rees & Lumby 1954; Kimura *et al.* 1978). Considering the commercially-important abalone and rock lobster fisheries in the southwestern Cape (Branch *et al.* 1994), it is surprising that no studies have examined the potential impact of octopus as predators of these species.

The aims of this chapter are to fill the void in knowledge about common southwestern Cape octopuses by examining the population biology (size, morphometric relationships, maturation & sex ratios) and diets of these species. Furthermore, information presented in this chapter provides the first stage in determining the most suitable octopus species for exploitation by commercial small-scale octopus fisheries in the southwestern Cape.

METHODS

Study sites & sampling techniques

A. schultzei

Specimens of *A. schultzei* were collected infrequently between June 1997 and March 1998, in the Granger Bay (Fig. 1.4) intertidal zone during low tide, usually during the morning but also once at night. Sampling involved two techniques: 1) lifting of flat rocks, and 2) squirting a solution of copper sulphate, or other suitable skin irritant, into rock crevices.

O. magnificus

O. magnificus were obtained infrequently between May 1997 and March 1998 from Sea Fisheries Research Institute (SFRI) experimental trawls, the south coast lobster trap fishery and inshore trawl fishery operating between Cape Town and Port Alfred (Fig. 1.4). The depths at which this species was caught ranged between 100-300 m, but the bulk of the specimens were obtained between 100-150 m.

O. vulgaris

O. vulgaris were frequently collected between February 1997 to January 1998. Due to SFRI issuing a moratorium on all experimental fishing permits in 1996 the sampling of this species was conducted by using SCUBA. Sampling was undertaken during the day at three main sites (Boulders, Miller's Point and Buffels Bay) on the west coast of False Bay (Fig. 1.4), although additional specimens were sampled from Glencairn and Cape Hangklip (Fig. 1.4). From May 1997 to November 1997, each of the main sites were sampled at least once monthly. Sampling was undertaken between the mean low water mark and a maximum depth of 10 m. To avoid size selection the first octopuses seen were collected. The bias in this sampling technique is that small octopuses are probably missed more often as they are harder to see (Smale & Buchan 1981). However, this bias should be constant throughout the study.

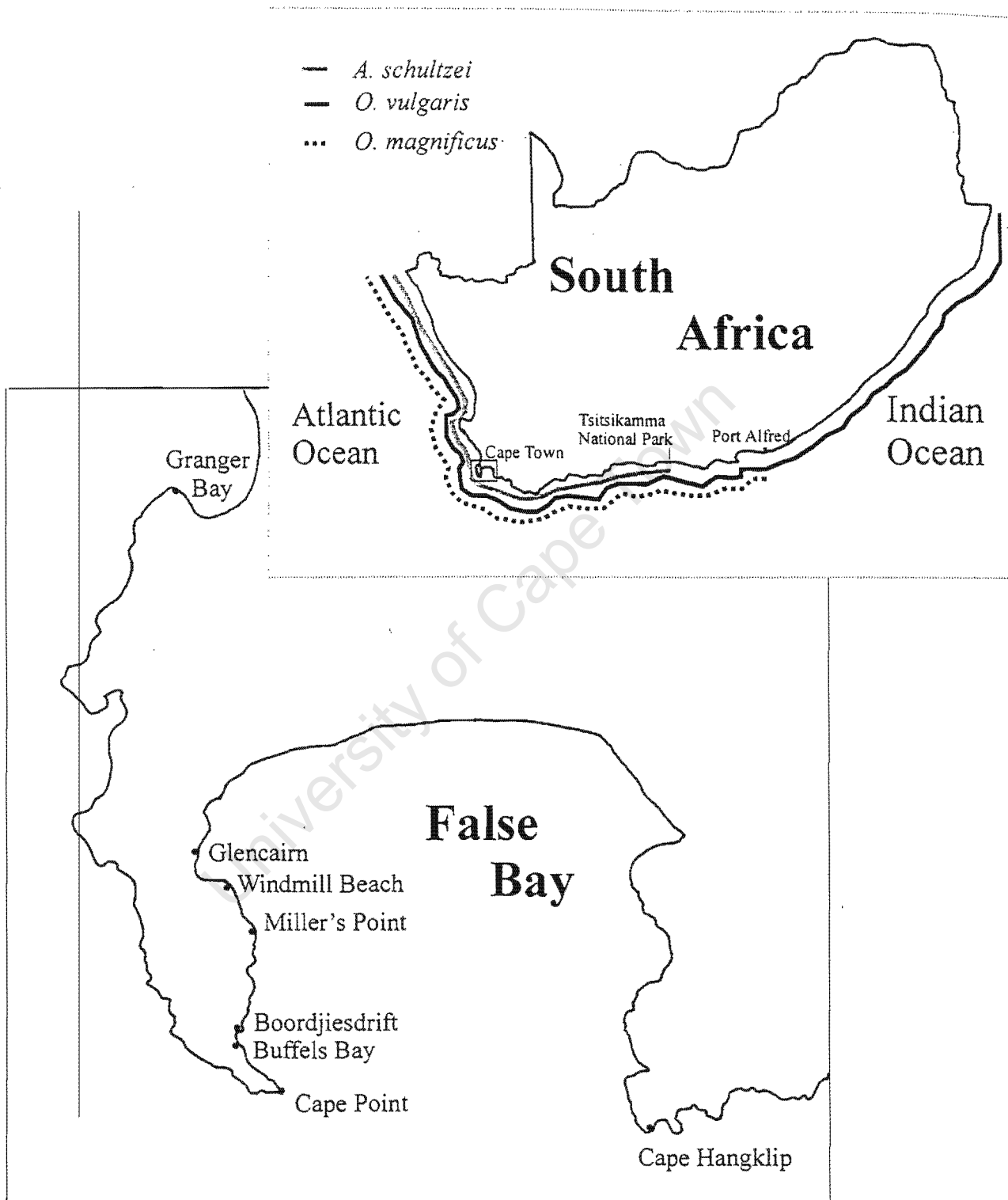


Fig. 1.4 Map of South Africa showing the geographic distributions of *A. schultzei*, *O. magnificus* and *O. vulgaris* (SAM records). The enlarged map of False Bay shows the localities of study sites and other places mentioned in text.

Capture was facilitated by introducing a suspension of copper sulphate in seawater to octopus dens from a plastic squirt bottle. On capture, octopus were placed in bags.

Biological analysis

Once captured, *A. schultzei* and *O. vulgaris* specimens were killed by placing them into an isotonic solution of magnesium chloride (Joll 1977 cited in Smale & Buchan 1981). The specimens were then frozen at -20°C . Freezing was used to standardize measurements of all octopus species, as *O. magnificus* specimens were frozen when obtained from the above-mentioned fisheries. Once thawed, the following information about each octopus was recorded.

- Total length (TL): The distance between the posterior tip of the mantle and the tip of the longest arm when extended (Smale & Buchan 1981), measured to the nearest centimetre.
- Mantle length (ML): The distance between the posterior tip of the mantle and the midpoint of the eyes (Mangold-Wirz cited in Smale & Buchan 1981), measured to the nearest 5 mm.
- Body mass (BM): The total wet mass of the octopus with the mantle drained and excess water wiped from the skin (Smale & Buchan 1981). Specimens larger than 200 g were weighed with a 5 kg spring balance calibrated in 25 g units and smaller specimens were weighed with a 200 g spring balance, calibrated in 2 g units.
- Sex was determined by the presence of a spermatophoric groove on the third right arm in males. This structure is absent in females (Mangold 1983). However, small specimens could only be sexed after dissection (Mangold 1983). All octopuses were then dissected to obtain the lower beak, alimentary canal (crop, stomach and intestine) and gonad with associated tubes and organs. These were preserved in four percent formalin in fresh water for later analysis. Lower beaks were rinsed in fresh water and wiped dry before weighing to the nearest 0.01 g. Only lower beaks were used, as their mass is more highly correlated with

body mass and mantle length than that of the upper beak (Nixon 1969). Gonads were rinsed in water and wiped dry before analysis. The total wet mass of the gonad and associated tubes and organs (GM) (after Smale & Buchan. 1981) was determined to 0.01 g. Gonads were then examined to determine the maturity of specimens. Males of each species were classified as sexually mature if spermatophores were present in the Needham's sac. Female maturity was categorized according to Mangold (1987) as either stage 1 (immature) where the ovary is small and white; stage 2 (maturing) where the ovary is larger and the eggs are off-white in colour, or stage 3 (mature) where loose eggs are present in the ovisac.

Dietary analysis

Diets of *A. schultzei*, *O. magnificus* and *O. vulgaris* were compared using stomach content analysis. The alimentary canal of each octopus was cut and all the contents were removed and rinsed through a 500 μ m sieve. The material retained by the sieve was sorted under a dissecting microscope and identified to the lowest possible taxon. However, octopuses generally ingested only small fragments of prey hard parts, hence prey items were difficult to identify to species level except for small prey (small crustaceans and juvenile winkles) which were occasionally found intact in the guts of octopuses. Large prey items in the guts of octopuses could only be identified by diagnostic features or if octopuses were consuming the prey item at time of capture. For example the presence/absence of dense fur of fleshy projections and radula shape were used to distinguish between limpets and abalone. For comparisons of diet, crustaceans were categorized into two groups according to size: all crabs and rock-lobsters were grouped as large crustaceans, and euphausiids, megalopa larvae, isopods and amphipods etc. were classified as small crustaceans. As some *O. magnificus* were caught in rock-lobster traps baited with hake, all specimens containing hake or lobsters in their guts were excluded from the dietary analysis. The percentage occurrence, volume and

number of prey for each octopus species was determined to calculate an index of relative importance (IRI). The number of each prey item found in a octopus gut was considered to be one except when more than one head or radula or pair of eyes were found. IRI calculations were derived using a modified version of Pinkas *et al.* (1971) equation.

$$\text{IRI} = (\% \text{ number} + \% \text{ volume}) * \% \text{ frequency of occurrence}$$

This new equation replaced % mass with % volume, assuming that 1 ml approximates 1g.

Statistical analysis

Morphometric relationships for each species were analysed by least square regression, using the best fit curve. A Student t-test was conducted on the mass of males and females of *A. schultzei* and *O. magnificus* to determine if significant differences existed between the mean mass of the sexes. To identify whether there were any differences in *O. vulgaris* mass related to season or sex of individuals, a two-way ANOVA was performed with mass as the dependent variable and season and sex as independent variables. The seasonal component of these results is dealt with in Chapter 3. All mass data were log transformed to improve normality and homoscedasticity (Zar 1984), as some displayed unequal variance. A Chi-square test was used to test whether sex ratios differed significantly from a 1:1 ratio.

RESULTS

Population biology

Species size & morphometric relationships

A total of 64 *A. schultzei*, 353 *O. vulgaris* and 48 *O. magnificus* was collected. The mean mass of *A. schultzei* was 65 g, with a range of 0.8-350 g (Fig. 1.5). *O. vulgaris* had a mean mass of 1 019 g, and a mass range of 57-4 625 g (Fig. 1.5). The mean mass of *O. magnificus* was 2 091 g, with a range of 125-8 625 g (Fig. 1.5).

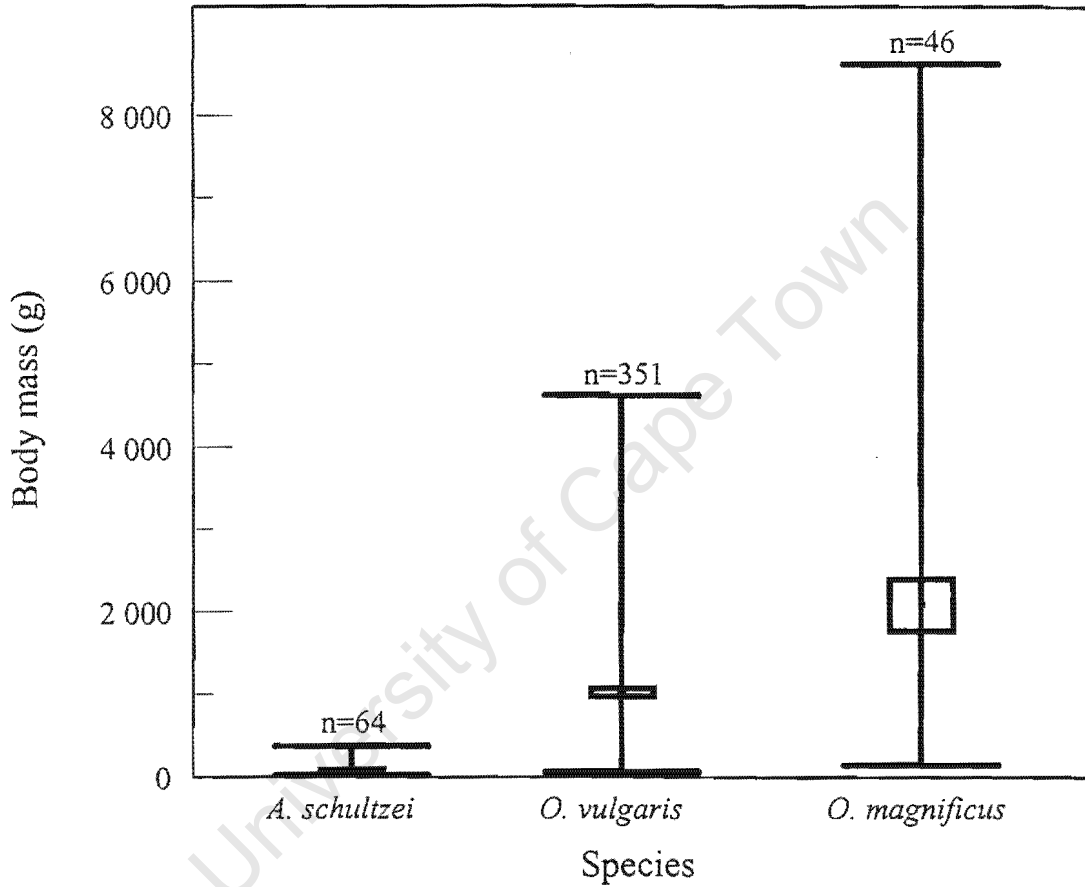


Fig. 1.5 Mean body mass, range and SE of *A. schultzei*, *O. vulgaris* and *O. magnificus*. The boxes show the SE and the whiskers the range.

Morphometric relationships between ML and TL, BM and LBM are presented for *A. schultzei* (Fig. 1.6), *O. vulgaris* (Fig. 1.7) and *O. magnificus* (Fig. 1.8). The relationship between ML and TL was linear for all three species, and the relationships between ML and BM, and ML and LBM followed power curves for all three species.

Male and female size structural analysis

Mean mass of male *A. schultzei* (97.8 g) was significantly heavier than that of females (34.8 g) ($p < 0.01$) (Table 1.1). Only 42% of male *A. schultzei* collected were less than 40 g compared to 72% for females (Fig. 1.9.a). Furthermore, no females weighing more than 160 g were found, whereas 27.2% of males exceeded this mass (Fig. 1.9a). The mean masses of male *O. vulgaris* (976.9 g) and male *O. magnificus* (1 609 g) were not significantly different from those of their female counterparts, 1 114 g and 2 170 g respectively (Table 1.1). Small octopuses constituted the bulk of the samples for both sexes of *O. vulgaris* and *O. magnificus* (Fig. 1.9.b & c). However, in contrast to *A. schultzei*, large specimens were found for both sexes of these species.

Maturation

The smallest mature male *A. schultzei*, *O. vulgaris* and *O. magnificus* were 30 g, 136 g and 3 275 g respectively. However, fully developed spermatophores were only present in males larger than 100 g, 325 g and 4 000 g respectively. The smallest female *A. schultzei* found to be maturing was 80 g, but no fully mature females were found. The smallest maturing female *O. vulgaris* and *O. magnificus* were 275 g and 4 900 g respectively. However, maturing female *O. vulgaris* usually weighed more than 1 000 g. Except for one spent female *O. vulgaris* found in November, no mature females were found during the entire research period. Furthermore, only one female *O. magnificus*, weighing 8 625 g, was found to be mature.

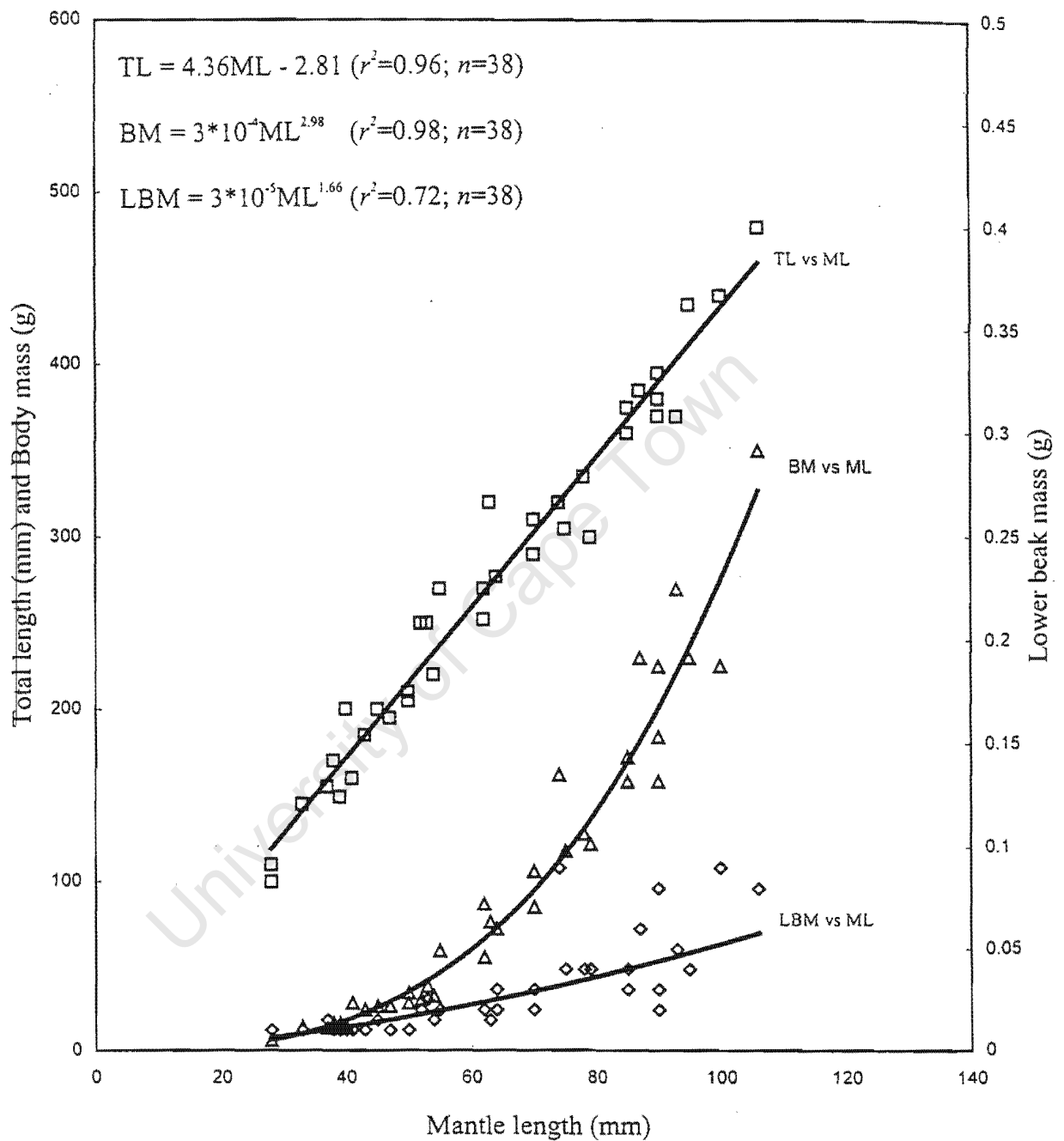


Fig. 1.6 *A. schultzei* morphometric relationships. ML=mantle length, TL=total length, BM=body mass and LBM=lower beak mass.

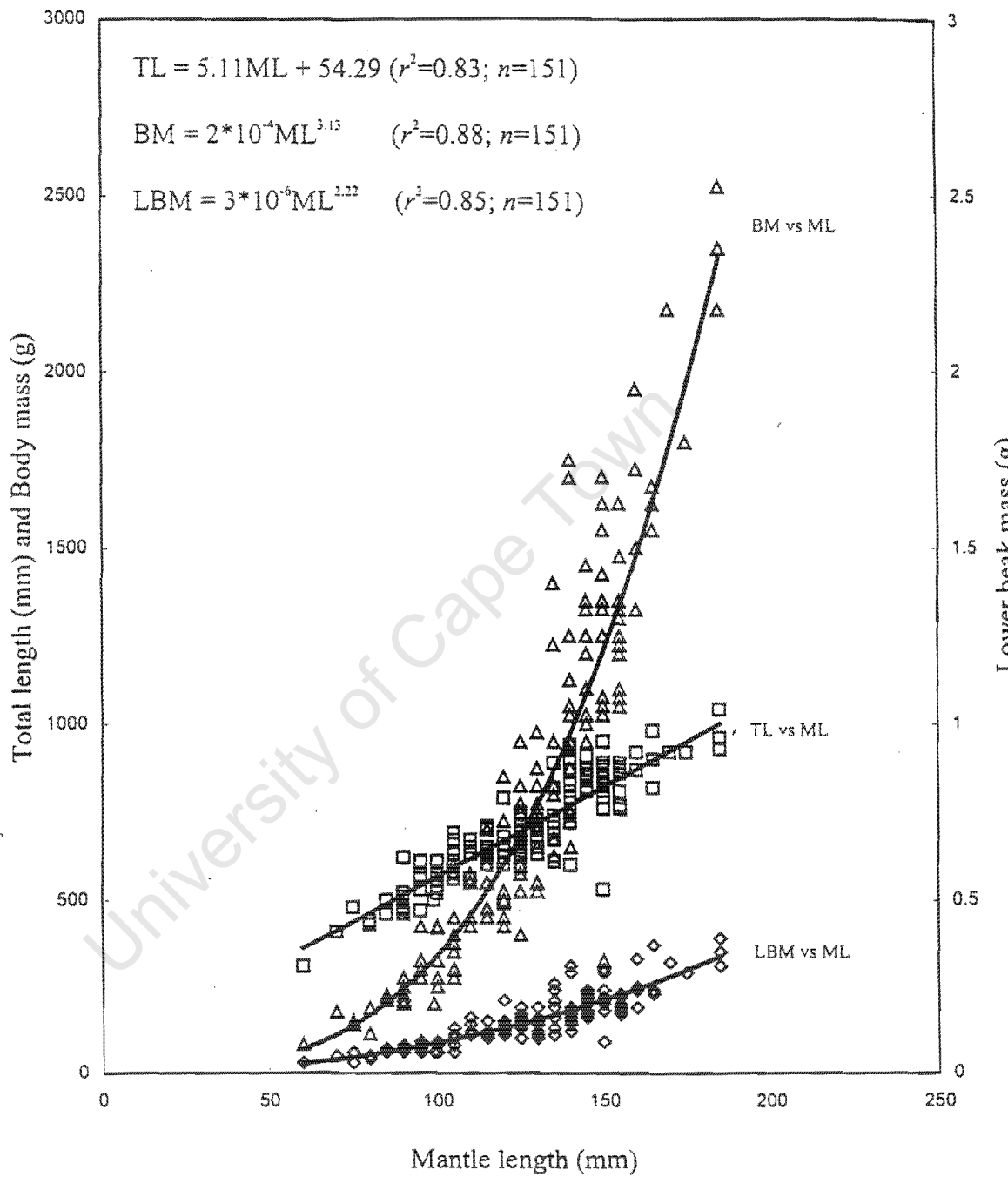


Fig. 1.7 *O. vulgaris* morphometric relationships. ML=mantle length, TL=total length, BM=body mass and LBM=lower beak mass.

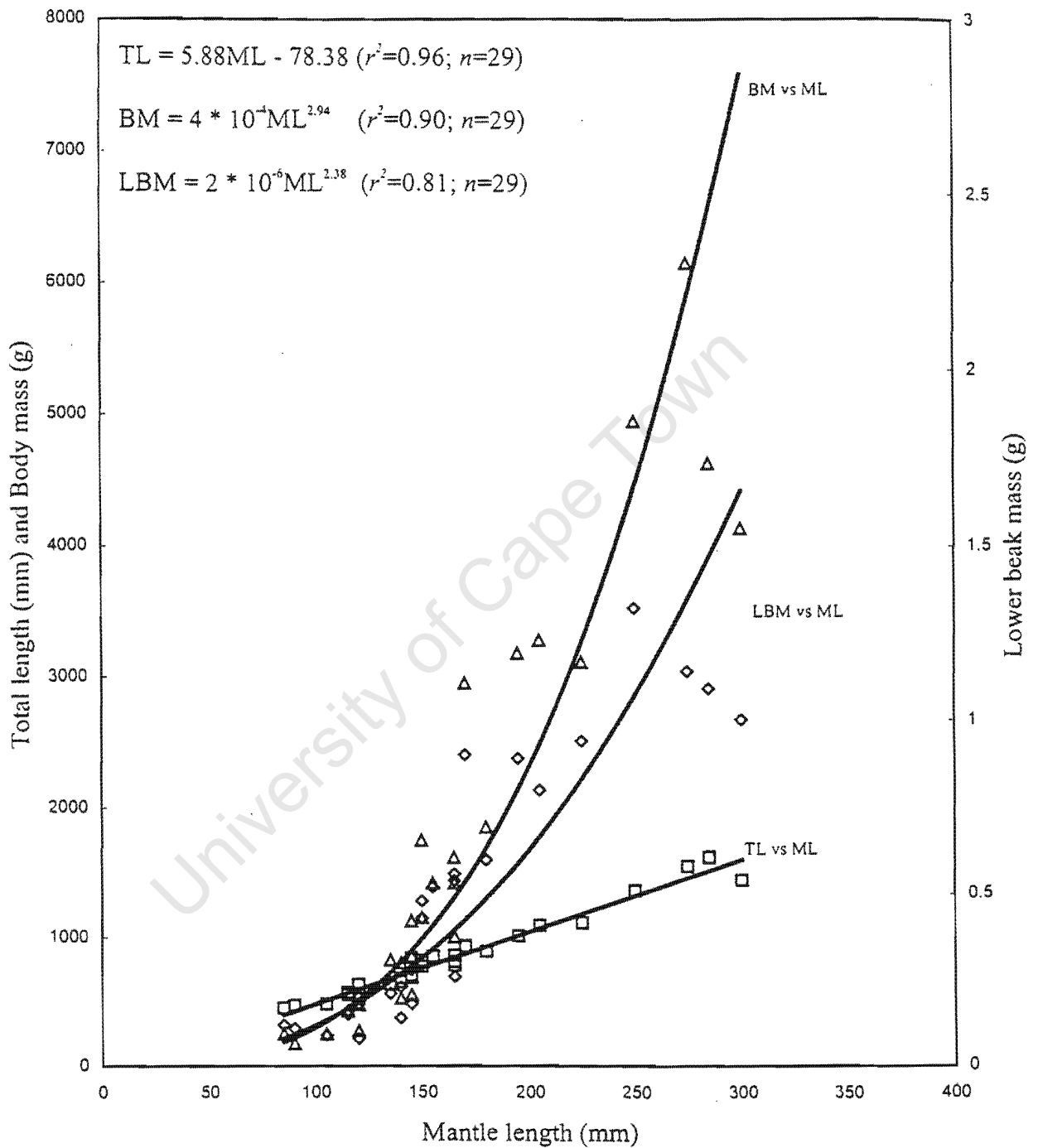


Fig. 1.8 *O. magnificus* morphometric relationships. ML=mantle length, TL=total length, BM=body mass and LBM=lower beak mass.

Table 1.1 Comparison of male and female mass for *A. schultzei*, *O. vulgaris* and *O. magnificus*.

Species	Male (M)			Female (F)			m avg mass / f avg mass
	Mean \pm SE (g)	Range (g)	<i>n</i>	Mean \pm SE (g)	Range (g)	<i>n</i>	
<i>A. schultzei</i>	97.8 \pm 15.9	2-350	34	34.8 \pm 7.4	2-128	24	2.8**
<i>O. vulgaris</i>	976.9 \pm 47.5	75-4 625	221	1 114 \pm 72.9	75-3 675	132	0.9 ^{n.s.}
<i>O. magnificus</i>	1 609 \pm 383.6	175-7 500	21	2 170 \pm 385.2	275-7 675	26	0.7 ^{n.s.}

** $p < 0.01$ n.s. not significant $p > 0.05$

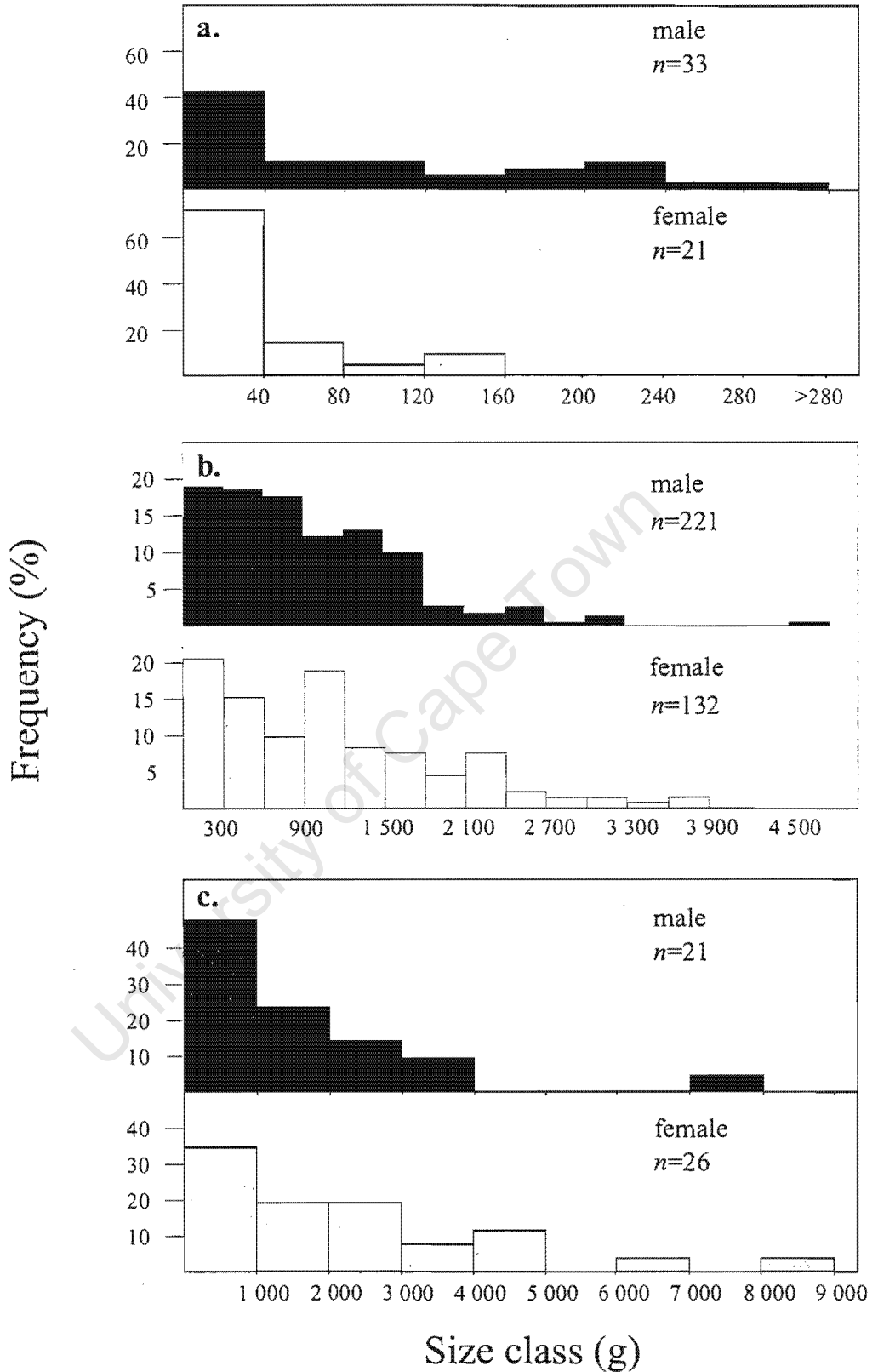


Fig. 1.9.a. Male and female size frequency distribution of *A. schultzei* collected in Granger Bay intertidal zone, using 40 g size classes.
b. Male and female size frequency distribution of *O. vulgaris* captured in False Bay, using 300 g size classes.
c. Male and female size frequency distribution of *O. magnificus* obtained from the south coast, using 1 000 g size classes.

Gonad mass and body mass relationships were modelled by curves with the highest r^2 value. Male GM was a linear function of BM for *A. schultzei* and *O. vulgaris* males, but an exponential function for *O. magnificus* (Fig. 1.10). In female octopuses GM and BM followed a power curve for *A. schultzei* and *O. vulgaris*, but an exponential curve for *O. magnificus* (Fig. 1.10).

Sex ratios

The overall sex ratio was not significantly biased for *A. schultzei* (0.7F:1.0M, $\chi^2=1.86$, $n=58$, $p>0.05$). For *O. vulgaris*, the overall sex ratio was significantly biased towards males (0.6F:1.0M, $\chi^2=22.4$, $n=353$, $p<0.0001$). This was largely attributed to medium and large females being underrepresented in the summer and spring samples (Table 1.2). No significant differences were found in the sex ratios of *O. magnificus* (1.2F:1.0M, $\chi^2=0.53$, $n=47$, $p>0.05$).

Diet of octopus species

Of all the specimens collected, only 43.8% of *A. schultzei* ($n=64$), 70.8% of *O. vulgaris* ($n=353$) and 60.4% of *O. magnificus* ($n=48$) had prey remains in the gut. The raw dietary data for *A. schultzei*, *O. vulgaris* and *O. magnificus* are provide in Table 1.3.

The single most important prey group in the diet of *A. schultzei* was winkles (Table 1.4), namely *Oxystele sinensis* and *Turbo sarmaticus* (Table 1.3), accounting for over 68% of the total IRI (Fig. 1.11). Other important dietary components included small crustaceans (i.e. isopods and amphipods, Table 1.3) and octopuses themselves, which attributed 11.4% and 12.5% of the total IRI respectively (Fig. 1.11). However, octopuses were only found in the diet of large *A. schultzei* (>100 g.)

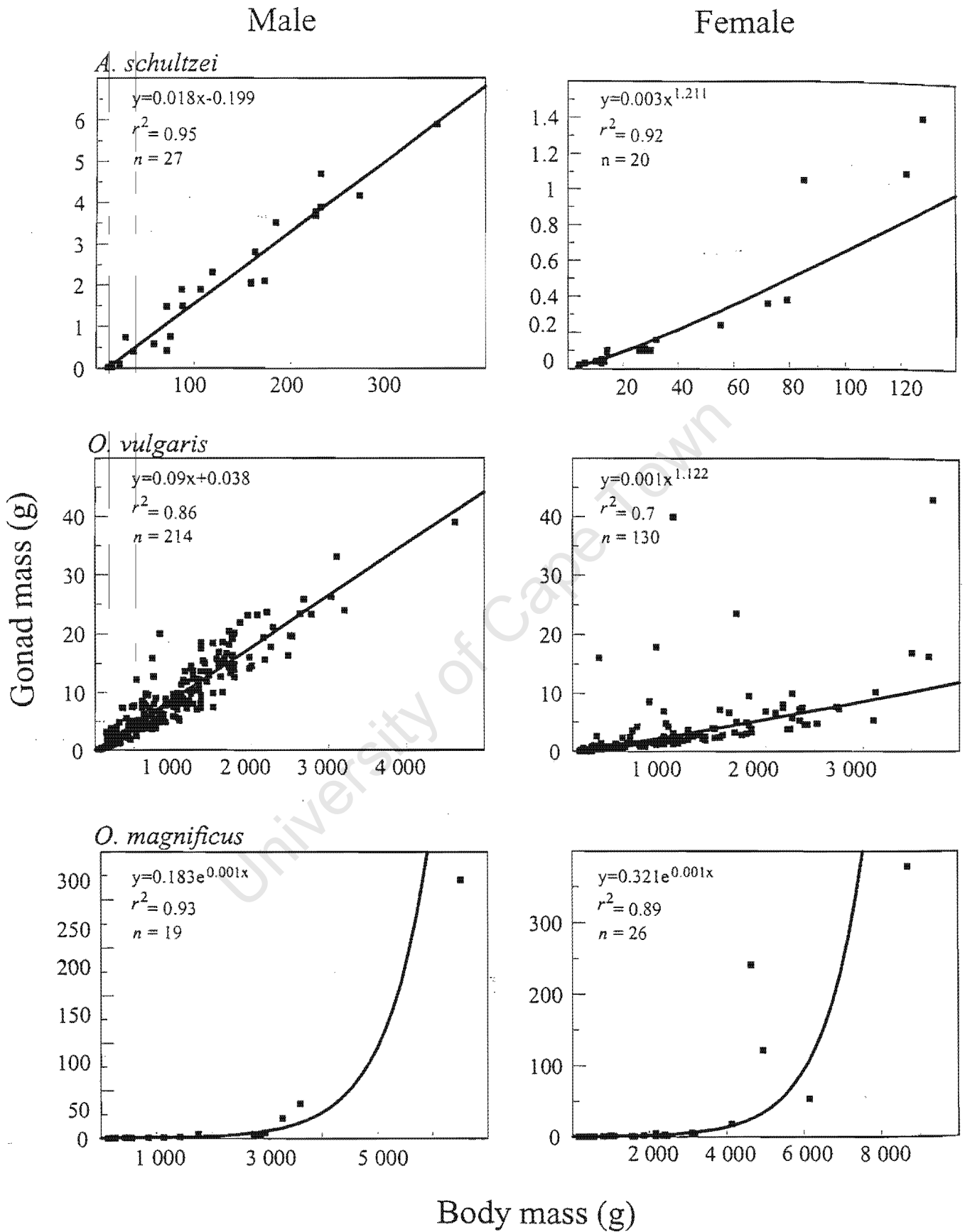


Fig. 1.10 Relationship between gonad mass and body mass for male and female *A. schultzei*, *O. magnificus* and *O. vulgaris*.

Table 1.2 Seasonal and overall sex ratios for small (0-300 g), medium (301-1 000 g) and large (>1 000 g) *O. vulgaris* in False Bay.

size class (g)	summer		autumn		winter		spring		Overall	
	male	female	male	female	male	female	male	female	male	female
0-300	7	8	11	9	16	8	8	2	42	27
301-1 000	14	2	15	9	20	13	29	8	78	32
>1 000	33	18	20	15	17	12	28	20	97	72
Total	54	28	46	33	53	33	65	30	217	131

Table 1.3 Overall diet of *A. schultzei*, *O. vulgaris* and *O. magnificus* from the southwestern Cape by lowest identifiable taxon. Number of octopus containing food in guts were 28, 250 and 29 respectively.

Prey categories	Octopus species								
	<i>A. schultzei</i>			<i>O. vulgaris</i>			<i>O. magnificus</i>		
	% occ.	no.	vol.	% occ.	no.	vol.	% occ.	no.	vol.
Crustaceans									
Large crustaceans									
<i>Jasus lalandii</i>	-	-	-	0.8	2	34	-	-	-
<i>Paguristes gamianus</i>	-	-	-	5.2	16	5.7	-	-	-
<i>Palinurus gilchristi</i>	-	-	-	-	-	-	3.5	1	32
<i>Plagusia chabrus</i>	3.6	1	0.5	24.8	75	78	-	-	-
Unidentified crabs	3.6	1	0.1	11.2	26	9.7	51.7	26	16.5
Small crustaceans									
Amphipods (<i>Paramoera capensis</i>)	-	-	-	7.6	69	3.9	-	-	-
Other	10.7	8	0.1	6.8	57	2.9	6.9	2	0.1
Euphasids	-	-	-	-	-	-	34.5	56	7.7
Isopods	10.7	7	1.1	2	15	1.8	-	-	-
Megalopa larvae	-	-	-	18	256	57.8	-	-	-
Molluscs									
Abalone									
<i>Haliotis midae</i>	-	-	-	17.2	47	341.5	-	-	-
<i>Haliotis spadicea</i>	-	-	-	0.4	1	3.5	-	-	-
Bivalves									
<i>Choromytilus meridionalis</i>	-	-	-	0.4	1	0.3	-	-	-
<i>Lutraria lutraria</i>	-	-	-	0.4	1	2.5	-	-	-
Limpets									
Patella spp.	-	-	-	10	25	40.3	-	-	-
Octopus									
<i>Aphrodoctopus schultzei</i>	14.3	4	4.2	0.4	1	6	-	-	-
<i>Octopus magnificus</i>	-	-	-	-	-	-	6.9	2	97.2
<i>Octopus vulgaris</i>	-	-	-	2.8	7	129.1	-	-	-
Winkles									
<i>Oxystele sinensis</i>	32.1	26	1.5	6.8	22	1.2	-	-	-
<i>Turbo cidaris</i>	-	-	-	2.4	6	4.3	-	-	-
<i>Turbo sarmaticus</i>	14.3	28	0.5	-	-	-	-	-	-
Unidentified	-	-	-	-	-	-	10.3	4	0.2
Other molluscs									
<i>Gibbula zonata</i>	-	-	-	2	5	0.2	-	-	-
<i>Phyllodesmium serratum</i>	-	-	-	0.4	1	0.2	-	-	-
<i>Tambja capensis</i>	-	-	-	0.4	1	0.2	-	-	-
<i>Volvarina zonata</i>	-	-	-	0.4	1	0.1	-	-	-
Polychaetes									
Errantia spp.	21.4	7	0.2	7.6	26	37.9	3.5	1	2
Sedentaria spp.	-	-	-	3.2	12	19.3	-	-	-
Teleosts	7.1	2	0.4	11.2	28	39.3	27.6	26	213.8
Unidentified crustaceans	10.7	3	0.2	4.8	12	6.3	3.5	10	5
Unidentified molluscs	3.6	1	0.5	2.4	6	5.5	-	-	-
Unidentified	14.3	4	0.6	9.2	26	27	10.3	3	8.7
Total		92	9.9		746	866.5		131	383.2

The dominant items in the diet of *O. vulgaris* were small crustaceans, followed by large crustaceans and abalone (Table 1.4), comprising 45.5%, 28.1% and 17.1% of total IRI respectively (Fig. 1.11). Small crustaceans were dominant due to the combined high numerical abundance (53.2% of total number of prey items) and high frequency of occurrence (33.7%) (Table 1.4) of megalopa larvae and to a lesser extent big-eye amphipods, *Paramoera capensis* (Table 1.3). Large crustaceans, although the second most important dietary category contained the most important single prey species in the diet of *O. vulgaris*, namely the crab *Plagusia chabrus* (Table 1.3). The second most important prey species of *O. vulgaris* was *H. midae* (Table 1.3). Other commercially-important species consumed included the rock-lobster, *Jasus lalandii*, although this had a low frequency of occurrence of 0.8% (Table 1.3).

The diet of *O. magnificus* was also dominated by small crustaceans (mainly euphausiids, Table 1.3) and large crustaceans (mainly crabs, Table 1.3) accounting for 31.8% and 30.1% of the total IRI respectively (Fig. 1.11). However, the remainder of the diet and the largest single component was teleosts, accounting for 34% of the total IRI (Fig. 1.11).

DISCUSSION

Population biology

Species size & morphometric relationships

Mean size differed greatly between octopus species, with *A. schultzei* being a small species, *O. vulgaris* a medium sized species and *O. magnificus* a large species. When comparing the morphometric relationships at a given ML between 80-100 mm for *A. schultzei* and *O. vulgaris*, *O. vulgaris* is longer, with a higher BM and LBM (using the equations in Fig. 1.6 & 1.7). Similarly, *O. vulgaris* is longer and heavier than *O. magnificus* at a given

Table 1.4 Diets of *A. schultzei*, *O. magnificus* and *O. vulgaris* from the southwestern Cape by major prey categories.

Large and small crustaceans are defined in text. %n = percentage of the total number of all prey items found in octopus guts. %v = percentage of the total volume of all prey items found in octopus guts. %f = percentage frequency of occurrence of prey item in octopuses guts. IRI = %f * (%n + %v).

Prey category	Octopus species											
	<i>A. schultzei</i> (n=28)				<i>O. vulgaris</i> (n=250)				<i>O. magnificus</i> (n=29)			
	% n	% v	% f	IRI	% n	% v	% f	IRI	% n	% v	% f	IRI
Crustaceans												
Large crustaceans	2.2	6.1	7.2	60	16.0	14.7	41.2	1265	21.1	12.7	55.1	1862
Small crustaceans	16.3	12.1	21.4	608	53.2	7.7	33.7	2052	45.4	2.0	41.4	1962
Unidentified	3.3	2.0	10.7	57	1.6	0.7	4.7	11	7.8	1.3	3.4	31
Molluscs												
Abalone	-	-	-	-	6.3	39.4	16.9	772	-	-	-	-
Limpets	-	-	-	-	3.5	4.9	10.2	86	-	-	-	-
Winkles	58.7	20.3	46.4	3666	4.4	0.6	11.1	56	3.1	0.1	10.3	33
Bivalves	-	-	-	-	0.1	0.1	0.4	-	-	-	-	-
Octopus	4.3	42.4	14.3	668	1.2	16.5	3.5	62	1.6	25.4	6.9	186
Unidentified	1.1	5.1	3.6	22	0.8	0.6	2.4	3	-	-	-	-
Polychaetes												
	7.6	2.0	21.4	205	5.1	6.6	10.6	124	0.8	0.5	3.4	4
Teleosts												
	2.2	4.0	7.1	44	3.6	3.6	10.6	76	20.3	55.8	27.6	2100

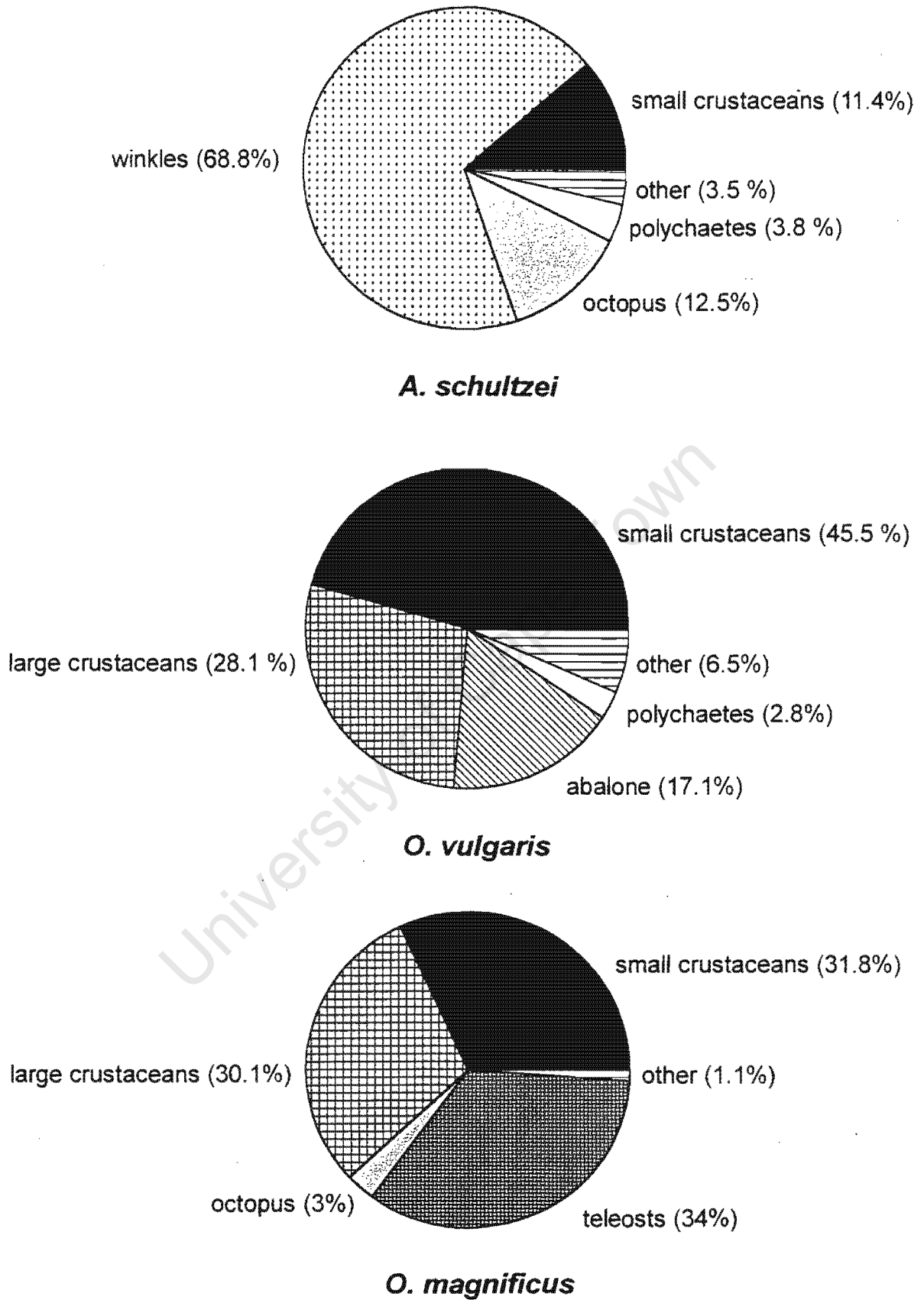


Fig. 1.11 Diets of *A. schultzei*, *O. vulgaris* and *O. magnificus* from the southwestern Cape, using IRI percentages. See Table 1.3 for numerical calculation of IRI values. All IRI values in Table 1.3 less than 100 were grouped as "other".

ML between 100-170 mm, but *O. magnificus* has a heavier lower beak (using the equations in Fig. 1.7 & 1.8). However, at a given ML >170 mm *O. magnificus* is longer than *O. vulgaris*.

The morphometric relationships for *O. vulgaris* in False Bay were similar to those reported by Hatanaka (1979a), Smale & Buchan (1981) and Sanchez & Obarti (1993) for *O. vulgaris* specimens off the northwest coast of Africa, east coast of South Africa and the Spanish Mediterranean coast respectively. This agrees with the statement made by Mangold (1997) that *O. vulgaris* occurring along the eastern Atlantic and in the Mediterranean Sea are one and the same species. Moreover, these relationships are useful for fisheries management as octopus size can be estimated from various measurements.

Male and female size structural analysis

The difference between the mean male and female mass of *A. schultzei* in the intertidal zone is largely attributed to absence of females heavier than 160 g. Females of this mass are probably mature and most likely to occur in the subtidal zone, which probably provides more favourable conditions for female maturation (as was shown for *Octopus tehuelchus*, which had higher fecundity in the subtidal zone than in the intertidal zone, Iribarne 1991). Thus the unsuitable spawning conditions of the intertidal zone probably affected the population size structure of *A. schultzei* in this zone. Therefore to obtain a complete size spectrum of this species the subtidal zone should be sampled as well.

Maturation

Males matured at a smaller size than females in all three species, which is in agreement with all other studies on cephalopods (Mangold 1987). However, it is most likely that males only mate when their spermatophores are fully developed. Hence, if male maturity was based on

spermatophore development, and not the presence thereof, then males would attain maturity at a slightly larger size, of approximately 100 g, 325 g and 4 000 g for *A. schultzei*, *O. vulgaris* and *O. magnificus* respectively. This size at maturity for male *O. vulgaris* is similar to that reported by Smale & Buchan (1981). Species fecundity could not be compared, due to the absence of mature female *A. schultzei* and *O. vulgaris*. Although mature females were not found for all species, the minimum size at maturing indicates that most spawning is likely to occur in females larger than 80 g, 3 000 g and 5 000 g for *A. schultzei*, *O. vulgaris* and *O. magnificus* respectively. The absence of mature female *O. vulgaris* probably indicates that spawning occurs in deeper water (>10 m). Smale & Buchan (1981) postulated a similar hypothesis for a shallow-water population of *O. vulgaris* along the east coast of South Africa. This agrees with Whitaker *et al.* (1991) and Sanchez & Obarti (1993) who obtained a high proportion of mature *O. vulgaris* females between 10-30 m along the South Carolina and Spanish Mediterranean coasts respectively. Hatanaka (1979a) also found spawned egg masses between 15 - 94 m.

Male gonad mass should increase linearly with body mass. This is generally true for most male octopuses, as there is a continuous production and release of sperm (Mangold 1983). However, in male *O. magnificus* gonad mass increased exponentially with body mass, with gonad development prominent in specimens heavier than 3 000 g. Late maturation in males may be a common phenomenon in long-lived octopus species, as was found for another long-lived, large, closely-related species, namely *O. dofleini* (Mottet 1975). Delayed gonad maturation could have a two-fold benefit. Firstly, faster growth rates can be attained as no energy is expended in the development of gonads when individuals are young. Secondly, faster growth rates increase an octopus potential to escape predation by minimizing the time

period when it is most vulnerable to predators (see Chapter 5). In contrast, the power and exponential relationships between GM and BM indicates late maturation to be a common phenomenon in female octopuses. This agrees with other studies on octopuses (Mangold 1987). As octopuses are semelparous (Calow 1987) late maturation would increase their fecundity because the number of eggs spawned is proportional to body mass (Mangold 1987). Despite the benefit of late maturation, a few *O. vulgaris* were found maturing at a small size (< 1 000 g). Hence, female body mass is not as good an indicator of maturity as is male body mass. Because female maturity may also be influenced by complicated interactions between light intensity (Wells and Wells 1959), temperature (Richard 1966 cited in Mangold 1987; Robinson & Hartwick 1986), food availability (van Heukelem 1976 cited in Mangold 1987; Robinson & Hartwick 1986) and predation pressure (see Chapter 5).

Sex ratios

The samples of *A. schultzei* and *O. magnificus* may have been too small to determine if the overall sex ratios differed significantly from a 1:1 sex ratio. The largest difference in the sex ratio for *O. vulgaris* coincided with the peak spawning seasons (see Chapter 3). Similarly, fewer *O. vulgaris* females were collected during the peak spawning seasons along the east coast of South Africa (Smale & Buchan 1981). Hence, the disparity in sex ratios could be explained by medium to large females migrating to deeper waters to spawn, thereby decreasing the abundance of females in the kelp bed. However, differences in sex ratios have been attributed to behavioural differences between the sexes (Hartwick *et al.* 1984), greater mobility in males (Wells 1978) and death of post-spawning females (Hatanaka 1979a). In contrast, other studies (Hatanaka 1979a; Guerra 1981; Quetglas *et al.* 1998), which sampled over a larger depth range, found the overall sex ratios of *O. vulgaris* to approach parity.

Diets of octopus species

The diets of the three species of octopuses in the southwestern Cape differed in two ways. Firstly, the bulk of the diet of *A. schultzei* was attributed to one category, whereas the bulk of both *O. vulgaris* and *O. magnificus* diet was shared between three categories. The increase in the variety of prey appears to be a dependant on octopus size, as a similar trend was found when comparing the diet of small and large *O. vulgaris* (see Chapter 4). This is further supported by a study conducted by Smale & Buchan (1981). Secondly, prey types differed considerably between octopus species. These differences are probably attributable to the different depth zones in which the octopus species were collected and hence difference in prey availability in these zones. For example juvenile winkles, such as *O. sinensis* and *T. sarmaticus*, are abundant in the intertidal zone (Pulfrich 1997) and are thus prey for *A. schultzei*, but rarely for the other two species. Similarly, abalone, which is a shallow subtidal species (Branch *et al.* 1994), was consumed only by *O. vulgaris*. *O. magnificus*, in contrast, consumed a large proportion of teleosts which was similar to the diet of deep water *O. vulgaris* populations (Table 1.5), indicating a possible higher relative abundance of teleosts in deeper water. Furthermore, the increase in importance of teleosts in the diet of *O. magnificus* may also be dependant on octopus size (see Chapter 4 for *O. vulgaris*). Therefore the differences in diet of the three octopus species appears to be a combination of predator size and prey availability.

The importance of winkles in the diet of *A. schultzei* was similar to that reported for *Octopus bimaculatus* by Ambrose (1997), another intertidal species. The low importance of teleosts in the diet of *O. vulgaris* in this study was similar to other shallow water (<15 m) populations of *O. vulgaris* (Table 1.5).

Table 1.5 Importance of crustaceans, molluscs and teleosts in shallow (<15 m) and deep (>15 m) populations of *O. vulgaris*. % IRI - percentage index of relative importance, F - abundance index, %f - percentage frequency of occurrence, OCI - occurrence index and %W - percentage weight.

Shallow water (most samples < 15 m deep)			
geographic area	statistic	diet	reference
southwest coast of South Africa	% IRI	73.8 % - crustacean 21.7 % - molluscs 1.6 % - teleosts	present study
western Mediterranean	F	76.0 - crustacean 27.5 - molluscs 6.7 - teleosts	Sanchez & Obarti 1993
east coast of South Africa	% f	67.8 % - crustacean 68.8 % - molluscs 3.8 % - teleosts	Smale & Buchan 1981
Deep water (most samples > 15 m deep)			
site	statistic	diet	reference
western Mediterranean	OCI	65.8 - crustacean 6.5 - molluscs 27.0 - teleosts	Quetglas <i>et al.</i> 1998
off South Carolina	% f	57.0 % - crustacean 21.0 % - molluscs 49.0 % - teleosts	Whitaker <i>et al.</i> 1991
northwest coast of Africa	% w	7 - 16 % - crustacean 45 - 60 % - molluscs 19 - 34 % - teleosts	Hatanaka 1979a
northwest coast of Africa	% f	61.5 % - crustacean 6.3 % - molluscs 29.5 % - teleosts	Nigmattulin & Ostapenko 1976

CHAPTER 2

University of Cape Town

POTENTIAL FOR A SOUTHWESTERN CAPE OCTOPUS INDUSTRY

For a fishery to be successful a suitable species must be targeted based on appropriate biology and distribution. The target species should also be relatively abundant with good market potential. The aim of this chapter is firstly to determine the status of global octopus catches, the marketability of octopus species and location of important markets. In the light of this, South African octopus catches and market potential are discussed to determine the most suitable candidate for exploitation by small-scale fisheries in the southwestern Cape. This is achieved by a review of literature, Sea Fisheries Research Institute (SFRI) unpublished data and unpublished data from the industry.

GLOBAL PATTERNS

Octopus landings

Global annual octopus landings have fluctuated considerably over the past two decades, ranging from 150 000 to 280 000 metric tons (Food and Agricultural Organisation (FAO) statistical reports 1973 - 1994) (Fig. 2.1). However, catches have steadily increased since 1984 (Fig. 2.1). In 1994 more than 65% of global octopus landings were taken from two fishing areas, namely the Saharan Bank, off the northwest coast of Africa, and the seas adjacent to Japan (FAO statistical reports 1994) (Fig. 2.2). Other important octopus landings were attributed to Thailand and Korea (24 114 tons combined), Mexico (16 845 tons), USSR (13 885 tons), Australasia (8 456 tons) and Spain (3 000 tons) (FAO statistical reports 1994).

Species marketability

Most commercially-exploited octopus species belong to the family Octopodidae, including *O. vulgaris* from the Mediterranean Sea (Quetglas *et al.* 1998), eastern Atlantic (Hatanaka 1979a) and northwestern Pacific (Rathjen & Voss 1987), *O. dofleini* from the north Pacific (Paust 1988), *O. maya* from the western Atlantic (Voss 1988), *O. cyanea* and *O. ornatus* from the

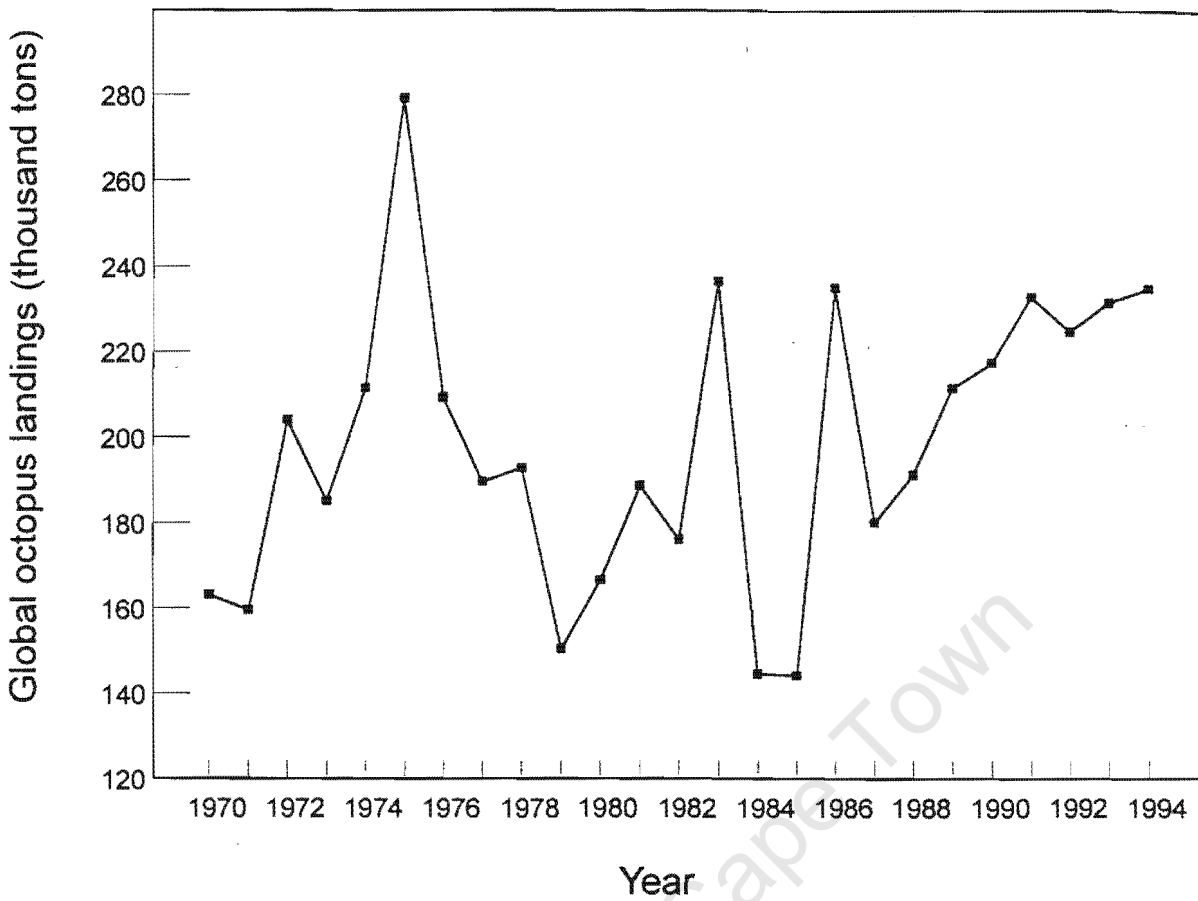


Fig. 2.1 Recorded global octopus landings, from 1970 - 1994 (from FAO fishery statistics catches and landings 1973 - 1994).

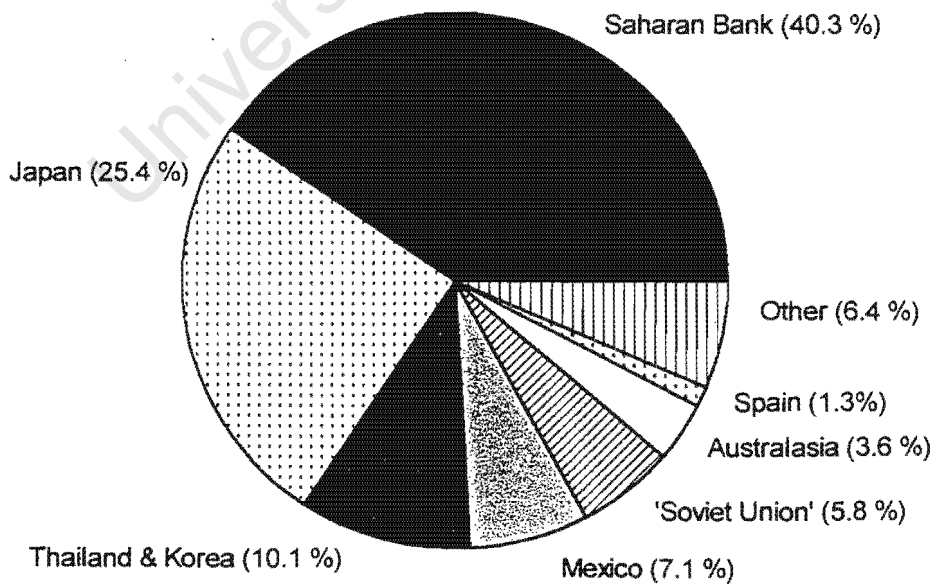


Fig. 2.2 Percentages of the total octopus landings of 235 036 tons taken from each of the major fishing areas in 1994 (FAO fishery statistics catches and landings 1994).

Pacific (Young and Harman 1989) and *Cistopus indicus* from the northern Indian Ocean (Rathjen & Voss 1987). Octopus species belonging to this family are all benthic with well developed musculature, making them suitable candidates as a food source (Anon 1981). However, large species, such as *O. dofleini*, are usually used as bait (Paust 1988).

Although many octopus species are targeted, *O. vulgaris* accounted for approximately 80% of the global octopus catch in 1986 (FAO statistical reports 1986). This dominance by *O. vulgaris* is attributed to two factors. Firstly, Japan, the largest octopus market, consuming approximately 70% of the world's catch, regards this octopus as having the highest quality meat among all octopus species. Consequently, this species has the highest commodity value of any octopus (Anon 1981). Secondly, this species was considered to have wide depth and geographic distributions, occurring from the intertidal zone to depths of over 300 m (Guerra 1981), and being common to all temperate, tropical and subtropical waters (Mangold 1983).

Octopus markets

Important markets for octopus, besides Japan, are situated in Portugal, Italy, Spain, Greece and oriental countries (Voss 1988). As a food source octopus is also gaining greater recognition by other countries such as those in northern Europe and North America (Voss 1988). Moreover, the supply of octopus caught in the waters of Japan and Spain can no longer meet the demand in these countries. Hence, Japan and Spain are increasingly depending on imported octopus (Anon 1981; Sanchez & Obarti 1993).

SOUTH AFRICA

Octopus landings

Domestic reported octopus landings are small in comparison to global landings, accounting for less than 0.05% of total landings. These landings, however, are substantial considering that there are no commercial fisheries targeting octopus in South Africa. Reported landings ranged from 182 metric tons in 1980 to 33 tons in 1995 (Fig. 2.3). Furthermore, these values are gross underestimates of the total annual octopus landings in South Africa, as they are predominantly west coast by-catch landings of *O. magnificus* for some inshore and offshore trawl fisheries. Octopus are also caught as by-catch by the lobster trap and the hake long-line fisheries, but these catches are usually not reported. These landings are substantial, for example one lobster trap fishing vessel operating along the south coast can catch in excess of 8 tons of *O. magnificus* in one trip, lasting 30 days. To put this in perspective, it is not unusual for this by-catch to exceed the total tonnage of targeted lobsters caught on the same trip (E. Moor, manager of Premier Fishing company, pers. comm.). Landings of octopus are also not reported for artisanal and recreational fisheries, which have been documented to target *O. vulgaris* in the intertidal zone for use as bait since the beginning of the twentieth century (Thompson 1913). These fisheries are mainly situated along the southern and eastern coast of the country, including Transkei. In 1994-1995 an estimated 12.3 tons of octopus was caught along the Transkei coast (Robertson & Fielding 1997) and in 1995 a further 12.9 tons (25 783 octopuses) were removed from the Kwa-Zulu Natal coast (Anon 1997). Presented with the above information, domestic octopus landings could be more than double those presented in Fig. 2.3.

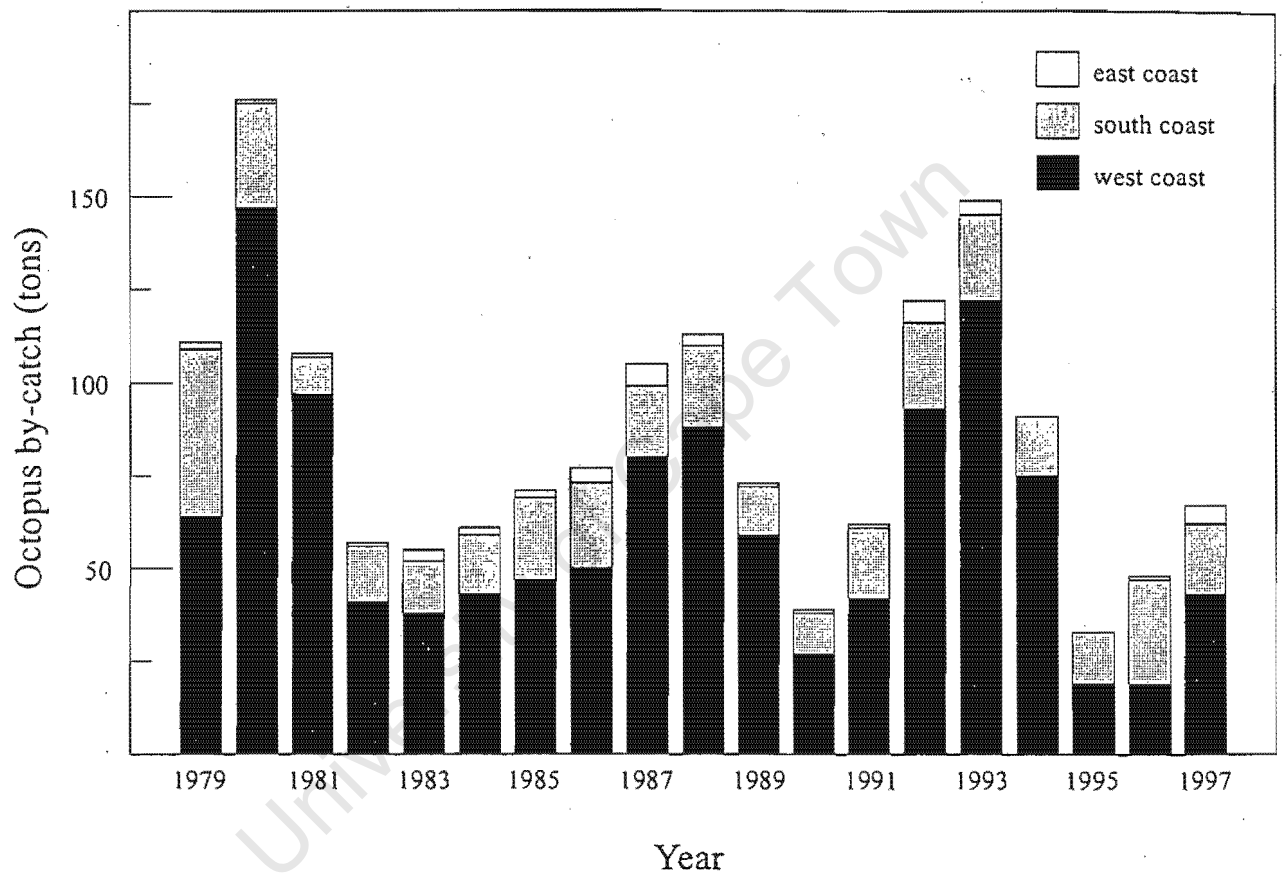


Fig. 2.3 Reported octopus by-catch landings from South African inshore and offshore trawls, between 1979 - 1997 (SFRI unpublished data).

Octopus market potential

The absence of a commercial fishery targeting octopus in South Africa is largely attributed to the limited domestic market, as octopus is not part of the staple diet of South Africans. Indeed, octopus is predominately used as bait. However, juvenile octopuses appear to be increasingly common in supermarkets, although they are sold as “squid” (pers. obs.) and appear to be imported. Poor coastal communities in the Transkei also eat octopus but are unlikely to ever buy it as this protein source is easily collected. Thus the potential domestic market for octopus is likely to remain low. However, most octopuses caught as by-catch are exported. For example Irvin and Johnson and Premier Fishing received a gross of approximately R18/kg in 1998 for frozen *O. magnificus* exported to North America and Spain respectively (B. Rose, fleet operations manager, Irvin & Johnson, pers. comm.)(E. Moor, manager, Premier Fishing, pers. comm.). Therefore octopus export potential appears to be promising.

In conclusion, global octopus catches are increasing and export potential looks good, since both Japan and Spain are increasingly dependent on imported octopus. Furthermore, *O. vulgaris*, which is the most sought-after global octopus species, is common in South African waters. This information, together with the information obtained in Chapter 1, on the distribution, biology and diet, makes *O. vulgaris* the most suitable octopus candidate for exploitation by small-scale fisheries in the southwestern Cape. Thus subsequent chapters focuses on the spatial distribution, population dynamics and ecology of this species only, with the aim of determining information required for future octopus fishery operations.

CHAPTER 3

University of Cape Town

SPATIAL DISTRIBUTION AND POPULATION DYNAMICS OF *OCTOPUS VULGARIS*

INTRODUCTION

Studies on distribution and population biology of octopus species have largely been conducted for commercially-exploitable species, particularly *O. vulgaris* (Hatanaka 1979a,b; Guerra 1981; Smale & Buchan 1981; Ambrose & Nelson 1983; Mather 1991; Mather & O'Dor 1991; Whitaker *et al.* 1991; Sanchez & Obarti 1993; Quetglas *et al.* 1998) and *Octopus dofleini* (Hartwick *et al.* 1978, 1984, 1988; Robinson & Hartwick 1986). *O. vulgaris* is known to have a wide depth distribution: occurring from 0->300m, with density decreasing towards the continental slope (Guerra 1981). Furthermore, this species is mostly an inhabitant of coral reefs or rocks in shallow water, but in many areas, it can be more abundant over sandy or muddy bottoms or in seagrass (Mangold 1983). Individuals of this species are normally solitary and build homes near octopus of similar size (Guerra 1981). This author also found males and females to be randomly dispersed within patches of different density. Moreover, the above-mentioned studies showed that abundance, population size structure and spawning activity are highly variable between seasons and areas.

Knowledge about the variability of any octopus species targeted in a proposed fishing region is important for efficient fishing operations and management. Therefore the aims of this chapter are to determine the spatial distribution and population dynamics of *O. vulgaris* in False Bay. Spatial distribution involved *in situ* investigations of shelter-dependency of octopus during the day as well as habitat preference and depth distribution. Seasonal

population size structure and mean seasonal Gonadal Somatic Index (GSI) were also obtained to determine the population dynamics of this species.

METHODS

O. vulgaris was collected during the day as described in Chapter 1. On collection, notes were made on whether each octopus was in or out of its shelter, habitat type (reef, boulder rubble, edge of reef or sand) and depth of capture. Mating was assumed if a male and female were cohabiting the same shelter. These notes were used to determine the spatial distribution and time of mating of this species in the kelp beds of False Bay. Furthermore, mean octopus size obtained in Chapter 1 was further broken down by season to analyse the seasonal population size structure of *O. vulgaris* in this region. Peak spawning was determined by plotting the mean monthly female GSI against time, where $GSI = \text{gonad mass (GM)} / \text{body mass (BM)} * 100$. Population size structure and GSI were plotted with water temperature to investigate whether the observed fluctuations in the former were correlated to water temperature. Water temperature was inferred from a thermoscript at Boordjiesdrift situated on the west coast of False Bay (Fig. 1.4).

Statistical analysis

A contingency table was used to test for significant differences between the proportions of octopuses found outside vs inside shelters for each of three size classes of octopus. A one-way ANOVA was performed on the depths at which octopuses were collected to determine if there were any significant differences in the mean depth of small (0-300 g), medium (301-1 000 g) and large (>1 000 g) specimens. To identify whether there were any differences in mass related to season or sex of individuals, a two-way ANOVA was performed with mass as the dependent variable and season and sex as independent variables. *Post hoc* multiple

comparisons were performed using a Tukey test for unequal sample size (Statsoft 1996). Mass data were log transformed to improve normality and homoscedasticity (Zar 1984), as some samples displayed unequal variances. The correlation between mean monthly octopus mass and water temperature were analysed by linear regression.

RESULTS

Spatial distribution

In total, 353 *O. vulgaris* specimens were collected, of which 83% were found in a shelter. The bulk of these octopuses were collected from boulder rubble (53%) and reef (35%) habitats, whereas the number of octopus sheltering in sand was low (1.0%) (Fig. 3.1). There was a significant difference in the proportion of octopuses found outside shelters between size classes ($\chi^2=29.67$, $df=2$, $p<0.01$). The proportion of octopuses found outside shelters was significantly higher for small octopuses (37%) compared to medium (15%) or large octopuses (8%) (Fig. 3.2). Furthermore, there was a significant difference in the mean depth of small, medium and large octopuses (ANOVA: $F_{324}=9.78$; $p<0.0001$) (Fig. 3.3). Small octopuses had a significantly shallower distribution (mean=2.9 m) than medium (3.8 m, $p<0.01$) and large specimens (mean=3.9 m, $p<0.001$).

Seasonal population size structure

There was a significant difference between the seasonal mean mass of the species (ANOVA: $F_{343}=3.26$; $p<0.05$) (Fig. 3.4), the winter mean mass being significantly lower (766 g) than that of summer (1 161.2 g, $p<0.05$) and spring (964.3 g, $p<0.05$). Mean mass of octopus in autumn was highest (1 193.8 g), but because of the large variance in masses of this sample it was not significantly different from that of winter (Fig. 3.4). Seasonal fluctuations were positively correlated with subsurface water temperature ($n=12$, $r^2=0.22$, $p<0.0001$) (Fig. 3.5).

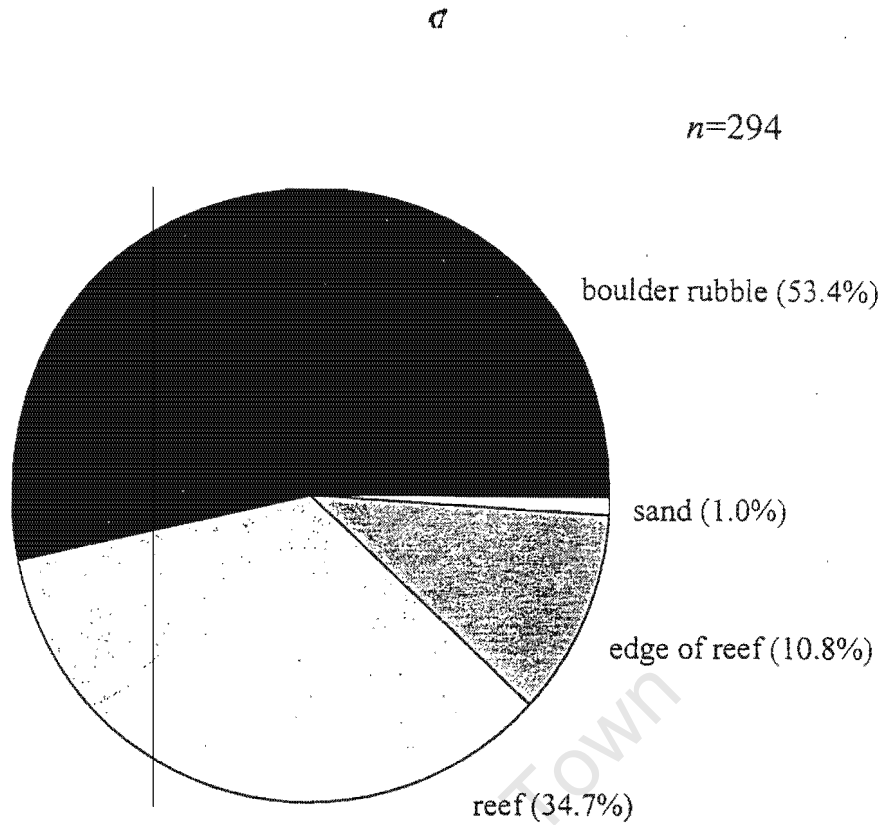


Fig. 3.1 Habitats of *O. vulgaris* collected within the kelp beds of False Bay, expressed as a proportion of the total collected, excluding octopus found outside their shelters.

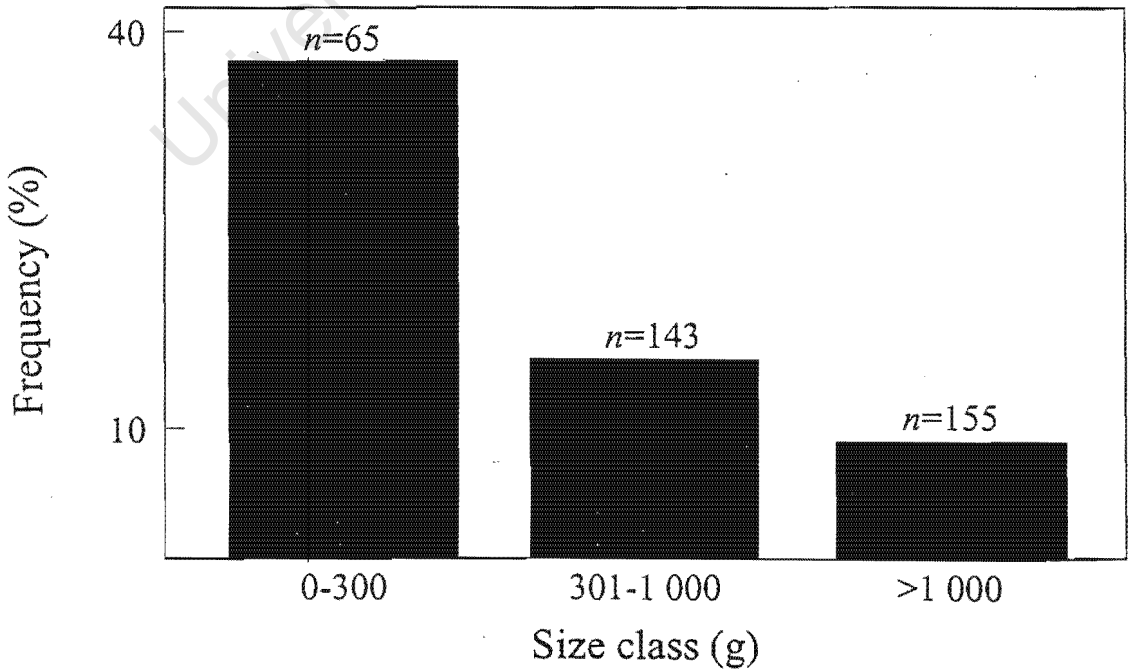


Fig. 3.2 Proportion of octopuses collected outside shelter for small, medium and large size classes of *O. vulgaris* collected in False Bay.

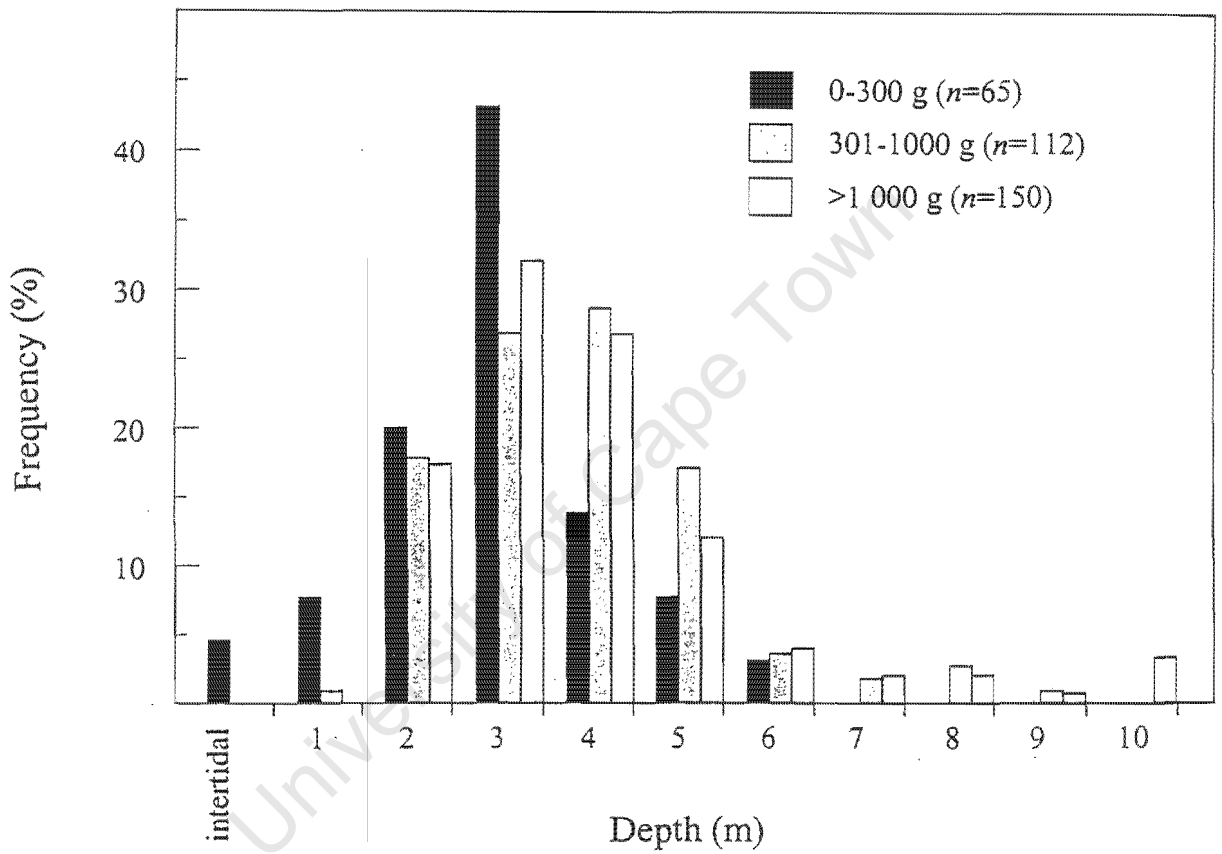


Fig. 3.3 Depth distribution of small (0-300 g), medium (301-1 000g) and large (>1 000 g) *O. vulgaris* in the kelp beds of False Bay.

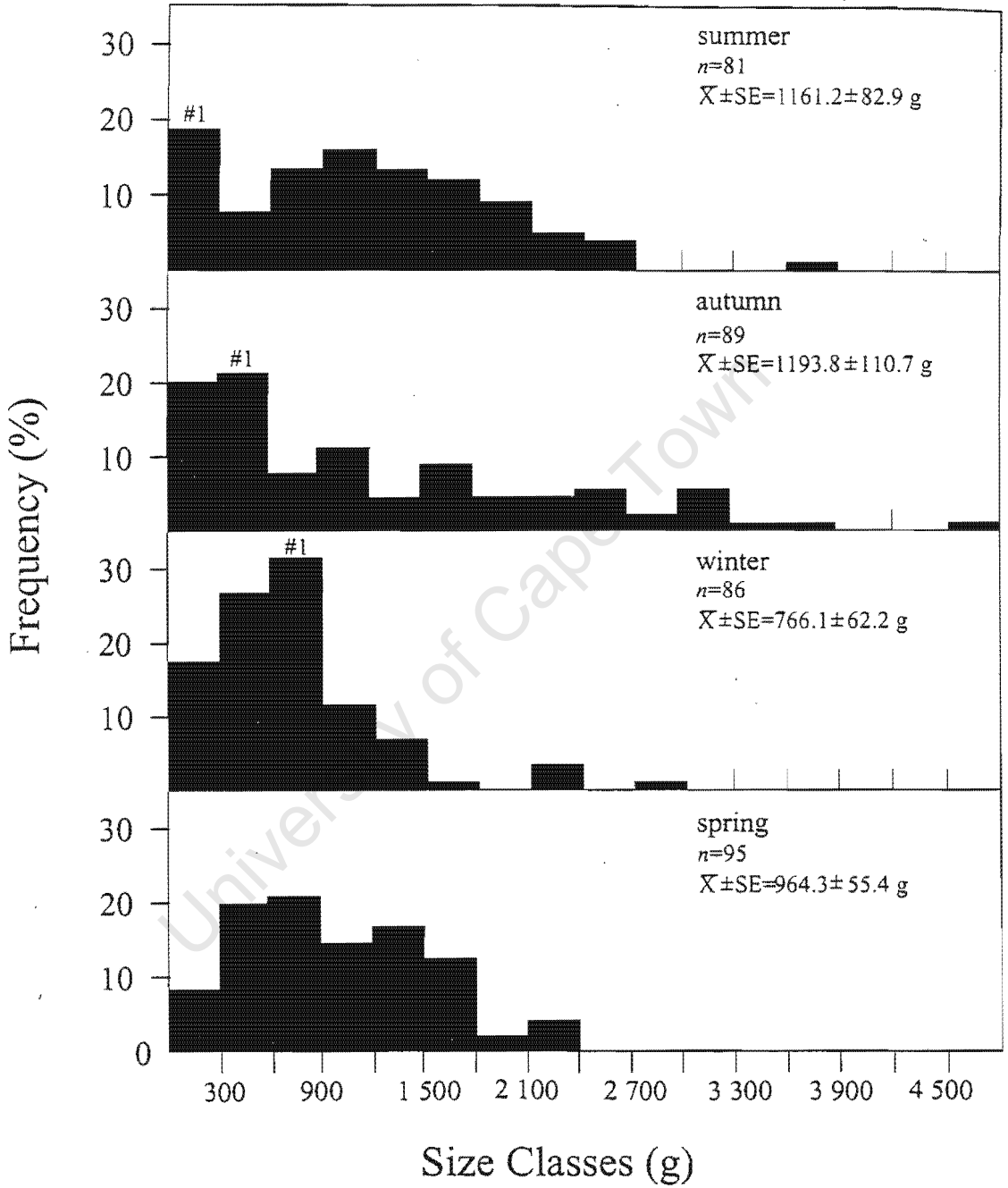


Fig. 3.4 *Octopus vulgaris* size frequency distribution per season in False Bay, from February 1997 to January 1998. Seasonal growth in cohort is indicated by #1.

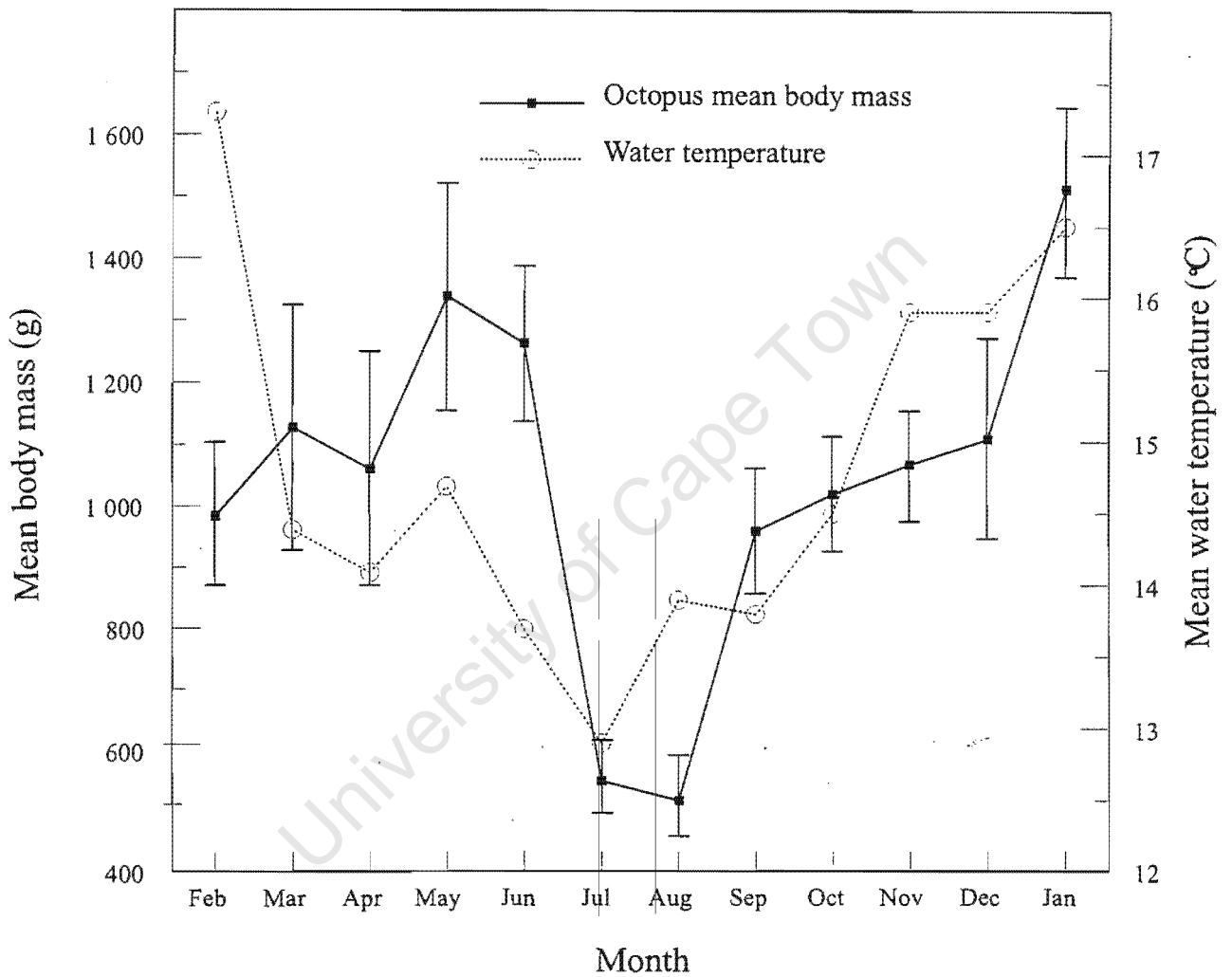


Fig. 3.5 Mean monthly body mass and associated SE of *O. vulgaris*, collected in False Bay, together with mean subsurface water temperature, measured at Boordjiesdrift, between February 1997 and January 1998.

Furthermore, recruitment (number of octopuses <300 g) was constant throughout the year except in spring, when recruitment was less than half that found in other seasons (Fig. 3.4).

Reproduction

Mating was observed on three occasions, once each in May, June and September. Male and female specimens cohabiting the same den were between 600 g and 900 g. Despite the similar sizes of cohabiting males and females the females were always immature. No individuals of the same sex were found cohabiting a den. Maturing females were found in all seasons, but mean GSI for female *O. vulgaris* peaked in spring and summer which coincided with warmer water in False Bay (Fig. 3.6).

DISCUSSION

Spatial distribution

O. vulgaris, like all benthic octopus species, is highly dependant on dens, which provide protection against predators (Ambrose 1982; Hartwick *et al* 1988; Aronson 1991; Mather *et al.* 1991). The necessity for dens probably arose in the course of evolution when cephalopod ancestors lost their shells (Aronson 1991), thereby reducing their defence against predators. Dens of *O. vulgaris* were found in all habitats within the kelp beds, but there appeared to be a preference for sheltering in boulder rubble. This is expected as shelters in boulder rubble habitats are easily modified to provide octopuses with the best protection (Anderson 1997). However, the proportion of octopuses sheltering in this habitat is probably over-estimated, as the sampling effort was more focused in this “good” habitat. Few octopuses were found sheltering in sand. The low preference for this habitat in the kelp bed is probably attributed to two factors. Firstly, sandy habitat areas were smaller than that of other habitat types. Secondly, other habitats provided better, more easily modified shelters.

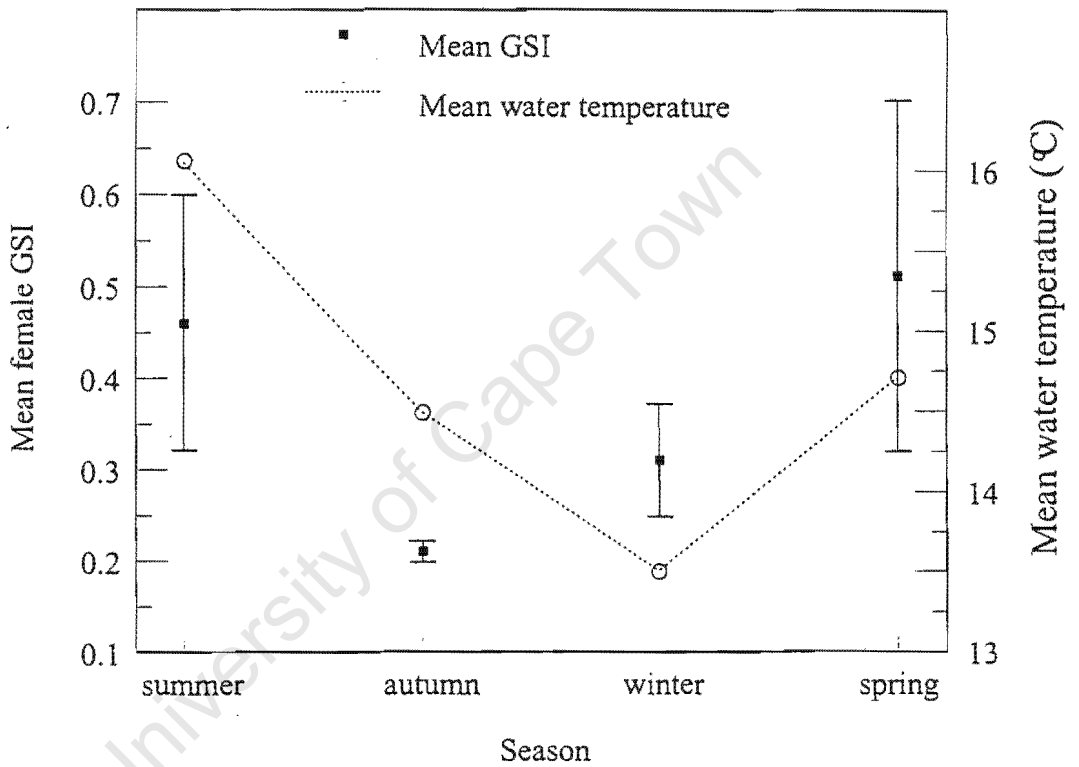


Fig. 3.6 Mean seasonal water temperature and mean female *O. vulgaris* GSI \pm SE. Total number of females examined from False Bay = 129. Number of females examined in summer =26, autumn =42, winter =33 and spring =31.

However in the absence of other habitats, *O. vulgaris* is known to be abundant on sand, as is found off the northwest coast of Africa, which consequently supports the largest trawl fishery for this species in the world (Hatanaka 1979a). This has also been observed in the deeper waters of False Bay (South African Navy divers, pers. obs.).

O. vulgaris larger than 300 g were largely found in dens during the day, as observed by Kayes (1974). Therefore these specimens are probably predominantly active at night, as stated by Kayes (1974), Mangold (1983) and Wells *et al.* (1983). However, this study showed that small (<300 g) octopuses do not conform strictly to this pattern, with a high proportion of small octopuses found outside of shelters during the day. This corresponds with the results of Mather & O'Dor (1991), who found juvenile *O. vulgaris* engaged in exploration and hunting during the day. Juveniles also had a significantly shallower depth distribution pattern than larger specimens. Mather (1994) also indicated that larger *O. vulgaris* were found further offshore than juveniles. Similarly, *O. dofleini* mean mass off Japan and Vancouver Island was shown to be significantly higher offshore than inshore (Kanamaru & Yamashita 1967 cited in Hartwick *et al.* 1978; Hartwick *et al.* 1988). In contrast to these studies, *Octopus tetricus* juveniles were found in deeper water and adults in shallow water (Anderson 1997). Differences between juvenile and adult distributions and their activity patterns may be an escape method used by juveniles to avoid contact with large octopuses, which are cannibalistic (see Chapter 4).

Seasonal population size structure

The lower mean mass in winter is attributed to fewer large male and female specimens being caught. This may be the result of natural male and female mortality. Also, if females were brooding during winter they may be more cryptic, heading deeper into reefs to lay eggs and hence not encountered in the sampling technique. Alternatively, the migration of large specimens offshore during winter and inshore during spring, summer and autumn would also affect the mean seasonal mass. This is supported by the close relationship between mean monthly body mass of the inshore population and mean monthly subsurface water temperature. Offshore - onshore migrations of octopus have been suggested for other *O. vulgaris* populations (Hatanaka 1979a; Guerra 1981; Mangold-Wirz 1963 cited in Mangold 1983; Whitaker *et al.* 1991), *O. dofleini* (Kanamaru *et al.* 1969 cited in Hartwick *et al.* 1978; Hartwick *et al.* 1984) and *O. tetricus* (Anderson 1997). Suggested reasons for these migrations include drastically reduced inshore salinities (Hartwick *et al.* 1984), changes in prey abundance (Paust 1988), higher offshore temperatures (Whitaker *et al.* 1991), and difference in habitat preference between juvenile and adult octopus (Anderson 1997). However, if offshore - onshore migration occurs in False Bay the reasons for this can not be distinguished due to a lack of information on the population dynamics and diet of deeper-water specimens.

The data also indicate the possibility that the population within the kelp bed consists of two components: a migrating component (generally octopuses larger than 900 g) and a resident inshore component (generally octopuses smaller than 900 g). A migrating and non-migrating component has also been suggested for a shallow northeast Pacific *O. dofleini* population (Hartwick *et al.* 1984). Although seasonal population size structure is largely affected by the

migrating component, the resident component also affects the population size structure by growth within the population. Seasonal growth can be monitored for the first cohort (denoted by #1 in Fig. 3.4) from summer to winter. However, age cannot be inferred from these cohorts, because size is not a reliable indication of octopus age (Mangold & Boletzky 1973). Moreover, octopus do not have bone structures from which growth rings can be counted, hence most ageing techniques are inappropriate for octopus. However, growth lines in beaks of octopus (Raya & Hernandez-Gonzalez CIAC symposium 1997) may offer possible methods for estimating age.

Reproduction

O. vulgaris in False Bay is likely to mate throughout the year, as is the case for many other *O. vulgaris* populations (Wodinsky 1972; Smale & Buchan 1981; Guerra 1975 cited in Mangold 1983). Spawning is also likely to occur throughout the year, but mean female GSI values indicated an increase in reproductive activity in spring and summer. This is not in conflict with the time of mating, as female octopuses are known to store spermatophores for over three months until sexually mature (Wodinsky 1972). Coinciding spawning activity with higher water temperature is desirable as this would increase the growth rate of juveniles. Consequently, this may explain the presence of spawning peaks of *O. vulgaris* populations in temperate regions (Hatanaka 1979; Whitaker *et al.* 1991). In contrast, the apparent lack of definite spawning seasons in tropical and subtropical regions (Wodinsky 1972; Smale & Buchan 1981) are probably attributed to relatively constant water temperatures throughout the year. Hence, juvenile developmental time will be similar irrespective of spawning season.

In conclusion, the spatial distribution and population dynamics of *O. vulgaris* in False Bay are complex and influenced by octopus size and water temperature respectively. However, this study only investigated part of the octopus population inhabiting the kelp beds of False Bay. Thus, in order to gain a better understanding of the spatial distribution and population dynamics of the entire population further sampling is required on the offshore part of the range. The following chapter aims at distinguishing the best method of assessing octopus diet and the factors influencing diet of *O. vulgaris*.

University of Cape Town

CHAPTER 4

University of Cape Town

METHODS OF ASSESSING OCTOPUS DIET AND FACTORS INFLUENCING THE DIET OF *OCTOPUS VULGARIS*

INTRODUCTION

Octopuses are fast-growing animals, capable of eating large quantities of food (Augustyn & Smale 1989). Furthermore, a wide variety of prey items are consumed by octopus, including molluscs, crustaceans, polychaetes and fish (Hatanaka 1979; Ambrose & Nelson 1983; Ambrose 1984; Nixon & Budelmann 1984; Nixon 1987). Octopus diets have largely been assessed by gut content analysis, but various other methods of diet assessment are also used, including midden pile analysis, direct observations in the sea and laboratory studies (Nixon 1987). However, due to inherent biases, each method gives a different representation of octopus diets (Smale & Buchan 1981).

Diets also vary as a function of octopus species (see Chapter 1; Nixon 1987). Dietary studies (Nigmatullin & Ostapenko 1976; Guerra 1978 cited in Mangold 1983; Smale & Buchan 1981; Cortez *et al.* 1995) show octopus to be opportunistic predators, with diet often reflecting abundance of prey available. Consequently, depth and habitat type, which change prey communities, have been shown to be factors responsible for dietary shifts within octopus species (Ambrose 1984). Seasonality in octopus diets has also been shown for *Octopus mimus* (Cortez *et al.* 1995) and suggested for *O. vulgaris* (Smale & Buchan 1981). Despite sampling within a homogeneous habitat, individual octopus have been found to consume different proportions of prey items. This was partly attributed to the size (Nigmatullin & Ostapenko 1976; Smale & Buchan 1981) and state of maturity of the octopus (Cortez *et al.* 1995).

The aims of this chapter are firstly, to determine the diet of *O. vulgaris* in False Bay by three methods of diet assessment, namely field observations during the day, midden pile analysis and stomach content analysis. The results obtained by these methods are then compared to determine the best method of octopus dietary assessment. Secondly, the diet of *O. vulgaris* is compared between octopus size classes and seasons to determine the influence of these factors on octopus diet. Additional information on the prey size-selectivity of *O. vulgaris* on the abalone, *Haliotis midae*, is also provided, as it may be of importance to abalone fisheries in the southwestern Cape.

METHODS

Methods of octopus diet assessment

O. vulgaris was collected during the day as described in Chapter 1. Night sampling may have been a more suitable method of assessing the diet of *Octopus vulgaris* as this species is predominately nocturnal (Kayes 1974), but this was not possible due to various logistical problems. While sampling notes were made on what octopus were eating at time of capture. Furthermore, non-encrusted den remains were collected from midden piles and placed together with the occupant in a bag. Only non-encrusted remains were collected as these are considered to be fresh, thereby preventing the inclusion of previous inhabitant's prey (Smale & Buchan 1981). The frequency of occurrence of prey items observed being consumed in the field, found in midden piles, and in octopus guts (from Chapter 1) were compared as methods of octopus diet assessment. A contingency table was used to determine if there were significant differences between the frequencies obtained by these three methods of diet assessment.

Factors influencing octopus diet

Influence of octopus size on diet

The IRI values obtained in Chapter 1 for *O. vulgaris* were further broken down to three size classes, namely small (0-300 g), medium (301-1 000 g) and large (> 1 000 g), and plotted to determine if octopus diet is influenced by size.

Influence of season on octopus diet

Seasonality in diet was investigated for *O. vulgaris* caught at Windmill Beach, as it had the largest sample size. (Only one site was used to avoid possible site differences in the availability of prey items.) The diet of *O. vulgaris* was compared over two seasons, summer (September - February) and winter (March - August), to increase the sample size per season. IRI values (see Chapter 1) were then calculated per season and compared to determine seasonality in octopus diet.

Prey size selectivity

Additional data on prey size selectivity of *O. vulgaris* on *H. midae* were obtained by measuring the lengths of shells obtained from middens of octopuses of known sizes to the nearest 1 mm and plotting length-frequency distributions of abalone taken by three size classes of octopus. The size classes of octopus used were small (0-300 g), medium (301-1 000 g) and large (>1 000 g). An ANOVA was performed on the mean abalone shell length consumed by each size class of octopus to determine if significant differences existed between them. These data were further submitted to a Tukey test for unequal sample size to determine which octopus size classes differed significantly from the others.

RESULTS

Methods of octopus diet assessment

Field observations

Results of 29 day-time observations of octopus taking prey in the field are shown in comparison too those by other methods in Fig. 4.1. Observations of abalone and winkles being consumed were frequent, accounting for 58.6% and 20.7% of the observations respectively. However, the observation frequency of crustacean consumption was low. Large crustaceans accounted for 10.4% of the observations, whereas small crustaceans were completely absent. Teleosts accounted for only 3.5% of observations. Moreover, limpets, bivalves and polychaetes were never observed being consumed by *O. vulgaris* at time of capture.

Midden piles

Abalone, winkles, limpets and bivalves were frequently found in midden piles, occurring in 55.8%, 40.3%, 37.9% and 23.8% of all midden piles respectively (Fig. 4.1). Similarly to field observations, the frequency of occurrence of crustaceans was also low. Large crustaceans occurred in 22.3% of octopus dens, whereas small crustaceans were absent. Furthermore, frequency of occurrence of octopus (0.5%), polychaetes (1.0%) and teleosts (1.0%) found in midden piles were low.

Gut contents

In contrast to the previous methods, gut contents showed a higher frequency of occurrence of large and small crustaceans, polychaetes and teleosts, occurring in 41.2%, 33.7%, 10.6% and 10.6% of octopus guts respectively (Fig. 4.1).

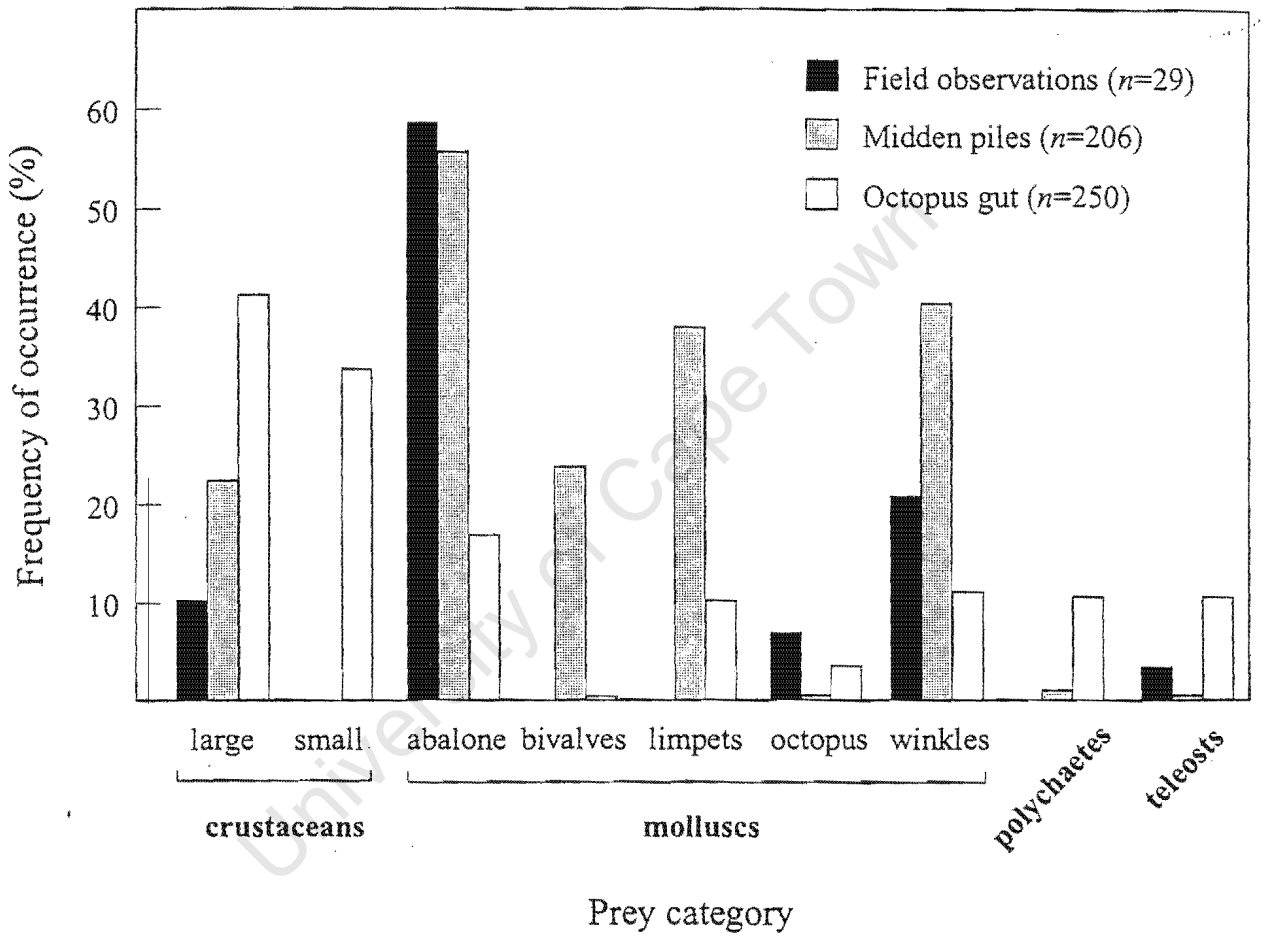


Fig. 4.1 Dietary assessment of *O. vulgaris* in False Bay based on three methods: field observations, midden piles and gut content. Comparisons were made using frequency of occurrence of prey items in each method.

However, in relation to the other methods, molluscs had a lower frequency of occurrence in octopus guts, being 16.9% for abalone, 10.2% for limpets, 0.4% for bivalves and 11.1% for winkles.

A 3*3 contingency table showed that there was a significant difference in the frequency of occurrence of crustaceans, molluscs and other prey items (polychaetes and teleosts) obtained by each method of diet assessment ($\chi^2=238.4$, $df=4$, $p<0.0001$). Raw dietary data obtained by each method of diet assessment are included in Appendix 4.1.

Factors influencing octopus diet

Influence of octopus size on diet

Diets of small, medium and large octopuses are compared in Fig. 4.2 & Table 4.1. The diet of small *O. vulgaris* was dominated by one category, namely small crustaceans (87.4% of the total IRI) (Fig. 4.2). This prey category consisted of high numbers of megalopa larvae (63%). The only other components making up >1% of the diet were large crustaceans, winkles and abalone, contributing 6.8%, 3.1% and 1.3% of the total IRI respectively (Fig. 4.2). Forty-five percent of the total number of large crustaceans consumed was made up of the hermit crab *Paguristes gamianus*, followed by the crab *Plagusia chabrus* (11.1 %).

In contrast to small specimens, medium and large octopuses largely ate three prey categories (Table 4.1 & Fig. 4.2). Medium-sized octopuses consumed mainly small crustaceans (34.6 % of total IRI), followed by *H. midae* (32.9%) and large crustaceans (18.4%) (Fig. 3.2). Megalopa larvae were once again the most abundant small crustaceans (68%). However, *P. gamianus* only accounted for 16.7% of the total number of large crustaceans consumed,

compared to *P. chabrus* which now accounted for 66.6%. Other prey categories of note were polychaetes and limpets, accounting for 7.9% and 3.2% of total IRI respectively (Fig. 3.2).

The diet of large *O. vulgaris* was dominated by the same three prey categories as medium *O. vulgaris*, but large crustaceans (33.8% of total IRI) were now more important than small crustaceans (28.9%) and *H. midae* (23.2%) (Fig. 4.2). *P. chabrus* accounted for 70.4% of the total number of large crustaceans and megalopa larvae accounted for 86.9% of the total number of small crustaceans. Other important prey categories were teleosts and octopuses themselves, comprising 6.0% and 3.7% of total IRI respectively (Fig. 4.2).

Influence of season on octopus diet

Since the diet of *O. vulgaris* was influenced by octopus size, the seasonal dietary data were further divided into small, medium and large size classes (Table 4.2).

Megalopa larvae were not an important dietary component in summer, comprising 5.0% of the total IRI of small, 0% of medium and 0.8% of large octopuses (Fig. 4.3). However, in winter these values increased to 63.3%, 21.4% and 12.0% respectively (Fig. 4.3). A similar trend was found for octopus, which was not eaten in summer, but accounted for 1.9% and 14.6% of the total IRI in winter for medium and large octopuses respectively (Fig. 4.3). In contrast, large crustaceans were more important in the diet of small and large octopuses in summer, accounting for 66.9% and 54.4% of the total IRI respectively. These values were considerably lower in winter, contributing 0% and 28.3% of the total IRI respectively. Similarly, the percentage IRI of abalone was high in summer, accounting for 28.1% of medium octopuses and 14.1% of large octopuses, but low in winter comprising 4.6 % and 3.9 % respectively.

Table 4.1 Diets by major prey category for 0-300 g, 301-1 000 g and >1 000 g size classes of *O. vulgaris* from False Bay.

Large and small crustaceans are defined in text. %n = percentage of the total number of all prey items found in octopus guts. %v = percentage of the total volume of all prey items found in octopus guts. %f = percentage frequency of occurrence of prey item in octopus guts. IRI = %f * (%n + %v).

Prey category	Octopus size class											
	0-300 g (n=54)				301-1 000 g (n = 87)				> 1 000 g (n=109)			
	% n	% v	% f	IRI	% n	% v	% f	IRI	% n	% v	% f	IRI
Crustaceans												
Large crustaceans	6.0	14.7	37	766	14.4	8.9	35.6	832	22.2	17.7	30.3	1 210
Small crustaceans	78.4	50.3	76	9 781	48.4	6.3	28.7	1 570	47.9	4.4	19.7	1 029
Unidentified	0.4	0.2	6.5	4	0.9	0.2	4.5	5	2.3	0.5	5.7	16
Molluscs												
Abalone	1.4	21.1	6.5	146	9.8	55.1	23	1 492	7.8	40.9	17	828
Limpets	1.8	4.5	10.9	69	5.6	7.2	11.5	147	2.7	3.9	7.3	48
Winkles	7.1	3.8	31.4	342	7.9	1.2	9.0	82	0.8	0.1	1.8	2
Bivalves	0	0	0	0	0.5	0.2	1.1	1	0.4	0.4	0.9	1
Octopus	0	0	0	0	0.5	3.1	1.1	4	2.7	21.2	5.5	132
Unidentified	0.4	0.2	2.2	1	1.4	1.6	3.4	10	1.2	0.7	2.8	5
Polychaetes	2.8	4.1	8.7	60	7.9	14.9	15.7	358	5.1	4.3	8.7	82
Teleosts	1.8	1.1	8.7	25	2.8	1.3	7.9	33	7.0	5.9	16.5	214

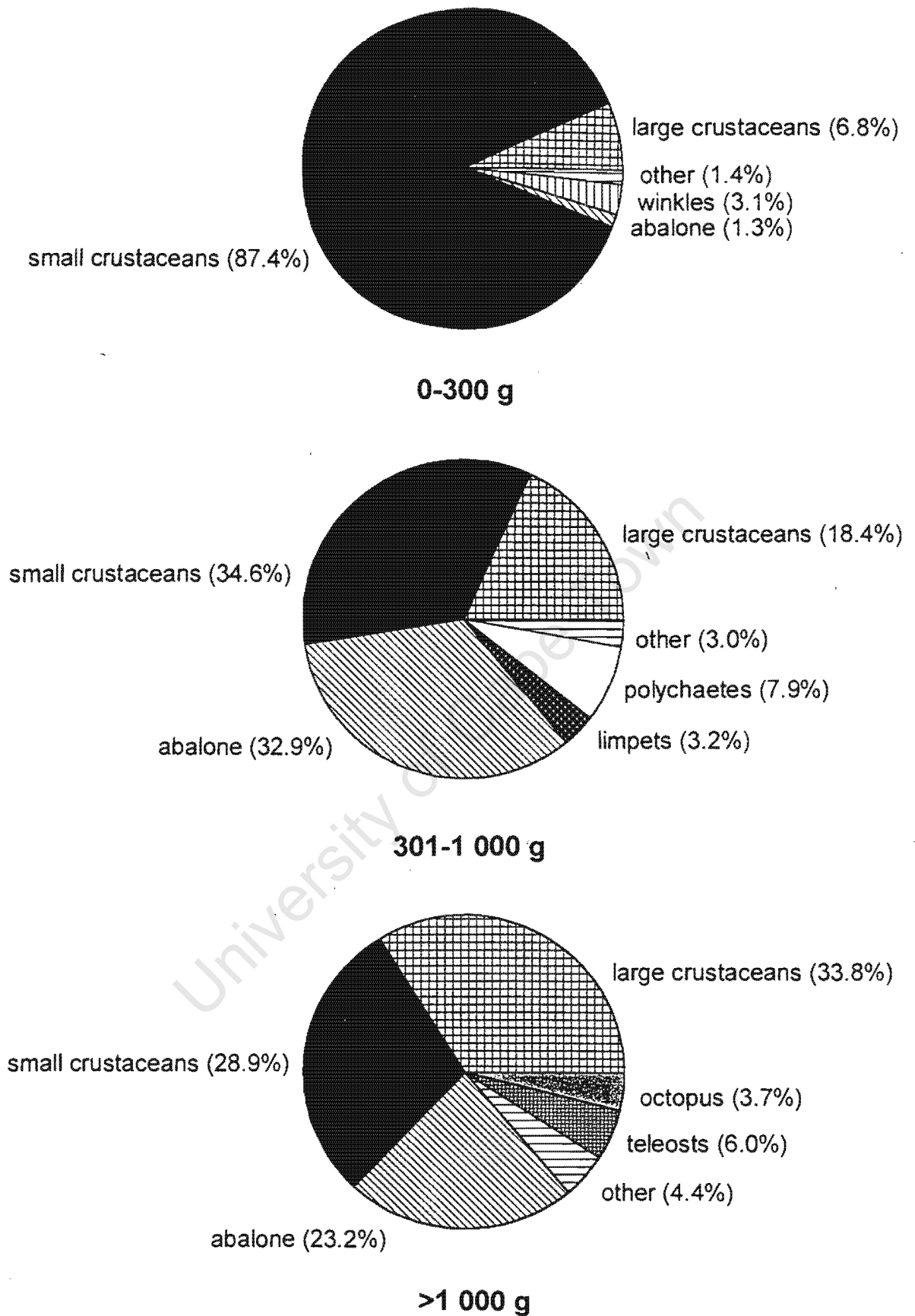


Fig. 4.2 Diets using percentage IRI for 0-300 g, 301-1 000 g and >1 000 g size classes of *O. vulgaris* in False Bay. See Table 4.1 for numerical calculations of IRI values. All IRI values less than 100 were grouped as "other".

Table 4.2 Seasonal diet by major prey category for 0-300 g, 300-1 000 g and >1 000 g size classes of *O. vulgaris* from Windmill Beach. Large and small crustaceans are defined in text. %n = percentage of the total number of all prey items found in octopus guts. %v = percentage of the total volume of all prey items found in octopus guts. %f = percentage frequency of occurrence of prey item in octopus guts. IRI = %f * (%n + %v). summer = September - February and winter = March - August.

Prey category	0-300g							
	Summer (n=12)			IRI	Winter (n=7)			IRI
	% n	% v	% f		% n	% v	% f	
Crustaceans								
Large crustaceans	32.5	65.3	58.3	5 706	0.0	0.0	0.0	0
Megalopa larvae	20.0	5.3	16.7	422	65.2	74.1	42.9	5 969
Other small crustaceans	35.0	13.3	25.0	1 208	13.0	7.4	28.6	584
Molluscs								
Abalone	0.0	0.0	0.0	0	0.0	0.0	0.0	0
Octopus	0.0	0.0	0.0	0	0.0	0.0	0.0	0
Other	12.5	16.0	41.7	1 187	21.7	18.5	71.4	2 875
Prey category	301-1 000 g							
	Summer (n=9)			IRI	Winter (n=16)			IRI
	% n	% v	% f		% n	% v	% f	
Crustaceans								
Large crustaceans	25.0	6.7	33.3	1 057	11.1	13.1	31.3	756
Megalopa larvae	0.0	0.0	0.0	0	43.1	8.4	25.0	1 285
Other small crustaceans	0.0	0.0	0.0	0	29.2	4.2	31.3	1 042
Molluscs								
Abalone	25.0	48.9	33.3	2 645	2.8	19.5	12.5	279
Octopus	0.0	0.0	0.0	0	1.4	16.7	6.3	113
Other	50.0	44.3	55.6	5 241	12.5	38.2	50.0	2 533
Prey category	>1 000 g							
	Summer (n=23)			IRI	Winter (n=25)			IRI
	% n	% v	% f		% n	% v	% f	
Crustaceans								
Large crustaceans	32.7	31.7	60.9	3 915	16.7	13.8	52.0	1 586
Megalopa larvae	12.2	0.4	4.3	55	50.9	5.1	12.0	673
Other small crustaceans	22.4	0.2	8.7	197	7.4	1.0	20.0	169
Molluscs								
Abalone	8.2	50.2	17.4	1 014	2.8	15.5	12.0	219
Octopus	0.0	0.0	0.0	0	3.7	47.5	16.0	819
Other	24.5	17.6	47.8	2 012	18.5	17.0	60.0	2 133

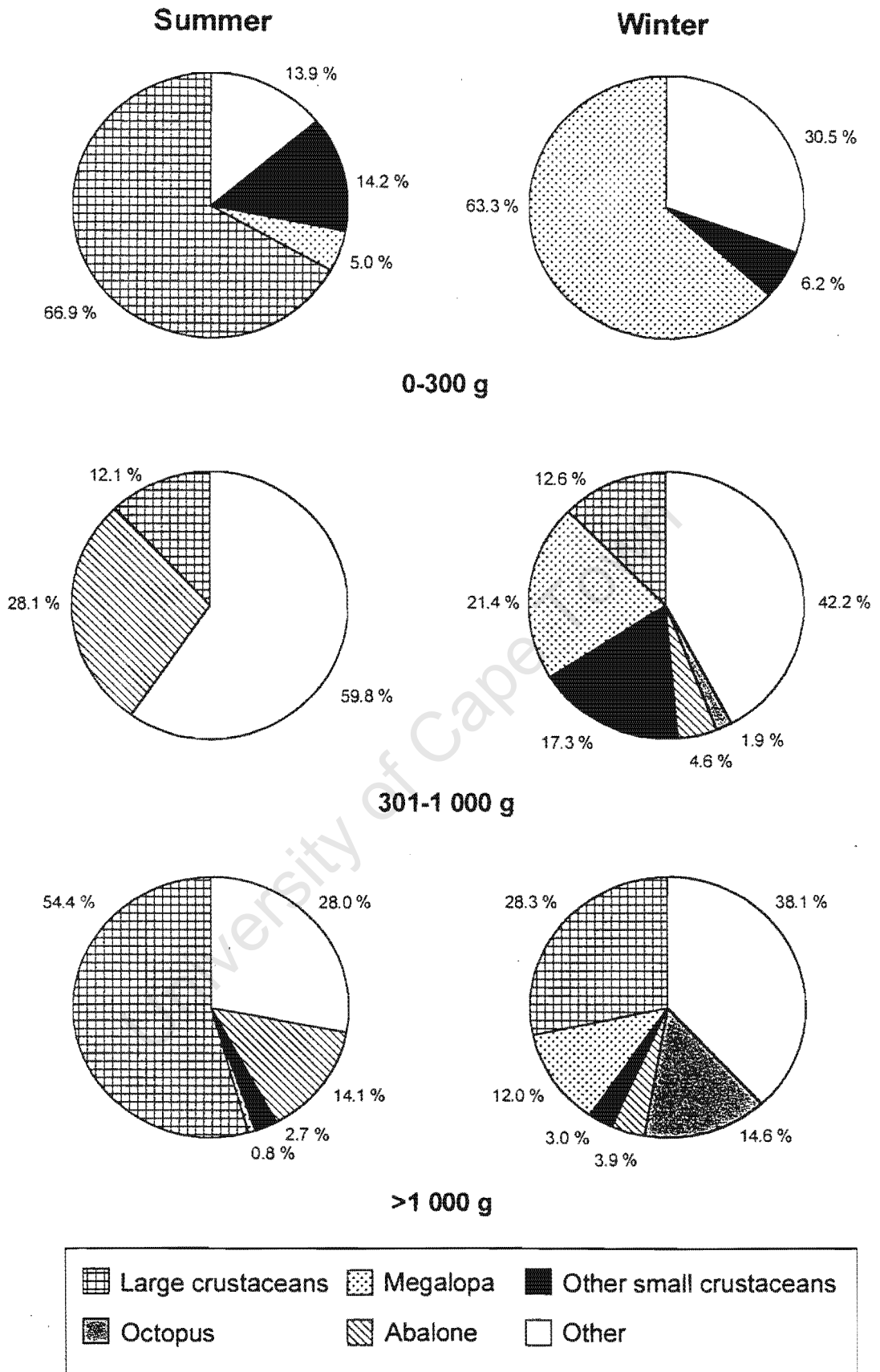


Fig. 4.3 Diets using percentage IRI for small (0-300 g), medium (301-1 000 g) and large (>1 000 g) *O. vulgaris* from Windmill Beach, during summer (September - February) and winter (March - August). See Table 4.2 for calculation of IRI values.

Prey size selectivity

Midden piles revealed that *O. vulgaris* consumed *H. midae* of shell lengths ranging from 30-131 mm (Fig. 4.4). There was a significant difference between the mean shell length of *H. midae* consumed by each size class of *O. vulgaris* (ANOVA: $F_{268}=23.71$; $p<0.0001$): the mean shell length of *H. midae* (mean=53.3 mm) consumed by small specimens was significantly smaller than that taken by medium (mean=72.6 mm, $p<0.01$) and large (mean=86.0 mm, $p<0.0001$) specimens. Medium octopuses also consumed significantly smaller ($p < 0.01$) *H. midae* than large specimens.

DISCUSSION

Methods of octopus diet assessment

Field observations

The number of octopuses found consuming prey during the day was low, which is likely a result of the nocturnal behaviour of *O. vulgaris* (Altman 1967; Kayes 1974). Moreover, the spectrum of prey items being consumed at time of capture was low, with small crustaceans, limpets, bivalves and polychaetes being absent. However, it is difficult to observe octopuses eating small crustaceans due to the small size of this prey. Hence, this category will always be under-represented by this method of diet assessment. Furthermore, more abalone than large crustaceans were being consumed at time of capture. This does not agree with the gut content analysis nor with previous prey preference studies (Takai 1941 cited in Nixon 1987; Mangold 1983), which show crabs to be an important and preferred component in the diet of *O. vulgaris*. Two reasons could explain this discrepancy. Firstly, abalone is one of the largest prey items of *O. vulgaris* in terms of volume, therefore octopuses would take a longer time to consume this prey than most other prey types. Hence, the probability of encountering octopuses feeding on abalone will be higher than other prey items. Secondly, the high

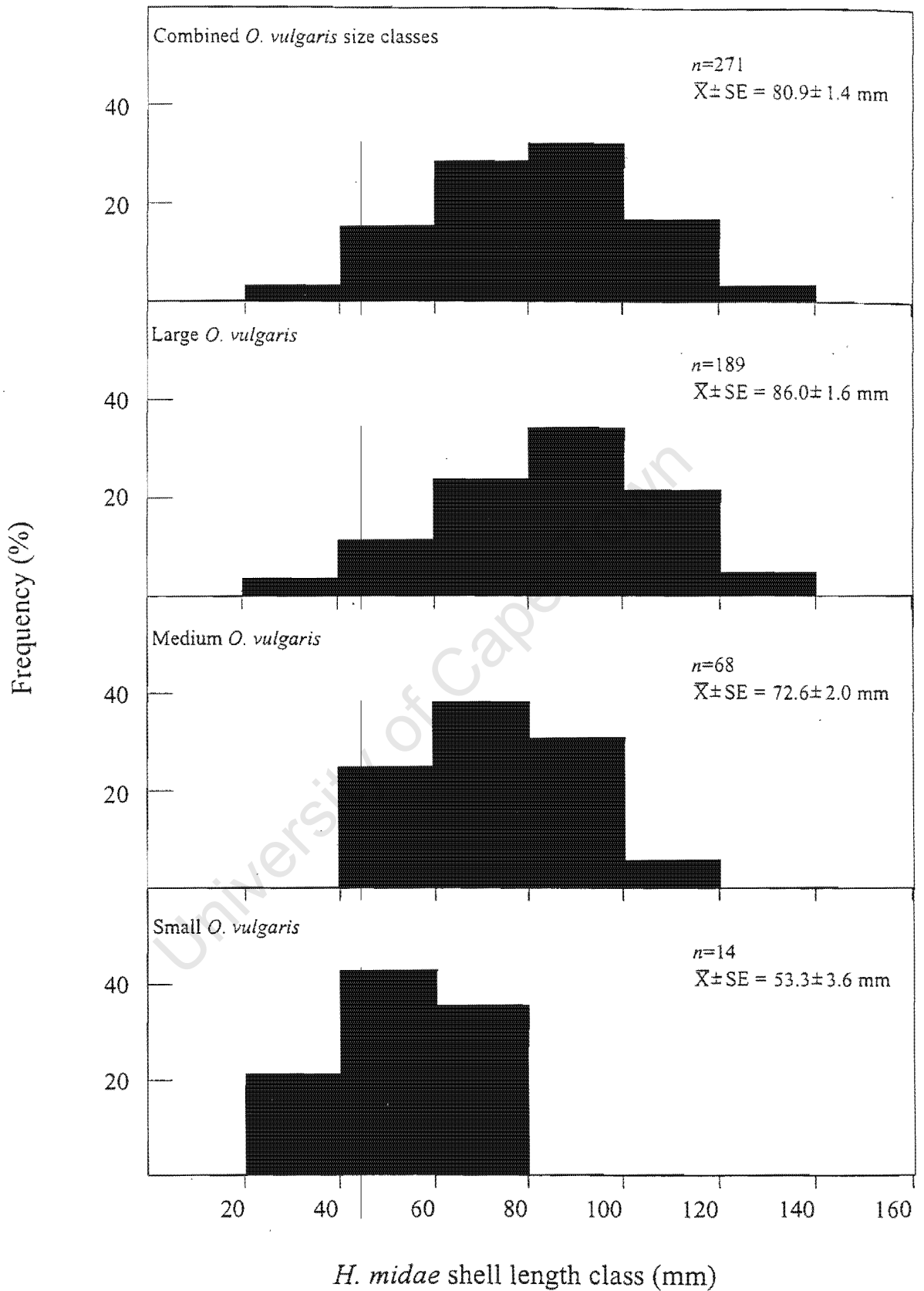


Fig. 4.4 Frequency distribution of shell length classes of *H. midae* found in dens occupied by small (0-300 g), medium (301-1 000 g) and large (>1 000 g) *O. vulgaris* in False Bay.

numbers of abalone consumed compared to the low number of crustaceans, polychaetes and teleosts consumed during the day may be due to *O. vulgaris* feeding predominately on the former during the day and the latter at night. Circumstantial evidence in support of this was the state and position of prey items in the gut of *O. vulgaris*. Since I only sampled by day, night-caught prey should have been at a more advanced state of digestion than day-caught prey. The remains of crustaceans, polychaetes and teleosts in the gut of *O. vulgaris* collected during the day usually included only skeletal fragments, setae, scales and bones respectively, indicating that they had been well digested, whereas the flesh of molluscs present in guts was generally not well digested. Furthermore, non-molluscan remains were more frequently found in the midgut (stomach) and hindgut (intestine) than the foregut (crop) of octopuses, whereas molluscan remains were more often found in the foregut than in the midgut and hindgut. Nigmatullin & Ostapenko (1976) also suggested that the prey spectrum of *O. vulgaris* changes between day and night. However, they thought that molluscs and crustaceans were predominately consumed during the day, and polychaetes and teleosts at night. However, additional nocturnal sampling and a determination of gut-passage times of various prey items would be necessary for conclusive proof.

Midden piles

This method revealed a larger prey spectrum than direct observations, but small crustaceans were still absent and the frequency of occurrence of octopus, polychaetes and teleosts was low. These prey categories, however, are seldom found in midden piles because they are consumed whole by octopuses (pers. obs.) and their remains are likely to decompose rapidly if deposited in a midden. Furthermore, shelled molluscs (abalone, winkles, limpets and bivalves) were frequently found in midden piles. These remains probably accumulate in dens as they are not easily decomposed or removed by currents and wave action (Ambrose

1983; Mather 1991). Whole carapaces of large crustaceans were also frequently found in midden piles, but these remains were always fresh, indicating a short residence time of approximately one day. The short residence time is due to the light weight of these remains. Consequently, they are easily removed by wave action, currents and scavengers.

Gut contents

Gut contents revealed the largest spectrum of prey items consumed by *O. vulgaris*. The high frequency of occurrence of large crustaceans also corresponded to previous prey preference studies showing crabs to be the most preferred prey item of *O. vulgaris* (Takai 1941 cited in Nixon 1987; Mangold 1983). Furthermore, this was the only method that showed the importance of small crustaceans, polychaetes and teleosts in the diet of octopuses. However, sampling was conducted during the day which may further under-represent polychaetes, teleosts (Nigmatullin & Ostapenko 1976) and possibly crustaceans (from day-time field observations), as these may be consumed predominately at night. Furthermore, different gut-passage rates will bias this technique: prey items with slow passage times are expected to be overestimated in the diet and, conversely, prey items with fast passage times are expected to be underestimated in the diet.

Factors influencing octopus diet

Influence of octopus size on diet

A wider range of prey types was eaten by larger octopuses. This agrees with the findings of Smale & Buchan (1981). Small octopuses predominately ate small crustaceans, which is similar to the diet of juvenile *O. vulgaris* in Bermuda (Mather & O' Dor 1991) and off the northwest coast of Africa (Nigmatullin & Ostapenko 1976). In contrast to the diet of small

octopuses, large crustaceans and abalone increased in importance in larger octopus diets. This is probably attributed to larger octopuses being more experienced in hunting and handling larger and/or more mobile prey. This was further supported by the increased importance of *P. chabrus*, which was the largest and most robust crab found in the diet of *O. vulgaris*, and of teleosts, in the diets of larger octopuses. Cannibalism was only found in octopuses larger than 1 000 g, and the victims were always smaller than 300 g. Thus, cannibalism is only expected to occur when octopus of very different sizes come into contact with each other. This phenomenon has been previously reported for *O. dofleini* (Hartwick, Thorarinsson & Tulloch 1978 cited in Nixon 1987), *O. magnificus* (Villanueva 1993) and *O. vulgaris* (Smale & Buchan 1981).

Influence of season on octopus diet

The increase in importance of megalopa larvae in the diet of small, medium and large octopuses in early winter probably reflects a seasonal increase in the abundance of this prey item. This is further supported by winter being the post-breeding season of *P. chabrus* (Le Roux 1991). Cannibalism was also most often found in early winter (March - May) in medium and large *O. vulgaris*. This corresponded to the highest frequency of occurrence of both large and small octopuses (Chapter 3), such that large octopuses have a higher probability of encountering octopuses small enough to be caught and consumed. Although IRI values indicated that large crustaceans and abalone are less important in the diet of octopuses in winter, it does not imply that less of these items were consumed in winter. On the contrary, there was no significant differences in the amount of large crustaceans and abalone consumed in summer and winter. The reason for the difference in IRI values is that higher numbers of megalopa larvae were consumed during winter, thereby reducing the percentage contribution of large crustaceans and abalone to the total number of prey items

consumed by *O. vulgaris* for this season. As a result, the IRI values for large crustaceans and abalone were reduced in winter. Thus the seasonality in diet of *O. vulgaris* appears to be largely influenced by its opportunistic predatory nature, reflecting fluctuations in prey abundance.

Prey size selectivity

To indicate prey size selectivity by octopuses feeding on abalone, two assumptions have to be made. Firstly, abalone shells in octopus dens are prey remains and not material used to modify the dens. As many octopuses were observed eating abalone in their dens (field observation), this assumption is most likely to be valid. Secondly, abalone shells collected from octopus dens are assumed to have been eaten by the inhabitant. Alternatively, if this is not the case, different inhabitants of a particular den must be assumed to be of a similar size. This is likely to be valid as den size and octopus size is closely related (Hartwick *et al.* 1978).

In addition to octopus size classes consuming different proportions of prey items, they also show prey size selectivity. The mean shell length and shell length range of *H. midae* consumed increased with the size of the octopus. This was also found for *O. vulgaris* feeding on the mussel, *Perna perna* (Smale & Buchan 1981). Unlike the high occurrence frequency of boreholes in molluscan shells reported by Nixon (1979), Ambrose & Nelson (1983) and Ambrose (1984), *H. midae* shells were seldom drilled (%f=3.4, n=236). This may be due to octopus being ineffective in drilling through thicker molluscan shells, as shown by Ambrose, Leighton & Hartwick (1988). The lack of boreholes in *H. midae* shells indicates that octopus probably removed this prey species by force. As strength increases with octopus size, it would explain why larger octopuses were capable of removing and hence consuming larger *H. midae*.

It is note-worthy that shells of *H. midae* less than 20 mm in length were not found in the dens of *O. vulgaris*. Abalone less than 20 mm are probably protected against octopus predation, as they are usually found sheltering under sea urchins (Day 1998). However, it is also conceivable that these shells are light enough to be removed from midden piles by currents.

In conclusion, though gut content analysis involves the killing of octopuses, it still provides the best method of dietary assessment. This technique is also useful for other octopus species, such as *O. magnificus*, which occur too deep for field observations. Moreover, some octopus species do not leave midden piles, such as *A. schultzei* (pers. obs.) and *O. bimaculatus* (Ambrose 1983). However, gut content analysis can be improved upon if sampling is conducted during the night as well, thus eliminating the problem of *O. vulgaris* feeding on different prey items during the day and night. Diet of octopuses was shown to be influenced by size and season. Variability of prey items consumed increased with octopus size, which was attributed to large octopus being more experienced and physically capable of hunting and handling larger and/or more mobile prey. Seasonality in diet was considered to be influenced by the opportunistic nature of *O. vulgaris*, reflecting seasonal fluctuations in prey abundance. Furthermore, prey selection by *O. vulgaris* was evident, with larger octopuses consuming larger abalone. This was credited to the increase in strength as octopus size increases.

To complete this study of the trophic relationships of *O. vulgaris* in the southwestern Cape, the important predators of the benthic stage of octopus themselves are presented in Chapter 5, with special reference to possible consequences of non-fatal attacks on octopuses.

Appendix 4.1 Raw dietary data of *O. vulgaris* in False Bay based on three methods: stomach contents, midden piles and field observations. Number of octopuses consuming prey at time of capture =29, number of dens with remains =206 and number of octopuses with food in gut =250.

Prey categories	Dietary assessment methods					
	Field observations		Midden piles		Stomach contents	
	% occ.	no.	% occ.	no.	% occ.	no.
CRUSTACEANS						
Large crustaceans						
<i> Jasus lalandii</i>	-	-	1.0	2	0.8	2
<i> Paguristes gamianus</i>	-	-	-	-	5.2	16
<i> Plagusia chabrus</i>	6.9	2	20.4	50	24.8	75
Other crabs	3.5	1	1.9	4	11.2	26
Small crustaceans						
Amphipods (<i> Paramoera capensis</i>)	-	-	-	-	7.6	69
Other	-	-	-	-	6.8	57
Isopods	-	-	-	-	2.0	15
Megalopa larvae	-	-	-	-	18.0	256
Other crustaceans						
<i> Austromegabalanus cylindricus</i>	-	-	0.5	1	-	-
MOLLUSCS						
Abalone						
<i> Haliotis midae</i>	58.6	17	55.3	287	17.2	47
<i> Haliotis spadicea</i>	-	-	0.5	1	0.4	1
Bivalves						
<i> Choromytilus meridionalis</i>	-	-	12.1	52	0.4	1
<i> Donax serra</i>	-	-	1.0	2	-	-
<i> Dosinia lupinsus orbigny</i>	-	-	1.0	2	-	-
<i> Lutraria lutraria</i>	-	-	4.9	22	0.4	1
<i> Macoma litoralis</i>	-	-	0.5	1	-	-
<i> Mytilus galloprovincialis</i>	-	-	6.8	17	-	-
<i> Tivela compressa</i>	-	-	0.5	2	-	-
<i> Venurupis corrugatus</i>	-	-	0.5	1	-	-
<i> Venus verrucosa</i>	-	-	3.9	9	-	-
Limpets						
<i> Dendrofissurella scutellum</i>	-	-	1.0	2	-	-
<i> Patella barbara</i>	-	-	4.4	14	-	-
<i> P. cochlea</i>	-	-	0.5	1	-	-
<i> P. compressa</i>	-	-	28.6	120	-	-
<i> P. granularis</i>	-	-	0.5	1	-	-
<i> P. longicosta</i>	-	-	1.9	4	-	-
<i> P. miniata miniata</i>	-	-	9.2	28	-	-
<i> P. tabularis</i>	-	-	2.9	7	-	-
Unidentified	-	-	-	-	10.0	25
Octopus						
<i> Aphrodoctopus schultzei</i>	-	-	-	-	0.4	1
<i> Octopus vulgaris</i>	6.9	2	-	-	2.8	7
Winkles						
<i> Oxystele sinensis</i>	6.9	2	12.1	29	6.8	22
<i> Gibbula zonata</i>	13.8	4	1.0	0.5	2.0	5
<i> Turbo cidaris</i>	-	-	31.1	110	2.4	6
<i> T. sarmaticus</i>	-	-	1.0	2	-	-
Other molluscs						
<i> Burnepena lagenaria</i>	-	-	0.5	1	-	-
<i> Choronia lampas pustulata</i>	-	-	1.0	2	-	-
<i> Conus mozambicus mozambicus</i>	-	-	0.5	1	-	-
<i> Cymatium cutaceum africanum</i>	-	-	1.0	2	-	-
<i> Phalium labiatum zeylanicum</i>	-	-	2.0	1	-	-
<i> Phyllodesmium serratum</i>	-	-	-	-	0.4	1
<i> Tambja capensis</i>	-	-	-	-	0.4	1
<i> Volvarina zonata</i>	-	-	-	-	0.4	1
POLYCHAETES						
Errantia spp.	-	-	-	-	7.6	26
Sedentaria spp.	-	-	1.0	2	3.2	12
TELEOSTS						
Unidentified	3.5	1	0.5	1	11.2	28
OTHER						
<i> Parechinus angulosus</i>	-	-	1.9	4	-	-

CHAPTER 5

University of Cape Town

PRELIMINARY INVESTIGATIONS ON THE POSSIBLE CONSEQUENCES OF NON-FATAL ATTACKS ON OCTOPUS

INTRODUCTION

Octopuses are preyed upon by various animals, including jelly fish, squid and fish during the planktonic phase (Nigmatullin & Ostapenko 1976), and large fish, moray eels, sharks, seals, dolphins and sea otters (Kenyon 1965; Hartwick *et al.* 1988; Augustyn *et al.* 1989; Mather & O' Dor 1991) during the benthic phase. However, predation is highest during the planktonic stage, being estimated at more than 90 % of total mortality (Mangold 1983).

In the shallow waters (<20 m) of the southwestern Cape the most important predators of benthic octopuses are thought to be the Cape fur seal *Arctocephalus pusillus pusillus* (Lipinski 1990), red roman *Chrysoblephus laticeps* (Lechanteur unpublished data), catsharks *Haploblepharus edwardsii*, *H. pictus*, *Poroderma africanum* and *P. pantherinum* (Bertolini unpublished data), and octopuses themselves (Chapter 1). The importance of octopuses in the diets of these predators are summarized in Table 5.1. Red steenbrass *Petrus rupestris* (Branch *et al.* 1994) and red stumpnose *Chrysoblephus gibbiceps* (van der Elst 1993) also consume octopuses, but due to their low abundance in False Bay (Bennett 1991) they are not considered to be important predators of octopus in this region.

Table 5.1 The importance of octopus in the diet of several predators occurring in the southwestern Cape region. Diets are compared using %f - percentage occurrence frequency, %n - percentage number and %b - either percentage volume or biomass.

Octopus Predators	Study Area	Statistic			Source
		%f	%n	%b	
Seals:					
<i>Arctocephalus pusillus pusillus</i>	South coast of South Africa	5.1	1.0	7.4	Lipinski 1990
	West coast of South Africa	22.0	16.3	51.6	Lipinski 1990
Fish:					
<i>Chrysoblephus laticeps</i>	False Bay	19.6	-	33.7	Lechanteur unpub. data
<i>Haploblepharus edwardsii</i>	False Bay	0.8	0.5	3.9	Bertolini unpub. data
<i>H. pictus</i>	False Bay	3.2	2.8	2.6	Bertolini unpub. data
<i>Poroderma africanum</i>	False Bay	5.6	5.0	3.3	Bertolini unpub. data
	East coast of South Africa	10.0	10.0	42.3	Bertolini unpub. data
<i>P. pantherinum</i>	False Bay	9.1	7.7	4.9	Bertolini unpub. data
	East coast of South Africa	13.5	12.5	32.9	Bertolini unpub. data
Octopus:					
<i>Octopus vulgaris</i>	False Bay	3.5	1.2	16.5	Chapter 4

Attacks on octopuses can either be fatal or non-fatal. Signs of non-fatal attacks, such as missing arms and scarring, are common in many benthic octopus species, including *Octopus dofleini* (Hartwick *et al.* 1988), *Octopus digueti* (Voight 1992), *Octopus cyanea* (Forsythe & Hanlon 1997). However, no studies have established the identities of the predators inflicting such wounds. In the southwestern Cape, gut content analysis of *O. vulgaris*, *A. pusillus pusillus* (Lipinski. 1990) and *C. laticeps* (van der Elst 1993; Lechanteur pers. obs.) indicate that these predators mainly consume the entire octopus, therefore they are probably not responsible for the majority of octopus arm amputations. In contrast, catsharks, which are a common occurrence in the kelp beds of False Bay, have been observed to tear off pieces of meat by violent twisting of the entire body (Lechanteur pers. obs.). Hence, these are the most likely predators responsible for the majority of octopus arm amputations in the southwestern Cape.

Collection of *O. vulgaris* in False Bay (Fig. 1.4) showed that octopuses collected at Buffels Bay (Fig. 1.4) were smaller on average and experienced higher frequencies of arm amputation than octopuses caught at Windmill Beach and Miller's Point. The aims of this chapter are firstly to determine the prevalence of *O. vulgaris* arm amputations in False Bay and whether this type and severity of predation decreases with octopus size. Furthermore, evidence supporting catsharks as the most likely predators responsible for octopus arm amputations is investigated. Lastly, male gonadal somatic index (GSI), female GSI and volume of food consumed by octopuses at Windmill Beach, Miller's Point and Buffels Bay are investigated to explain octopus size differences between sites. These correlations are preliminary investigations on the possible consequences of non-fatal attacks on octopus.

METHODS

Prevalence and severity of *O. vulgaris* arm amputations

Arm amputation occurrence frequencies were scored for all *O. vulgaris* collected in the manner described in Chapter 1. These frequencies were further broken down and compared for small (0-300 g), medium (301-1 000 g) and large (>1 000 g) specimens. Furthermore, the severity of amputations were plotted per size class of *O. vulgaris*. The severity of amputations was categorised into three subjective classes: class 1 injuries - octopuses in which amputations of arms did not exceed 10% of total arm length, class 2 injuries - octopuses which had at least one arm amputated between 10%-90% of total arm length with no other amputations exceeding 90 % and, class 3 injuries - octopuses which had more than 90 % of at least one arm amputated.

Predators responsible for non-fatal attacks on octopus

To test whether catsharks were the main predators responsible for non-fatal attacks, mean catshark abundance was investigated and examined for a positive correlation with arm amputation frequency at the three sites - Windmill Beach, Miller's Point and Buffels Bay. The mean abundance of catsharks per site were obtained from four separate counts at each site between December 1997 - February 1998. Counting was done by placing bait in a meshed bag and deploying it on reef at approximately 4m depth. The bait bag was monitored for ten minutes and all catsharks observed near the bait bag during this time period were captured, identified and counted.

Possible consequences of non-fatal attacks on octopus

To explain differences in mean sizes of octopus between sites, mean adjusted male GSI, mean adjusted female GSI and mean volume of food consumed were correlated with mean mantle length (ML) of octopuses at the three sites. Adjusted GSI's were determined for octopus which were predated, by calculating the percentage of mass lost due to amputations and adjusting the body mass accordingly. The calculations were based on six amputations at 10%, 60% and 90% of total arm length which corresponded to class 1, 2 and 3 injuries respectively. The resultant mean amputational mass loss for one amputation in each category was 0.25%, 2.05% and 6.5% of the total body mass respectively. To determine the possible consequences of attacks on octopuses mean adjusted GSI's and mean food volume, in turn, were correlated with amputation frequency between the sites. Comparisons between sites were only made during months in which octopuses were collected from all sites, namely May - December.

Statistical Analysis

Contingency tables were used on all frequency of occurrence data to test for significant differences between categories. ANOVA tests were run on predator abundance, ML, male GSI, female GSI of *O. vulgaris* at Windmill Beach, Miller's Point and Buffels Bay to determine whether significant differences existed in these means between sites. *Post hoc* multiple comparisons were performed using a Tukey tests for unequal sample size (Statsoft 1996). All mass data used in ANOVA and Tukey tests were log transformed to improve normality and homoscedasticity (Zar 1984). Food volume obtained from octopus guts from each site was analysed by a Kruskal-Wallis ANOVA to determine if food volume of octopuses differed between sites.

RESULTS

Prevalence and severity of *O. vulgaris* arm amputations

Arm amputations occurred in 31.4% (n=341) of all *O. vulgaris* caught in False bay. These frequencies were significantly higher in small (0-300 g) and lower in large (>1 000 g) *O. vulgaris* ($\chi^2=6.3$, $df=2$, $p<0.05$). Amputations occurred in 42% of small, 32.8% of medium and 25.3% of large octopuses (Fig. 5.1).

Arm amputations were also significantly more severe in small *O. vulgaris* than in medium and large specimens ($\chi^2=20.8$, $df=4$, $p<0.01$). More than 80% of the amputations occurring in small octopuses were class 2 & 3 amputations, compared to only 40% and 21% in medium and large octopuses respectively (Fig. 5.2).

Predators responsible for non-fatal attacks on octopus

As predation decreases with octopus size only octopuses <1 000 g were used to compare amputation frequencies between sites. A significant difference was found in amputation frequency between sites ($\chi^2=19.27$, $df=2$, $p<0.01$), being significantly higher at Buffels Bay (63.6%) and lower at Windmill Beach (8.7%) (Fig. 5.3.a). Similarly, a significant difference in mean catshark abundance was found between the three sites (ANOVA $F_2=8.13$, $p<0.01$), abundances being significantly higher at Buffels Bay (mean=9.5) than at Windmill Beach (mean=4.5, $p<0.01$) or Miller's Point (mean=5.5, $p<0.05$) (Fig. 5.3.b). The catshark species that was largely responsible for these differences between sites was *P. africanum* (Table 5.2).

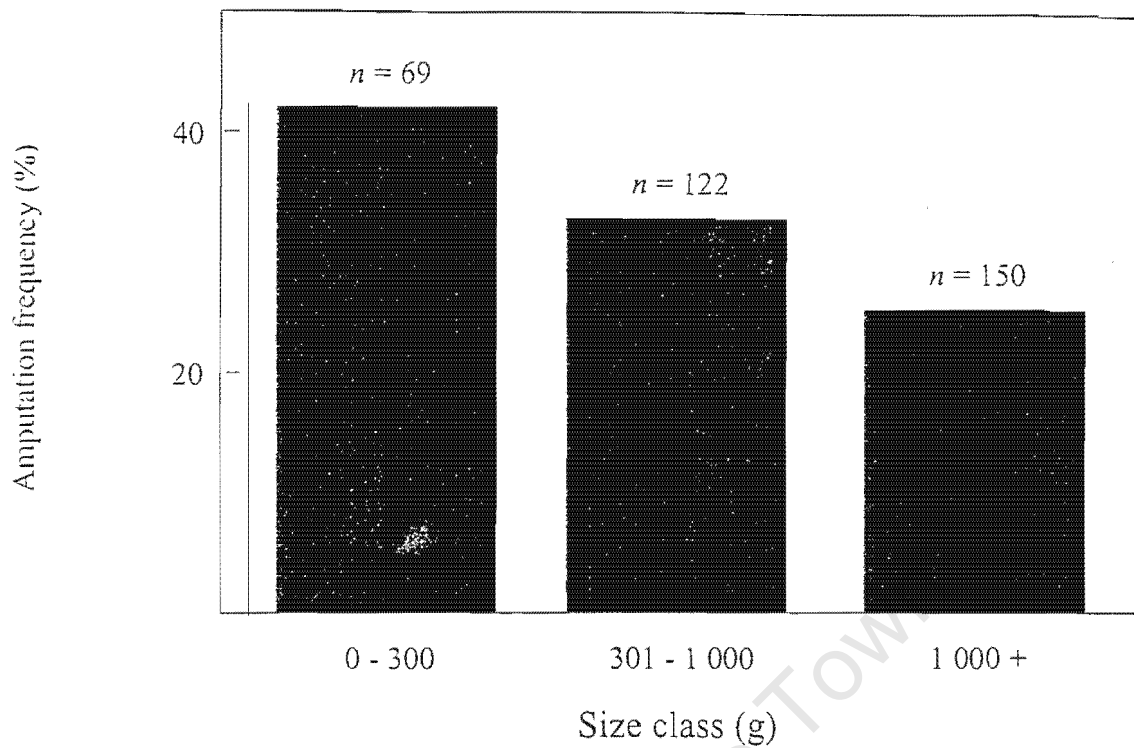


Fig. 5.1 Amputation occurrence frequency in small (0 - 300 g), medium (301 - 1 000 g) and large (> 1 000 g) *O. vulgaris*, caught in False Bay.

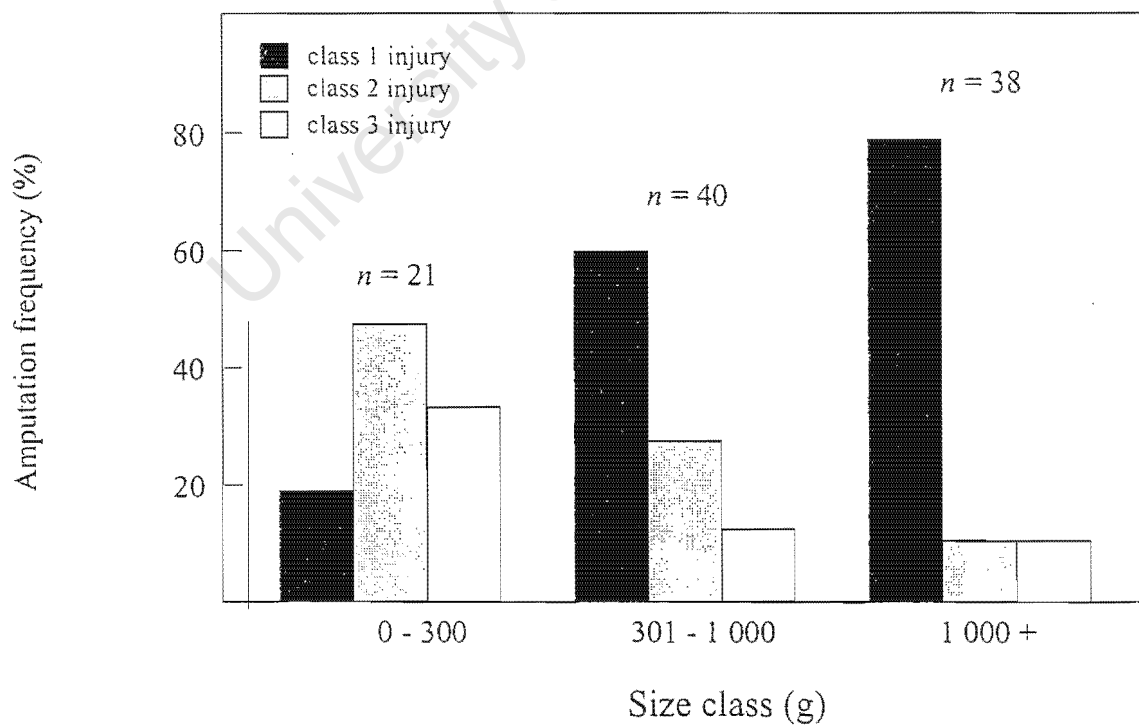


Fig. 5.2 Comparisons of the severity of amputations between small, medium and large *O. vulgaris*, caught in False Bay. Classes of amputation severity are defined in text.

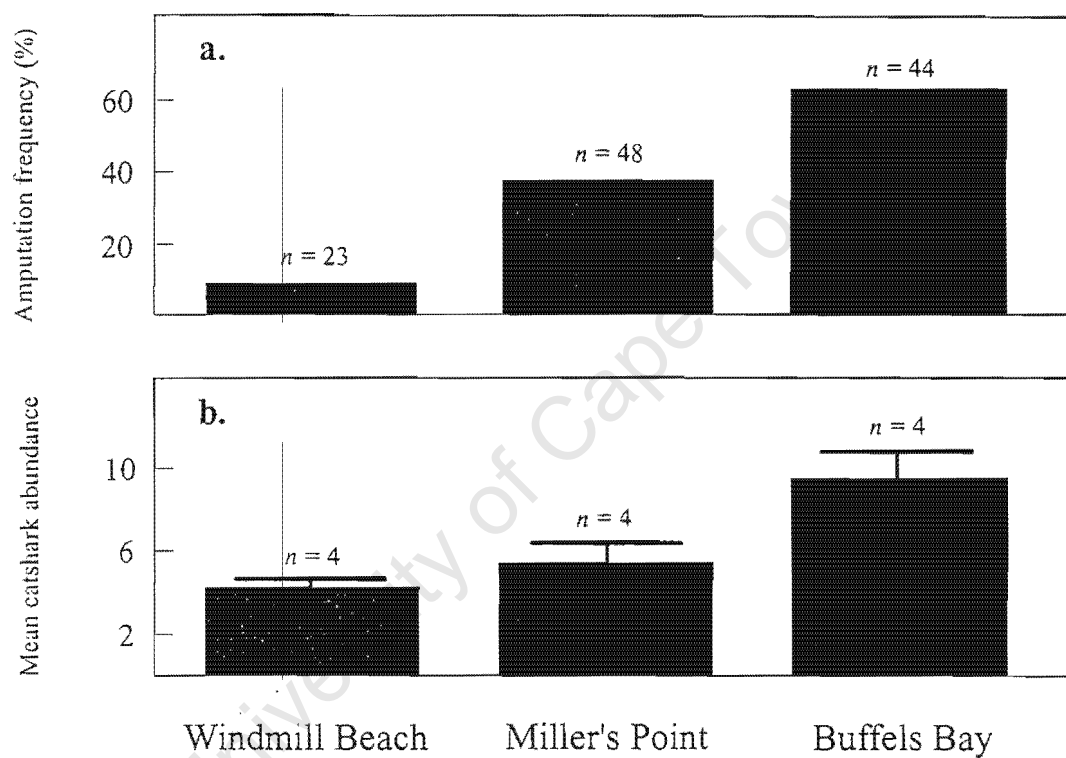


Fig. 5.3 a. Frequency of arm amputation sustained by *O. vulgaris* at the three False Bay sites.
b. Mean catshark abundances plus associated SE obtained at the three sites.

Table 5.2 Number of catsharks counted within ten minutes after deploying a baitbag at Windmill Beach, Miller's Point and Buffels Bay. Average counts were obtained from four separate counts at each site.

Site	Count No.	Catshark Species			Total catshark count
		<i>H. pictus</i>	<i>P. africanum</i>	<i>P. pantherinum</i>	
Windmill Beach	1	1	2	-	2
	2	2	2	1	3
	3	2	-	2	2
	4	2	3	1	4
	mean	1.8	1.8	1	2.75
Miller's Point	1	1	1	2	3
	2	1	5	1	6
	3	2	4	1	5
	4	2	2	-	2
	mean	1.5	3	1	4
Buffels Bay	1	1	5	2	7
	2	3	6	2	8
	3	2	8	2	10
	4	1	5	1	6
	mean	1.8	6	1.8	7.75

Possible consequences of non-fatal attacks on octopus

Mean octopus ML was significantly different between the three sites (ANOVA $F_{1,86}=24.31$, $p<0.00001$). Octopuses at Buffels Bay (mean ML=109.4 mm) were significantly smaller than octopuses at Miller's Point (mean ML=130.7 mm, $p<0.001$) and Windmill Beach (mean ML=144.5 mm, $p<0.0001$) (Fig. 5.4.a). Also octopuses at Miller's Point was significantly smaller than octopuses at Windmill Beach ($p<0.01$).

Mean adjusted male and female GSI per site were only determined for males between 350-800 g and females less than 1 000 g respectively. This was done to avoid possible variations in GSI caused by differences in mean octopus size between sites. Mean adjusted male GSI was significantly different between the sites (ANOVA $F_{2,39}=4.64$, $p<0.05$), being significantly higher for octopuses at Buffels Bay (mean=1.28) compared to Windmill Beach (mean=0.84, $p<0.05$) and Miller's Point (mean=0.85, $p<0.05$) (Fig. 5.4.b). Mean adjusted female GSI also differed significantly between sites (ANOVA $F_{2,33}=10.58$, $p<0.01$). Female octopuses from Buffels Bay had a significantly higher mean GSI (mean=0.99), compared to that of female octopuses caught at Windmill Beach (mean=0.23, $p<0.05$) and Miller's Point (mean=0.19, $p<0.01$) (Fig. 5.4.c).

Mean food volume for specimens between 300-1 000 g for Windmill Beach, Miller's Point and Buffels Bay was 2.49 ml, 2.29 ml and 0.72 ml respectively (Fig. 5.4.d). However, these differences were only marginally significant (Kruskal-Wallis ANOVA: $\chi^2=4.78$, $df=2$, $p<0.1$).

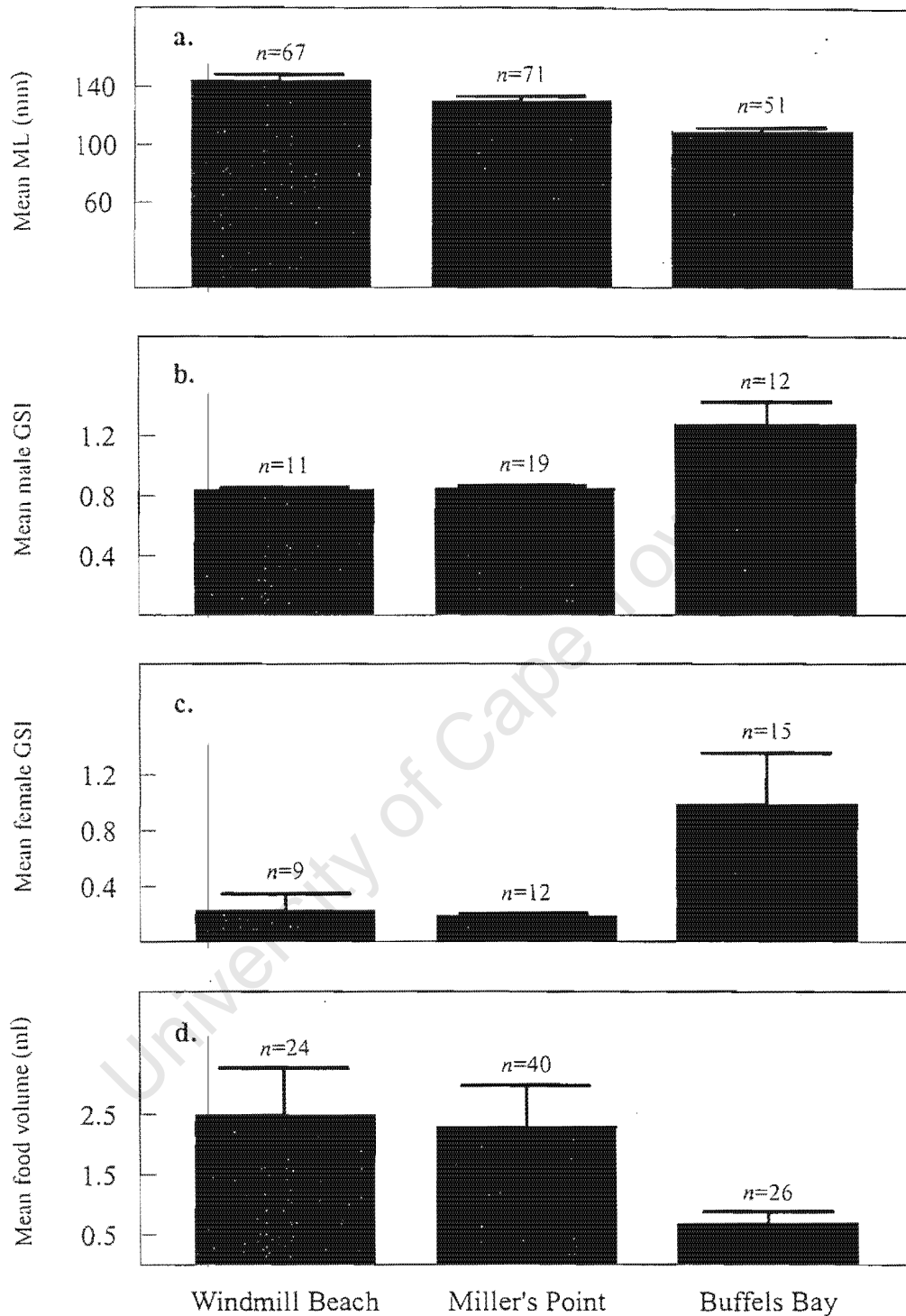


Fig. 5.4 a. Mean mantle length (ML) plus associated SE of *O. vulgaris* at the False Bay sites. b. Mean adjusted gonad somatic index (GSI) plus associated SE of male *O. vulgaris* between 350-800 g obtained at the three sites. c. Mean adjusted GSI plus associated SE of female *O. vulgaris* < 1 000 g collected at the three sites. d. Mean food volume plus associated SE of *O. vulgaris* between 300-1 000 g obtained at the three sites.

DISCUSSION

Prevalence and severity of *O. vulgaris* arm amputations

Frequency of arm amputations in *O. vulgaris* (31%) was comparable to that obtained in *O. digueti* (26%) (Voight 1992) and a nearshore *O. dofleini* population (23%), but lower than that obtained for an offshore *O. dofleini* population (57%) (Hartwick *et al.* 1988). The high incidence of non-fatal attacks in the latter was attributed to shelter limitation in the deeper waters (Hartwick *et al.* 1988).

Arm amputation frequency was also inversely proportional to body mass. As octopuses are considered to be amongst the most advanced invertebrates (Augustyn *et al.* 1989) capable of learning (Muntz & Gwyther 1988), it is conceivable that larger octopuses are more experienced in avoiding predators than smaller octopuses. This was evident in the different flight responses used by small and large specimens when collected during this study. Once forced out of their dens large specimens were noted on six occasions to seek shelter in kelp stalks near the water surface. This flight behaviour would be very effective in avoiding confrontations with catsharks, as these predators are always found in close proximity to the reef bottom. In addition, large octopus would be too large to be attacked by small catsharks. However, no relationship was found between amputation rate and size for *O. digueti* (Voight 1992) and *O. dofleini* (Hartwick *et al.* 1988). The contradictions between this study and the others is possibly due to the great differences in size classes used in each study. *O. digueti* is a small octopus, weighing between 0.6-75g (Voight 1992). Since this is a narrow mass range, it is conceivable that differences in octopus size would not make a difference to the predators concerned. In contrast, amputation frequency in *O. dofleini* was compared using 3 000g size classes. These size classes does not account for the impact of small predators on small octopus.

The inverse relationship between amputation severity and octopus mass could be attributed to octopus size. Larger octopus, being more robust, would fend off predators easier than smaller specimens, thereby suffering less arm damage.

Predators responsible for non-fatal attacks on octopus

The positive correlation obtained between amputation frequency and mean catshark abundance at the three sites provides further evidence favouring catsharks, particularly *P. africanum*, as the predators responsible for the majority of non-fatal attacks on octopus. It must be mentioned however, that *A. pusillus pusillus* and *C. laticeps* also have the potential to amputate octopus arms on failed attacks, but due to their low abundance in the study sites their contribution to observed frequency of arm loss in octopus is likely to be small. In tropical and subtropical waters moray eels may be the main predators responsible for octopus arm amputations. This is confirmed by their diet (Mather & O'Dor 1991) as well as the observed feeding behaviour of these predators (Forsythe & Hanlon 1997).

Possible consequences of non-fatal attacks on octopus

Growth and size at maturity are known to differ greatly within populations of various cephalopod species (Mangold 1987). These traits have been shown to be influenced by complicated interactions between factors, such as light intensity (Wells & Wells 1959), water temperature (Forsythe & Hanlon 1988), food supply (Wells & Wells 1959) and genetic make up (Calow 1987). However, the sites sampled here occur in a large single bay and are within 20 km of each other. Hence, these factors affecting growth and maturity are most likely to be similar between sites. If this assumption is valid then the correlations obtained between arm amputation frequency and octopus size per site could imply a cause and effect relationship.

Mean food volume data suggests that octopuses consume less food at Buffels Bay than at the other sites. It is conceivable that the increase presence of catsharks at this site could limit octopus foraging time and hence the amount of food consumed. Consequently, restricted feeding is known to decrease the size at maturity of octopus (Mangold 1987), and therefore it would explain the higher male and female GSI values obtained at Buffels Bay. Early maturation of octopuses at Buffels Bay was further supported by 33.3% ($n=15$) of female octopuses <1 000 g to be in the second stage of maturation whereas none were found at Boulders ($n=8$) nor at Miller's Point ($n=12$). Early spawning of octopuses at Buffels Bay would result in the absence of large females, as females die shortly after spawning. However, the lifespan of males is not solely determined by reproduction, hence further explanations are needed. A second explanation for the scarcity of large octopuses at Buffels Bay may be due to the emigration of large octopuses in areas with high predatory pressure. This may be further facilitated if dens, which provide protection against predators (Ambrose 1982), are limited for large octopuses in the kelp beds of Buffels Bay. The scarcity of large octopuses in areas with small naturally occurring dens has also been observed for *O. dofleini* (Hartwick *et al.* 1988). Thus the small octopus size at Buffels Bay may be a combination of the above-mentioned factors, but not enough time nor finances was available in this study to distinguish the contribution each factor made to the observed size differences between sites. However, if increased predational pressure played a significant role then the ultimate consequence of this is a reduction in octopus fecundity, as the number of eggs spawned is proportional to octopus size (Hanlon 1987; Mangold 1987).

In conclusion, non-fatal attacks on octopuses are common in False Bay, being more frequent and severe in small octopuses. Catsharks may be the predators primarily responsible for these attacks. Also the high incidence of non-fatal attacks could result in precocious maturity and hence, reduce octopus size and fecundity. However, the cause and effect relationships presented here are only preliminary investigations based on three sites. To improve the validity of these relationships further data are required from more sites.

University of Cape Town

CHAPTER 6

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FISHING GUIDELINES FOR AN EXPERIMENTAL *OCTOPUS* *VULGARIS* FISHERY IN THE SOUTHWESTERN CAPE

INTRODUCTION

The first two chapters of this thesis have shown *O. vulgaris* to be a suitable species for a fishery to target in terms of geographic range, depth distribution, apparent abundance, biology, potential threat to the abalone fishery and marketability. However, catch rates are still required to determine whether the fishery is economic. This can be determined by experimental fishing, which can be conducted by diving, trawling, long-lining using pots, long-lining using hooks, or spearing. From the perspective of a southwestern Cape small-scale octopus fishery, the fishing method used should be relatively inexpensive, efficient at catching octopus and capable of being operated in conjunction with primary fisheries, such as those for rock-lobster, abalone and line-fish.

The aims of this chapter are to describe the potential fishing methods, and then, based on the above-mentioned criteria, to determine the most suitable fishing technique that could be used in future small-scale *O. vulgaris* fisheries in the southwestern Cape. Guidelines are also presented to improve efficiency, and hence, the profit obtained by the chosen fishing method.

OCTOPUS FISHING METHODS

Diving

Divers usually detect octopus dens by the presence of midden piles. Once an octopus is spotted a skin irritant is introduced into the den (Robinson & Hartwick 1986), forcing the octopus to leave its den, making it easier to catch. Once caught the octopus is placed in a meshed bag, which is securely tied. The maximum CPUE obtained in this study was only 13 kg/diver/hour,

with a mean of 4 kg. By contrast the landings of *O. dofleini* by divers in British Columbia, accounted for almost 80% of the total annual catch of 206 t in 1988 at a CPUE of 10-73kg/diver/hour (Hartwick and Barriga 1997). Thus this method appears less efficient for catching *O. vulgaris* than it is for larger species. Furthermore, diving is fairly expensive and is restricted to shallow water. A further disadvantage is that diving operations can only be conducted in relatively good sea conditions. However, this method is compatible with the commercial abalone fishery, which is also conducted by diving.

Trawling

Trawling accounts for the highest landings of octopuses world-wide (Rathjen & Voss 1987). Trawlers targeting octopuses have bottom trawls rigged with giant tickler chains along the footrope (Anon 1981). These chains stir up the bottom sediment, scaring octopuses off the bottom and into the net (Anon 1981). This method is used extensively on the Saharan Bank (Rathjen & Voss 1987) and in the Mediterranean (Quetglas *et al.* 1998). The advantages of trawling are: 1) large operational range of trawler, 2) processing capabilities on board and, 3) efficient at catching octopus (Kimura *et al.* 1978). The disadvantages with trawling are that it is not octopus nor size-specific and can only be used on sand or mud bottoms. Moreover, trawling is costly, thereby restricting this method to large-scale fisheries. Trawling also disturbs benthic communities.

Long-lining using pots

Octopus long-lining with pots is the oldest and most widespread of all octopus fishing methods (Rathjen & Voss 1987). This method takes advantage of the fact that octopus take refuge in holes or crevices (Rathjen & Voss 1987). A variety of pots are used in different parts of the world. Some are single entrance pots (Fig. 6.1), e.g. clay pots (Kimura 1980), large shells (Anon

1981) and wooden boxes (Paust 1988); others are multiple entrance pots (Fig. 6.2), e.g. PVC pots and car tyres (Kimura 1980). These pots are tied with a branch line of approximately 1 m in length, and these branch lines are further attached to a main line (Fig. 6.3). The main line is usually about a kilometre long with pots spaced every 6-10 m along the line (Kimura & Isomae 1981). The long-line is then laid on sand/firm mud or on gravel/shell at a depth of 10-140 m (depending on species depth range). The soak time varies from place to place, but ranges from 1-30 days (Whitaker *et al.* 1991). Thereafter the lines are retrieved and the pots checked for octopuses. The line may then be returned immediately to the bottom. The advantages of this method are that it is efficient (Kimura & Isomae 1981), by-catch is low, and it is size selective. Furthermore, boats of 3-5 tons, which are commonly used in this fishery, are similar in size to those used in the rock-lobster and line-fish fisheries in the southwestern Cape. Hence, this approach is highly compatible with the primary fisheries of this region. As this method does not involve hooking or trapping octopus, they remain fresh and undamaged until the pots are retrieved. However, operational costs are fairly high and compounded by potential gear loss due to theft or adverse sea conditions. Other disadvantages of pot fishing are that the pots are not suitable in situations where they are constantly rolled by wave action (Anon 1981), nor where natural dens are abundant (Paust 1988).

Long-lining using hooks

Long-lining using hooks (Fig. 6.4) is another important way of catching octopuses. This method is used mainly over shallow rocky areas that are inappropriate for trawling or pot fishing (Anon 1981). The long-line consists of a main line with many branch lines attached. At the end of each branch line is a single or multiple barbless hook which can be used with bait or lures (Fig. 6.5) (Anon 1981). A variation of this method is the use of cask drift-lines with hooks (Fig. 6.6), as employed to catch *O. maya* in the gulf of Mexico (Voss 1988). A cask is attached to a

line, which in turn has a hook or several hooks fixed to it. The cask is allowed to drift with the current or wind. When the octopus is captured by the hooks, the cask stops moving. The fishing gear is then retrieved to land the octopus. This method is an inexpensive way of catching octopuses. However, the disadvantages are numerous. Firstly, in the southwestern Cape the efficiency of cask drift fishing will be low as kelp will impede the movement of casks and will entangle long-lines. Secondly, this type of fishery requires continuous monitoring and, hence, fishermen are restricted to this fishery only. Thirdly, favourable sea conditions, which are infrequent along the Cape south coast, are essential. Lastly, by-catch may be considerable, especially if bait is used.

Spearing

Spearing of octopus is usually conducted by wading in the intertidal zone at low tide or in calm shallow waters. When octopuses are found in the open they are speared. If an octopus den is found, a short pole with a hook on the end is thrust into the hole, given a twist and the octopus removed (Rathjen & Voss 1987). Spearing is the most common method of actively fishing for *Octopus cyanea* and *Octopus ornatus* in Hawaii (Young & Harman 1997) and *O. vulgaris* in South Africa. This method is octopus specific and it is the least expensive way of catching octopus. However it is confined to clear shallow water. Moreover, the CPUE of spearing is usually low and could never support a commercial small-scale fishery, particularly as *O. vulgaris* is predominately a subtidal zone species. Thus, this method is mainly utilised by anglers wishing to use octopus as bait or artisinal-type fisheries in areas where octopuses are common in shallow waters.

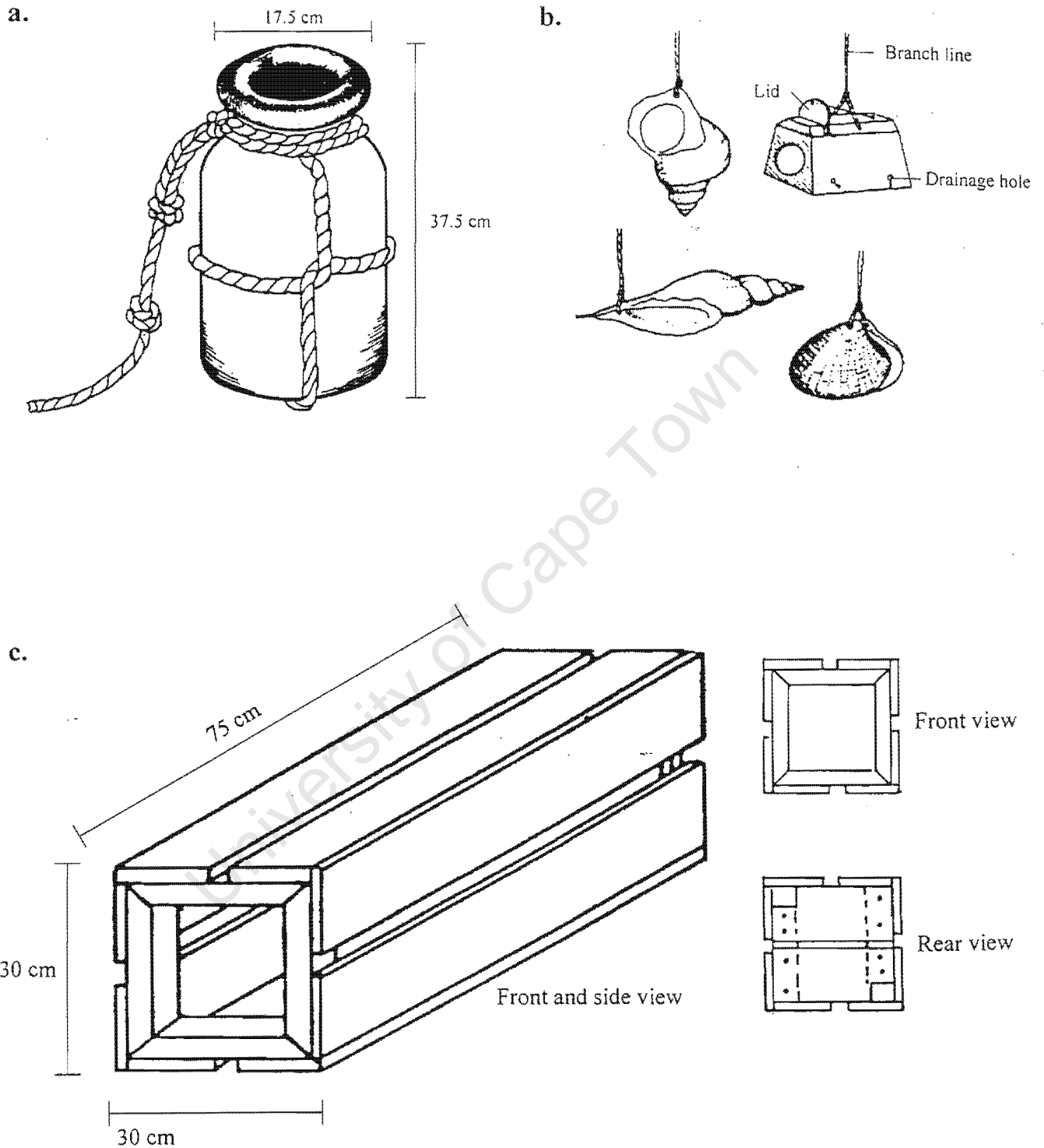


Fig. 6.1 Examples of single entrance octopus pots: **a.** Clay pot (from Paust 1988); **b.** Small pot and shells used to catch small octopus (from Anon 1981) and; **c.** Wooden slat box (from Paust 1988).

a.



b.



Fig. 6.2.a. Examples of multiple entrance pots. 160 mm diameter PVC pot on the left. 110 mm diameter PVC pot in the middle and tyre pot on the right (modified from Kimura 1980).
b. Side view of 160 mm diameter PVC pot showing construction of multiple entrance pots. Concrete plugs (5-8 mm thick) are placed in the center of pipe to act as a ballast and as a partition. These plugs are held in place with silicone. The two pipes are then held together by a steel rod with a loop at one end. Stainless steel strapping is optional, and is used to prevent pivoting of the two pipes.

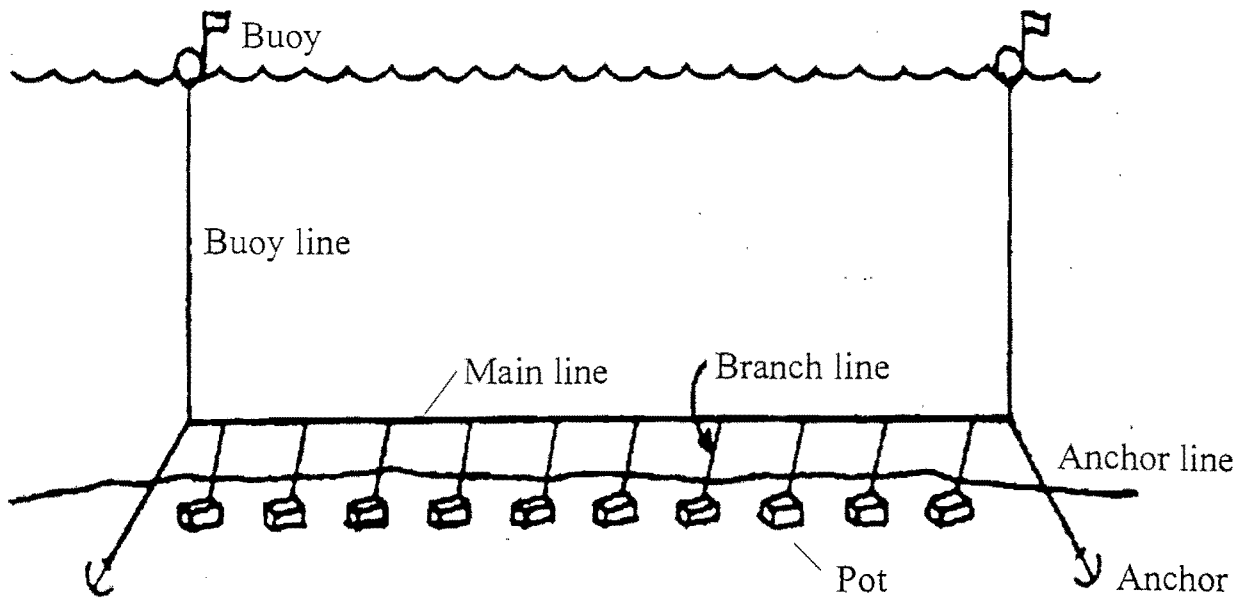


Fig. 6.3 Important components used in pot fishing (from Anon 1981).

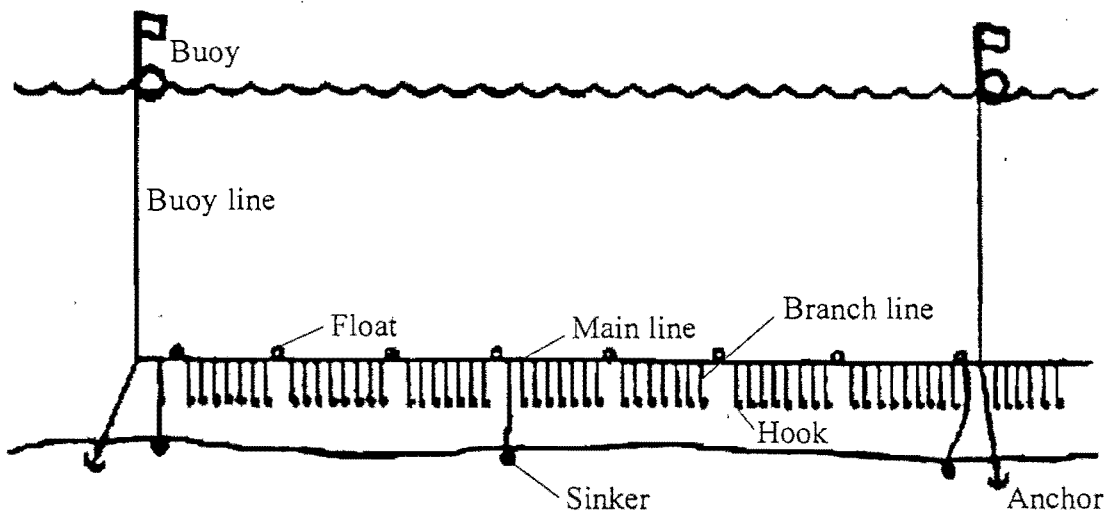


Fig. 6.4 Major components of long-lining using hooks (from Anon 1981).

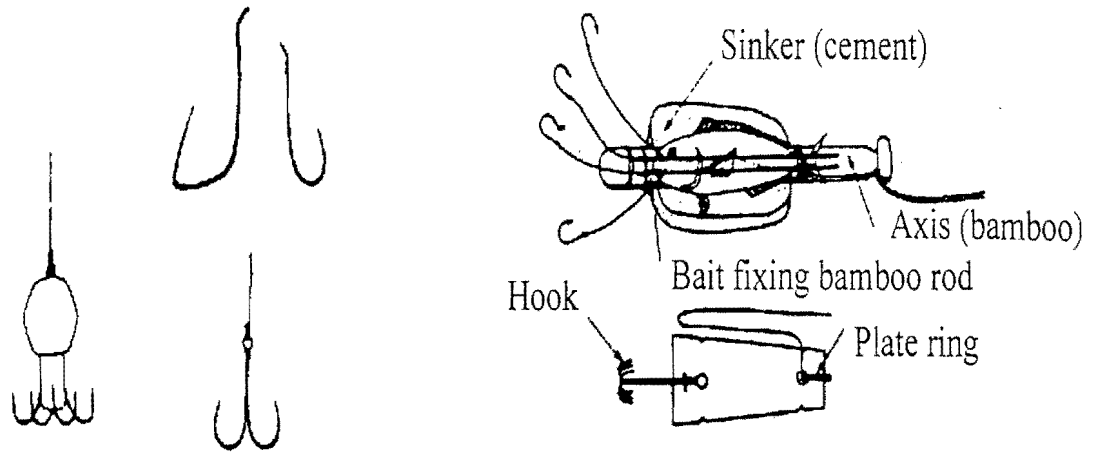


Fig. 6.5 Variations of single and multiple hooks used in long-lining for octopus (from Anon 1981).

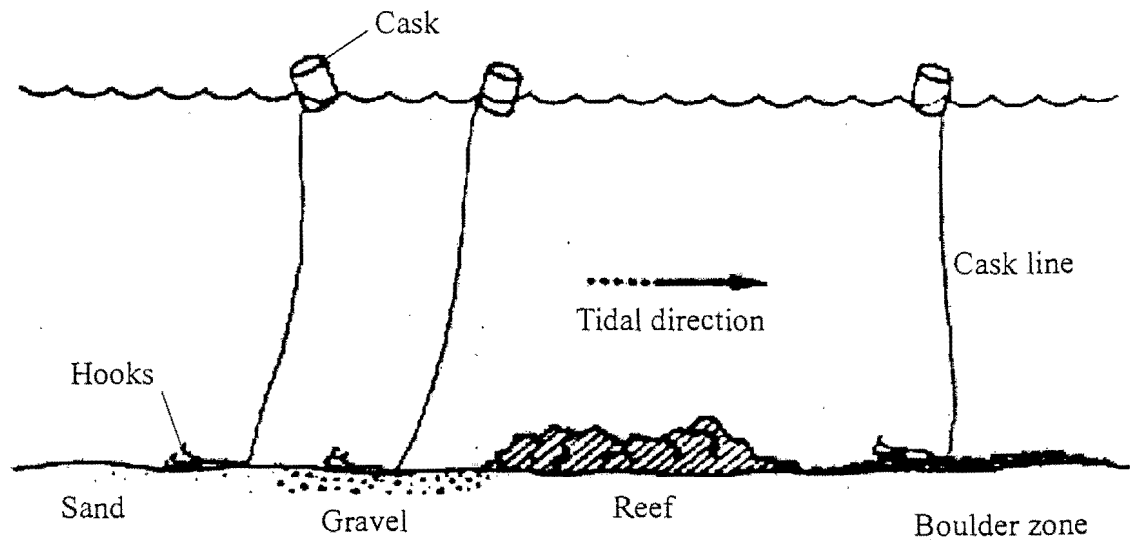


Fig. 6.6 Cask drift-lines using hooks (from Anon 1981).

In summary, pot-fishing is the most suitable fishing method for a small-scale fishery for *O. vulgaris* in the southwestern Cape, as it is relatively inexpensive, efficient at catching octopus, capable of being operated in conjunction with primary fisheries, and the by-catch is low (Table 6.1). Since pot fishing has not been conducted in South Africa before, guidelines on fishing operations are presented, using information obtained in previous chapters and by previous experimental octopus fisheries.

GUIDELINES FOR A SOUTHWESTERN CAPE *O. VULGARIS* POT-FISHERY

Profit margins of various experimental octopus pot fisheries, including those conducted along the coast of Australia (Kimura *et al.* 1978, 1981; Kimura 1980), Alaska (Paust 1988) and South Carolina (Whitaker *et al.* 1991), are small. However, profits can be increased by reducing labour costs, using appropriate pots and by improving fishing methods.

Labour reduction

Kimura & Isomae (1981) showed that labour can be reduced to two people by using vessels less than 5 tons. This is further facilitated by the introduction of a hydraulic line-hauler, which is used to deploy and retrieve the pot lines. This piece of machinery is also compatible with boats already using an hydraulic system and hence installation costs are reduced.

Selection of pots

Pots should be inexpensive, durable and efficient at catching octopus. Of the many pot types used in octopus fisheries the multiple entrance pots have been shown to be more efficient at catching octopus (Kimura & Isomae 1981). These pots are made of a variety of materials (see Fig. 6.2 for types of pots constructed for this fishery). Consequently, the cost of different pots varies greatly (Table 6.2). Initially the tyre pot, based on cost, appears to be a suitable pot type for a small-scale fishery because old tyres can be obtained free, but its catching efficiency

Table 6.1 A comparison of the relative expense, efficiency, compatibility with other fisheries and by-catch of each octopus fishing technique for *O. vulgaris* in the southwestern Cape. Relative comparisons of each category are made using asterixes, with * indicating unfavourable, ** indicating moderate and *** indicating favourable.

Fishing method	Expense	Efficiency	Compatibility	By-catch
Diving	**	*	**	***
Trawling	*	***	*	*
Pot fishing	**	**	***	***
Long-line using hooks	***	*	*	**
Spearing	***	*	**	***

Table 6.2 Comparative cost of materials used in making 50 of each type of multi-entrance pots, namely 110 mm PVC pot, 160 mm PVC pot and tyre pot. Cost of materials are based on 1996 prices in Cape Town.

Materials	Cost		
	110 mm PVC pot	160 mm PVC pot	tyre pot
60 m PVC pipe	R 360.00	R 1 000.00	N/A
tyre	N/A	N/A	R 0.00
concrete	R 53.00	R 77.00	R 53.00
6 mm steel rods	R 35.00	R 46.00	N/A
electroplating	R 50.00	R 65.00	N/A
nuts and washers	R 10.00	R 10.00	N/A
silicone	R 20.00	R 20.00	N/A
grease	R 30.00	R 30.00	N/A
cable ties	N/A	N/A	R 275.00
sanding disks	R 30.00	R 30.00	R 60.00
9.5 mm * 0.5 mm s/steel strapping	R 37.00	R 57.00	R 57.00
9.5 mm buckles	R 33.00	R 33.00	R 33.00
Total cost per 50 pots	R 658.00	R 1 368.00	R 478.00

should be verified. Therefore all the pots in Fig. 6.2 needs to be tested before any particular pot-type can be selected for a southwestern Cape *O. vulgaris* fishery.

Fishing operation

Suitable pot fishing grounds appear to be shell bottoms with little reef structure (Paust 1988; Whitaker *et al.* 1991). These can be identified by sea charts and by diving surveys. Once a suitable site has been identified the pots used should be cured for maximum catching efficiency. This requires soaking the pots in the sea for approximately two weeks. Thereafter the fishery can commence. However, for optimal efficiency, soak time, depth and pot type need to be determined. These factors are further complicated by seasonal migrations (see Chapter 3), fluctuations in population size-structure (see Chapter 3) and abundance of octopuses. Thus the depth fished may vary with season. Furthermore, the diameter of pot used in each season may change with average mass of octopus in each season (Whitaker *et al.* 1991), as the size of the octopus caught is dependent on the volume of the pot used (Paust 1988). Finally, soak time may fluctuate depending on the seasonal abundance of octopuses. Thus, experimental fisheries will need to be conducted in all seasons to identify the most profitable fishing seasons. Preferably, numerous pot lines should be fished simultaneously at various depths in all seasons, and each pot line should contain different pot types. Furthermore, different rotational soak times should be used in each season. In addition to efficiency, profit margins are also effected by octopus quality (Kimura & Isomae 1981). The highest quality is obtained by keeping octopuses alive while transporting them from the fishing ground to the processing plant. This can be achieved by placing octopuses in reserve boxes with circulating sea water and ice (Fig. 6.7) (Kimura & Isomae 1981).

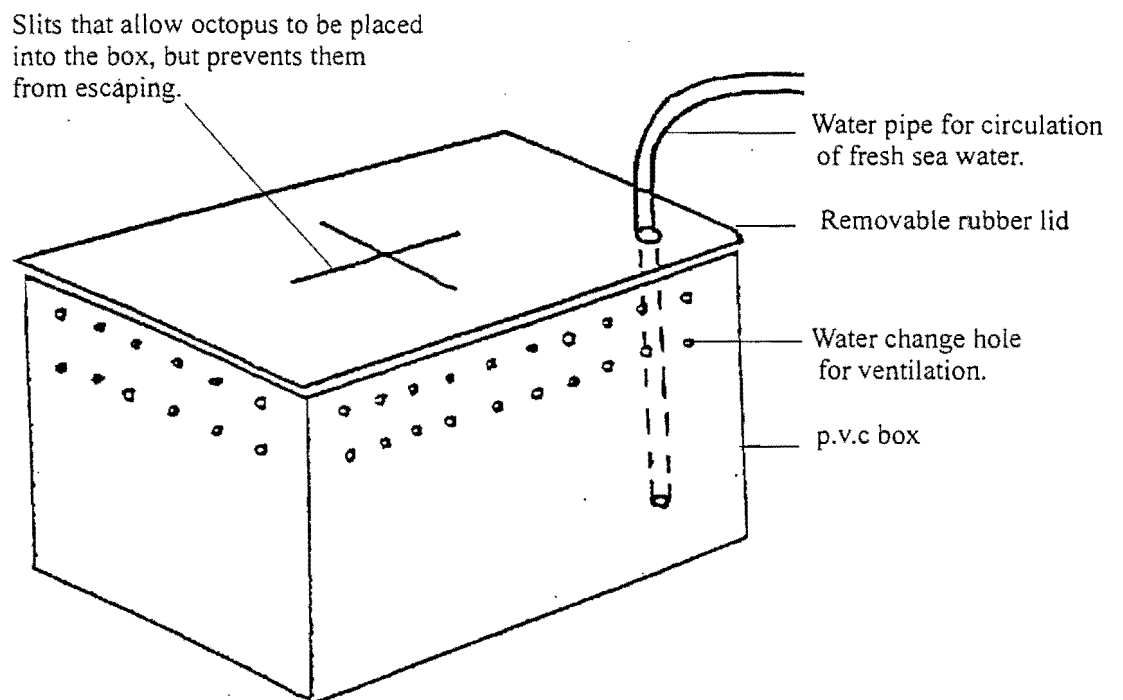


Fig. 6.7 Design of a reserve box which is used to keep octopus fresh while at sea (from Kimura 1980).

Lastly, vandalism and theft may adversely effect a pot-fishery in the southwestern Cape. However, the magnitude of this problem can be reduced by using time-delayed buoys or cheap buoys e.g. polystyrene filled cool drink bottles.

In conclusion, experimental pot fishing is necessary to provide data on catch rates and the economic viability of a small-scale *O. vulgaris* fishery in the southwestern Cape. Furthermore, this type of fishery should also provide important data on abundance, population size structure, migration patterns and spawning grounds of *O. vulgaris*, all information that is crucial for the management of this species.

CONCLUSIONS

CONCLUSIONS

This thesis aimed to provide information on the distribution, biology and diets of octopuses commonly found in the waters of the southwestern Cape. Three octopus species were found to be common in this region, namely *Aphrodoctopus schultzei*, *Octopus vulgaris* and *Octopus magnificus*. *A. schultzei* is a shallow-water species (intertidal zone - 18m) with a limited geographic distribution, predominately west of Cape Point. In contrast, *O. vulgaris* has an extensive depth range (intertidal zone - 290 m) and is common throughout South African waters. *O. magnificus* is common in deeper (100-560 m) temperate waters between Luderitz - Port Alfred. *A. schultzei* is a small species (max. mass 350 g), whereas *O. vulgaris* and *O. magnificus* are both large species, with maximum masses of 4 625 g and 8 625 g respectively. The morphometric relationship between mantle length (ML) and total length (TL) was linear for all three species, and the relationship between ML and body mass (BM), and ML and lower beak mass (LBM) followed power curves for all three species. Males of all species matured at a smaller size than females. The smallest mature males were 30 g for *A. schultzei*, 136 g for *O. vulgaris* and 3 275 g for *O. magnificus*. However, mating is only likely to occur when spermatophores are fully developed at sizes larger than 100 g, 325 g, 4 000 g respectively. Furthermore, male gonad mass (GM) increased linearly with BM in *A. schultzei* and *O. vulgaris*, but exponentially in *O. magnificus*. No mature females of *A. schultzei* or *O. vulgaris* were found. A single mature *O. magnificus* female (8 625 g) was recorded. The onset of gonad maturation was found in female specimens as small as 80 g, 275 g and 4 900 g for *A. schultzei*, *O. vulgaris* and *O. magnificus*. The relationship between GM and BM followed a power curve for *A. schultzei* and *O. vulgaris* and an exponential curve for *O. magnificus*. No significant differences were found from a 1:1 overall sex ratio of

A. schultzei and *O. magnificus*. However, mature female *A. schultzei* were absent, which reduced the number and mean size of females compared to males. For *O. vulgaris* the overall sex ratio was significantly biased towards males (0.6F:1.0M). The diets of the three species differed. *A. schultzei* predominately consumed winkles, accounting for 68.8% of the total index of relative importance (IRI). *O. vulgaris* mainly consumed small crustaceans (45.5%), large crustaceans (28.1%) and abalone (17.1%). The single most important prey species in the diet of *O. vulgaris* was the crab *Plagusia chabrus*, followed by the abalone *Haliotis midae*. Small crustaceans and large crustaceans were also important in the diet of *O. magnificus*, accounting for 31.85 and 30.1% of the total IRI respectively. However, the most important prey component was teleosts (34%).

From these results, *O. vulgaris* was found to be most suitable for harvest by small-scale fisheries for the following reasons. It is a large, common species with an extensive geographic range, occurring throughout South African waters. It has a suitable depth range for exploitation by fisheries using small boats (less than five tons). *O. vulgaris* was also identified as a potential threat to the abalone industry. Moreover, this species is used for human consumption and is the most-sought after octopus in the world. Consequently, the market price for this species is high. Export potential is also promising as Japan and Spain are increasingly dependent on imported *O. vulgaris*. *O. magnificus* may also be suitable for exploitation by a commercial fishery, but due to the deeper depth distribution of this species it is more suited for large-scale fisheries using bottom trawls, or as a by-catch in other trap or trawl fisheries.

Because *O. vulgaris* was found to be suitable for a small-scale fishery, further studies were conducted on the spatial distribution, population dynamics, diet and predation of this species.

Spatial distribution studies revealed that *O. vulgaris* seeks shelter in easily modified habitats such as boulder rubble and reef. Large octopuses were found more frequently in shelters than smaller specimens during the day, with only 8% of large individuals found outside of shelter compared to 37% for small ones. Depth distributions of large and small octopuses also differed, with small octopuses having a significantly shallower distribution. The study on the inshore population dynamics of *O. vulgaris* also showed mean seasonal mass to be lowest during winter in association with low water temperature. The offshore - onshore migration of large specimens (>900 g) was considered to be a potential factor responsible for seasonal mass fluctuations. Mating is most likely to occur throughout the year, but higher mean spring and summer GSI values indicate that spawning may coincide with warmer water.

Stomach content analysis was shown to be a superior method of octopus diet assessment compared to *in situ* day-time field observations and midden-pile analysis. The diet of *O. vulgaris* was shown to be influenced by octopus size and season. Small octopuses predominately consumed small crustaceans, accounting for 87.4% of the total IRI. Small crustaceans were less important in the diet of medium octopuses (34.6%) whereas abalone and large crustaceans increased in importance, making up 32.9% and 18.4% of the diet respectively. The most important prey category in large octopuses was large crustaceans, followed by small crustaceans (28.9%) and abalone (23.2%). Seasonal changes in diet were largely attributed to the high abundance of megalopa larvae and juvenile octopus in the winter months (April - August). Prey size selectivity was also shown in *O. vulgaris*, with larger octopuses consuming larger sizes and a greater size range of *H. midae*.

Important predators of *O. vulgaris* in False Bay are seals, *Arctocephalus pusillus pusillus*, fish, such as red roman *Crysolephus laticeps*, catsharks, *Haploblepharus edwardsii*, *H. pictus*, *Poroderma africanum* and *P. pantherinum*, and octopuses themselves. However, catsharks are probably responsible for the majority of non-fatal attacks on octopuses. Signs of non-fatal attacks were common and occurred in 31.4% of all *O. vulgaris* caught in False Bay. Amputation frequency and severity decreased with octopus size. Furthermore, preliminary investigations suggests the possibility of maturation size and fecundity of octopuses to be reduced by high incidence of non-fatal attacks.

Although experimental pot fishing would have been a better method to determine the population dynamics of *O. vulgaris* over its full depth range, this was not possible as Sea Fisheries Research Institute (SFRI) placed a moratorium on all experimental fishing permits during the period of this study. However, experimental fishing is still required to validate the spatial distribution and population dynamics obtained in this study, and to determine relevant management strategies for this fishery. Moreover, the economic feasibility of a small-scale *O. vulgaris* fishery in the southwestern Cape can only be determined by an experimental fishery. With this in mind, several methods of octopus fishing were reviewed to determine the best method for a small-scale octopus fishery. These methods included trawling, diving, pot fishing, long-lines using hooks and spearing. Of these, pot fishing was found to be the most appropriate because it is relatively inexpensive, efficient at catching octopus, octopus-specific, does not disturb other components of the ecosystem, and is compatible with primary fisheries of the southwestern Cape.

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