Reproductive biology and diet of the St. Joseph (*Callorhinchus capensis)* in South Africa

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Declaration

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Table of Contents

PAGE

CHAPTER 1 GENERAL INTRODUCTION PAGE

CHAPTER 2 BIOLOGICAL INVESTIGATION INTO *C. CAPENSIS*

CHAPTER 3 RESULTS

DISCUSSION

CHAPTER 4 CONCLUSION AND FUTURE WORK

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LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

Abstract

The reproductive biology of the commercially exploited fish St. Joseph or Cape Elephant fish *Callorhinchus capensis*, is described based on 173 fishes caught by gillnets in October 2010 from Velddrif along the west coast of South Africa. Segregation by sex was reflected by a difference in sex ratio from 1:1 for females to males fishes collected from the fishery (χ^2 = 16.23, d.f. = 1, p = 5.6 x 10^{-5}). In the sampled fish, the occurrence of fish sex was independent on maturity (χ^2 = 6.437, d.f. = 1, $p < 0.05$) and fish size (χ^2 = 10.542, d.f. = 2, $p < 0.05$). Sexual dimorphism was exhibited by the species in which mature females attained a larger maximum size than males; 852 mm TL for females and 740 mm TL for males. The growth pattern given by length-weight relationship ($M_T = a\mathrm{TL}^b$) differed between sexes, and was allometric ($b > 3$) in males, while isometric ($b \approx 3$) in both females and combined sex. The size at which 50% of males were sexually mature was 593 mm TL (78% of the maximum size), whereas 50% of females were mature at 754 mm TL (88% of the maximum size). The frequency distribution of the maximum oocyte diameter revealed an asynchronous oocyte development. Estimated fecundity of oocytes > 10 mm for mature females (n = 27) ranged from 1 to 14 oocytes (5.3 ± 3.79 oocytes) for fishes with total length ranging from 653 mm TL to 852 mm TL and total body weight from 600 to 2800 g. One-way ANOVA and Post-hoc test on the species biological indices revealed that GSI value was significantly higher for males (F = 5.306; d.f. (5, 26); p = 0.0017) than that of females (F = 3.286; d.f. (5, 44); p = 0.0132). The gonadosomatic index was correlated with fish size with peak value in females higher than males. HSI values per fish size also varied significantly (males: F = 4.285, d.f. (5, 51), p = 0.0025; females: F = 16.42, d.f. (5, 99), $p < 0.0001$). The condition factor for each fish size was different between sexes (males: F = 39.51, d.f. (5, 55), p <

0.0001; females: F = 16.72, d.f. (5, 102), p < 0.0001). Analysis of the variation of hepatosomatic index (HSI) and Le Cren's condition factor showed that HSI is a good indicator of the lipid reserves of *C. capensis.* The fish condition was influenced by the species reproductive effort. Crushed black mussels and un-identified digested materials dominated the stomach content by frequency in all length classes of fish sex, with diet not significantly different for both sex (t = - 0.74; p = 0.47, d.f. = 16). However, female *C. capensis* had a higher percentage of stomachs with food items than males. According to results obtained, the reproductive strategies make *C. capensis* highly vulnerable to over-exploitation due to expansion of deep-sea fisheries and cannot support intensive fishing. There is a strong need to manage the fishery by way of regular monitoring and effective effort regulation.

Thesis Composition

This thesis is divided into four chapters. **Chapter 1** gives a general introduction of the St. Josephs (*Callorhinchus capensis*). This is later followed by its biology and fishery. The last part of Chapter 1 provides information on the reason for the study. The aim and objectives is then outlined at the end of the introduction. **Chapter 2** embodies the materials and methods used in the biological investigation used in the study. The study site from where samples were collected is described. Laboratory dissections, collection for both morphometric and reproductive data were described and analysed. Life-history traits determined were the sex ratio, size-at-maturity, growth pattern and fecundity. These traits were studied to reveal their linkages to biological indices and feeding habits of *C. capensis.* Males and female reproductive traits of *C. capensis* were determined using distinctive reproductive organs, and a logistic function was fitted to the percentage maturity data to estimate medium size-at-50% maturity. Mature-active females provide information on the variation of oocyte diameter with fish size at time of study. In **Chapter 3**, the results obtained as estimates for the various life-history parameters are presented. Also described within the chapter is the food and feeding habit of *C. capensis*. Thesis results are next discussed on how they contribute in improving the understanding of the present reproductive biology of the shark. Estimated results are compared with previous studies and other sharks. As a conclusion in **Chapter 4**, the information from the previous chapters is used to relate to its possible implications in fishing pressures where possible management options are identified. Also in the last part of chapter 4, acknowledgement is made on possible sources of errors for this study. Proposed future work that could help in augmenting results is also mentioned. Finally, a list of literature used and cited in the thesis is provided under **References.**

Chapter 1: General introduction

1.1 *Species taxonomy and distribution*

The St. Joseph, *Callorhinchus capensis*, is a South African endemic Chimaerean species which belongs to a small group of cartilaginous fish commonly known as ratfish or ghostfish (Freer and Griffiths 1993, Hennemann 2001). They are demersal chondichthyans of the subclass Holocephali (chimaeras or ratfishes) which originated over 300 million years ago from Osteichthyans (Grogan and Lund 2004, Benton et al. 2009). The modern Holocephalans are currently composed of six recognised genera and 32 species compared with 170 genera and 911 species of modern elasmobranchs (Froese and Pauly 2000).

The subclass Holocephali has one order, the Chimaeriformes, which separates into three families of Chimaeriformes and a genus *Callorhinchus* (Barnett et al. 2006, Compagno 2005). These Holocephalans has a total of 37 species with approximately ten new species awaiting formal description (Barnett et al. 2009). The three families of the Chimaeriformes, each delineated by their snout morphologies, include: Callorhinchidae (elephant fish), Rhinochimaeridae (longnose chimaeras) and Chimaeridae (shortnose chimaeras) (Didier 1998, 2004). The genus *Callorhinchus* is made up of nine species among which is the South African endemic species, *Callorhinchus capensis*, commonly called the St. Joseph or Cape Elephantfish.

Morphological and behavioural characteristics that make the St. Joseph unique from other *Callorhinchus* include the presence of a snout with a hoe-shaped terminal lobe and a caudal fin with axis bent upward (heterocercal) (Figure 1.1).

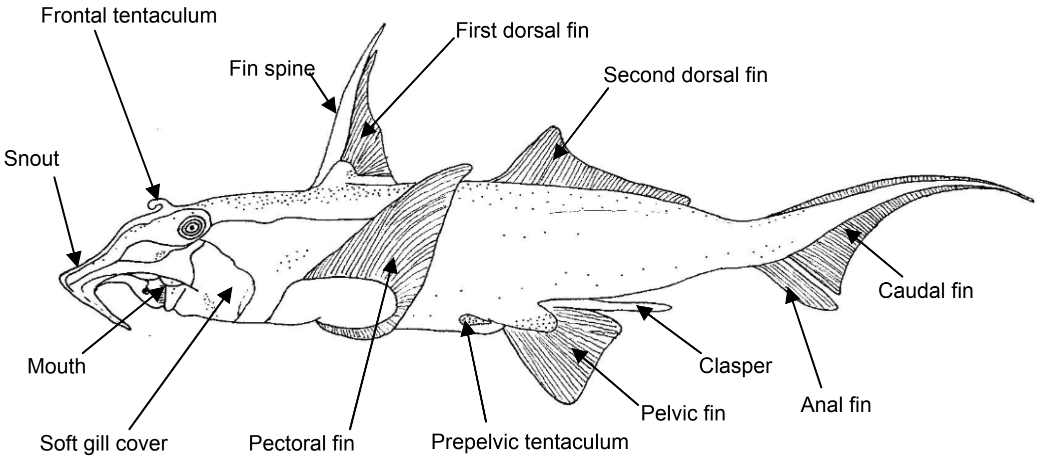


Figure 1.1. Diagram of a male St. Joseph *Callorhinchus capensis* showing the distinctive features, from Velddrif, west coast of South Africa (Drawing by author).

Chimaeroid fishes differ from other chondrichthyans by having four pairs of gill openings on the sides of the head inside a pair of soft gill covers, an upper jaw fused to the cranium and teeth fused into solid dental plates (Calis et al. 2005). Modern elasmobranchs, except Hexanchid sharks (6-7 pairs of gill openings), have five pairs of gill openings with the upper jaw movably articulated with the cranium and separate teeth (Heemstra and Heemstra 2004). Other distinguishing characteristics of chimaeras include long tapering bodies and very large heads, and mouths positioned on the underside of their heads, connected to nostrils by deep grooves. A venomous spine located in the front of the first dorsal fin serves as a defensive mechanism. Male St. Josephs possess unusual sexual structures such as retractable sexual appendage on their foreheads and in front of their pelvic fins for reproductive benefits (FAO 1984).

Callorhinchus capensis is prevalent in southern Africa and abundant off the west and south coasts of South Africa (Compagno et al. 1991) but rare off the KwaZulu-Natal coast (Van Der Elst 1988). Its range also extends to the north of

Namibia (Compagno et al. 1989). Within the southern hemisphere, the Callorhinchidae family is distributed off the coasts on the continental shelves of temperate oceans in South America (Chile and Argentina), New Zealand, southern Australia and South Africa (Gorman 1963, Smith and Heemstra 1986). St. Josephs are deep-sea chimaeras which occur on the shelf of the Agulhas Bank to a depth of 366 m, but are rarely caught deeper than 150 m (Freer and Griffiths 1993). Only females have been found below 250 m and *C. capensis* generally inhabits soft substrata, sheltered areas where they are nocturnal in their activities (Freer and Griffiths 1993).

1.2 Fishery for St. Josephs

The St Joseph is caught either as targeted or incidental by-catch species from anglers, trawlers, gillnets or beach seine fisheries (Smith and Heemstra 1986). In South Africa, the St. Joseph fishery is based primarily on the west coast, where there is a common seine- and gill-net fisheries at sea depth of <100 m with an annual average catch of 800 tons since 1980 (Freer and Griffiths 1993). Gill- and seine-net fisheries in South Africa have traditionally been operating along the west coast since 1652 targeting (*Callorhinchus capensis*) and haarder (*Liza richardsonii*) (Lamberth 2006). According to Hutchings and Lamberth (2002a/b) and Hutchings et al. (2002), by-catch of St. Joseph from an average countrywide catch of 1600 tons reported annually (from registered and illegal nets), varied greatly at an average of 12.7% of total catch and increased to 19% in 1993, with problems of under-reporting of catches and efforts in the fishery. In Namibia, the species is not commercially targeted but is taken in limited quantities as by-catch of demersal trawl fishing (Freer and Griffiths 1993).

Fishing efforts directed at *C. capensis* are regulated by the Department of Agriculture, Forestry and Fisheries (DAFF) through the issuing of commercial gill-net permits, and by regulating the number of nets and total allowable effort (TAE) (Da Silva, DAFF *pers comm* 2011). Lamberth et al. (1997) showed that during 1995 to 1996 the west coast had the highest number of gill-net fishermen compared to the southern, eastern and KwaZulu-Natal coasts. Approximately 162 permit holders yielded a catch per unit effort (CPUE) of 115 kg.net-day^{-1} during 1995 and 1996. The catch composition of this fishery in the west coast area is typically comprised of 70% haarder and 30% St. Joseph (Lamberth et al. 1997). Products of harvested *C. capensis* as dried or frozen shark meat or as smoothhound fillets are exported to Australia. Some 640 tons of St. Joseph exploited by gill-net fishermen were reported to have been consumed locally (De Swardt 1997, Stuttaford 1997).

Increasing markets for *C. capensis* and decreasing catches of high value teleosts and sharks could increase the targeting of *C. capensis* During the last ten years there has been an increasing export demand for shark products from South Africa to markets in Australia, Greece and Japan (De Swardt 1997, Stuttaford 1997, Vannuccini 1999). *C. capensis* is under an active management regime with the status of the fishery and biology of the species being reassessed every 5 – 10 years to determine if there are any changes which may indicate a decline in abundance.

Over-exploitation has been a major threat to the St. Joseph population on the west coast with concern for a declining species population (Freer and Griffiths 1993, Reynolds et al*.* 2005). Unlike most k-selected chondrichthyans, the St. Josephs are relatively more close to the r-selection scale in their life-history pattern with fast growth, early sexual maturity and reasonably high fecundity (Freer and Griffiths 1993). Despite being less resilient to exploitation than coastal and epipelagic species, St. Josephs as other chimaeroids are at an increased risk of being caught as targeted or by-catch species, or being threatened by habitat degradation due to trawling due to expansion of deep-sea fisheries (Cailliet 1990, Gordon 1999, Compagno and Musick 2005). Increasing movement of fishing efforts into deep-sea habitat, with low food availability and production has raised concerns over the sustainability of *C. capensis* as in other species (Freer and Griffiths 1993, Roberts 2002, Morato et al. 2006, Clarke et al. 2003). This is due to their very low intrinsic rebound potentials from population declines relative to continental shelf and pelagic species (Simpfendorfer and Kyne 2009). Threats to overexploitation are compounded with catches of St. Josephs often being under-reported in by-catch of fisheries (Freer and Griffiths 1993, Bonfil 1994, Dulvy et al. 2000). Other possible threats to the *C. capensis* population may include climate change, pollution and disturbance (Griffiths et al. 2010). Hence, there are needs for a periodic review on *C. capensis* to ensure sustainability of the species.

There has been growing international concern about the impact of fishing on chondricthyans due to increasing exploitation in recent decades (Steven et al. 2000). The extent to which illegal fishery activities have impacted on the general population of *C. capensis* is uncertain. In recognition of uncertainties about catch impacts on the St. Joseph and many other chondrichthyans' populations, an International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) was adopted by the 23rd session of the United Nations Food and Agricultural Organisation's (UN FAO) Committee on Fisheries in 1999 (FAO 1999, FAO 2005).

The FAO in 2000 identified certain major concerns on the status of sharks and their fisheries, which makes the implementation of the IPOA-Shark plan very challenging. Concern involving the St. Joseph includes: under or non-reporting (Walker, 1998), and a lack of fundamental data for managing *C. capensis* such as catch, effort, species, sex, length, age composition.

Lack of biological and fisheries data for the majority of targeted shark species such as *C. capensis* makes the development of a management plan very important. Such a plan will promote a precautionary approach to its fisheries management in the face of the many threats to its population. According to Punt et al. (2001), developing a precautionary harvest strategy for an exploited species such as *C. capensis* will require the following: 1) understanding the data from the fishery and using the information to determine a management plan, 2) estimating biological reference points to reduce risk of stock collapse and 3) stock assessments.

1.3 The biology of C. capensis

As in many other demersal sharks, there is evidence of sexual dimorphism in St. Josephs (Freer and Griffiths 1993). The female matures at larger sizes than the male. Females mature after 4.2 years at 49.6 cm fork length (FL) whereas males mature at 3.3 years and 43.4 cm fork length (FL). Maximum age is 10+ years and 7+ years, for females and males, respectively. At maximum size (total length- TL) the species is 120 cm TL. St. Josephs have internal fertilization and are oviparous, producing one egg case per oviduct. Egg cases are large, spindle-shaped with broad lateral flanges and are laid during parturition. Freer and Griffiths (1993) reported that the gestation time for embryos takes 9 to 12 months. Litters hatch at a birth size of about 13 cm TL. Breeding occurs throughout the year with distinct peaks in summer. During the breeding season, females move closer to shore to lay oocytes where the young remain for a period of 3 to 4 years. Sexual segregation is a typical characteristic in *C. capensis* where the two sexes sometimes spend time apart from each other. This is a typical characteristic in many other sharks. For instance the Spotted Ratfish (*Hydrolagus colliei*), horn shark (*Heterodontus francisci*) and swell shark (*Cephaloscylium ventriosum*) all show similar reproductive behaviour and have a defined reproductive season (Calis et al. 2005). Important parameters such as the average reproductive age, annual rate of population increase and natural parameters e.g. size or age-at-maturity, growth, recruitment, movement pattern and feeding ecology in *C. capensis* as in many shark species are poorly understood due to their high mobility and seasonal abundance patterns (Freer and Griffiths 1993, Cailliet et al. 2005, Snelson et al. 2008).

According to Freer and Griffiths (1993), St. Joseph feeds mostly on benthic invertebrates including sea urchins, bivalves, crustaceans, gastropods, polychaetes and predate on pelagic bony fishes. Other chimaeras are also benthic carnivores. Didier (2004) found marine worms and mussels prominent in the diet of Rabbitfish (*Chimaera monstrosa*). Natural predators of St. Josephs in the wild are the Cape fur seals and sharks, including bronze whaler *Carcharhinus branchyurus*, bluntnose sixgill shark *Hexanchus griseus*, spotted sevengill shark *Notorynchus cepedianus* and soupfin shark *Galeorhinus galeus* (Freer and Griffiths 1993). Other chimaeras such as the Elephant Shark (*Callorhinchus milii*) have been reported as primary prey to the New Zealand carpet sharks (Orectolobiformes) (Didier 2004). Knowledge of the feeding ecology of *C. capensis* can give an understanding of the species' current ecological role and its position within the food webs (Cortés 1999). Predators' diets as well as their interaction with prey usually vary with time and area in a dynamic natural system (Paine 1988). Understanding aspects of the feeding ecology of *C. capensis* is an important component for its growth and reproduction (Yodzis 1994).

C. capensis like other chimaeras are reliant on major senses (vision, smell, taste, mechanoreception, hearing and electroreception) to detect information about their external environment in order to find mates, locate food and habitat and avoid predators (Lisney 2010). Knowledge of their sensory biology helps in understanding the species interaction with fishing gear, hence an aid to by-catch reduction strategies (Southwood et al. 2008). However, deep-sea adaptation of these marine species with their sense organs are not well researched. The visual systems of chimaeroids are the only best-studied sensory system while most of the other senses remain poorly understood (Lisney 2010).

St. Josephs are most commonly infected by internal cestode (*Gyrocotyle plana, Callorhynchichola multitesticulatus*) and external copepod parasites, which are found in the stomach and gills (Freer and Griffiths 1993, Manter 1955). These parasites can be used as biological tags. Management decisions can be made from the information they provide on fish stock separation, recruitment, migration patterns, fish diet and feeding behaviour (Williams et al. 1992, Mosquera et al. 2003, Hussey et al. 2009a).

1.4 The importance of the reproductive biology of C. capensis

An investigation of the reproductive biology of the commercially exploited *C. capensis* population on the west coast of South Africa is an essential component in the understanding the species' ecology, life-history and population dynamics. A species' reproductive strategy, size or age-at-maturity and spawning seasonality are often controlled by abiotic factors, food availability, the presence of predators and the habitat of the parental fish (Matthews 1998, Welcomme 2001). Size, or age-at-maturity, is often used for setting minimum mesh sizes, while spawning seasonality is used in defining closed seasons and closed areas (Welcomme 2001). Knowledge of a species' reproductive biology provide one with key inputs required for stock assessment models by fisheries managers and give clues on the status of the sharks which will necessitate management (Malcolm 2001). The successful management of *C. capensis* will require a good understanding of the species reproductive traits such as size and age at maturity, fecundity and duration of their spawning season along with growth and mortality (Quinn and Deriso 1999).

Changes in biological indices such as the gonadosomatic index (GSI) values are a good predictor of the onset of spawning. High GSI values were interpreted as indicating reproductive activity. The hepatosomatic index (HSI) is often used as an indicator of condition and nutritional status of fish (Rueda-Jasso et al. 2004). A demersal fish like C. *capensis* stores lipid primarily in the livers (Sheridan 1988, Sargent 1997, Craig et al. 2000). In this species the HSI can therefore be considered an indirect index of the lipid energy status (Craig et al. 2000). Condition factor assesses the well-being of the fish and is based on the hypothesis that heavier fish of a given length are in better condition (Bagenal and Tesch 1978). Condition factor has been used as an index of growth and feeding intensity (Fagade 1979). Also, research has shown that condition factor is often influenced by the reproductive cycle and size variation of a fish (Bakare 1970, Fagade 1979, Welcomme 1979).

1.5 Rationale for the study

A shark advisory committee in 1947 expressed concerns about high catches of undersized sharks and introduced a minimum mesh size of 22.9 cm for gillnets (Crawford et al. 1993). The net-fish vessels operating in the St. Helena Bay decreased in 2004 with the Long Term Rights Allocation process. The amount of effort in the gillnet fishery has always been dependent on the availability of haarders as an alternative and more lucrative species. As has been in the case in the past, the overall catch composition is still mostly cartilaginous fish, with up to 80% of the catch comprising of St. Joseph (Crawford et al. 1993). There has been a shift towards targeting St. Josephs due to persistent poaching of a declining haarder population. The products of St. Josephs and other demersal sharks are gaining markets opportunities in Australia (Sauer et al. 2003). The St. Joseph is common on the continental shelves of temperate southern ocean with a single species in South Africa (Freer and Griffiths 1993). The shark breeds in sheltered embayments and the matured females usually face threats from fishers when they come inshore to bury oocytes in summer. Their inshore migratory behaviour makes their concentration predominant in nursery areas. Although the IUCN classified the St. Joseph population as Least Concern (LC), there are concerns that catch rates are not sustainable on the species population size and structure (Pheeha and Dagit 2006). Knowledge of the reproductive behaviour of *C. capensis* will therefore be of interest as it will provide an understanding of the species life-history traits that will help in its sustainable exploitation.

The aim of this study was to investigate the reproductive biology of the St. Joseph and to estimate critical parameters of the reproductive cycle, 20 years after the study by Freer and Griffiths (1993). Variations in these biological parameters are important in predicting how a population may respond to fishing pressures (Cailliet et al. 2005). Examples of such variations used in predicting over-exploitation include the reduction in mean size, reduction in age / size at maturity and increase in growth rate and fecundity (Hoenig and Gruber 1990).

Chapter 2: Biological investigation into *C. capensis*

2.1 **Introduction**

The investigation on the biological parameters of the commercially exploited *C. capensis* stocks is of vital importance (Cailliet et al. 2005). Fishing pressures causes variability in reproductive characteristics which may be different between populations, and the recognition of these differences is essential for designing proper management (Snelson et al. 2008). Determination of variable biological traits will help answer important questions as to what size, when and where *C. capensis* spawns, and allow to set the minimum allowable fish size in the catch and to protect the breeding stocks which become vulnerable as they aggregate at the spawning grounds (Ogutu-Ohwayo 1990, Hill 1992).

To assess the variability in life-history traits for St. Josephs, this study sought to: i) carryout both external and internal examination of both sexes of St. Joseph caught, ii) estimate the reproductive parameters, and iii) address population dynamics based on sexual maturity, sex ratio, gonadosomatic index (GSI), variation of oocyte size-frequency distribution and fecundity. In addition, sources of variation in the feeding habit of *C. capensis* such as sex and maturity will also be examined by: i) quantifying the overall dietary composition and account for how much variability would be expected when calculating the overall food items, and ii) testing the effects of maturity condition and sex variation on dietary composition. Information on the species feeding behaviour, as well as condition factor (K) and hepatosomatic index (HSI) are considered as a potential factor governing variation in fecundity (Murua et al. 2006).

2.2 **Materials and Methods**

2.2.1 Study site

Samples were obtained from commercial catch landings from fishermen on October 1st and 14th, 2010 at the Velddrif harbour (32° 80′ S and 18°18′ E) (Figure 2.1).

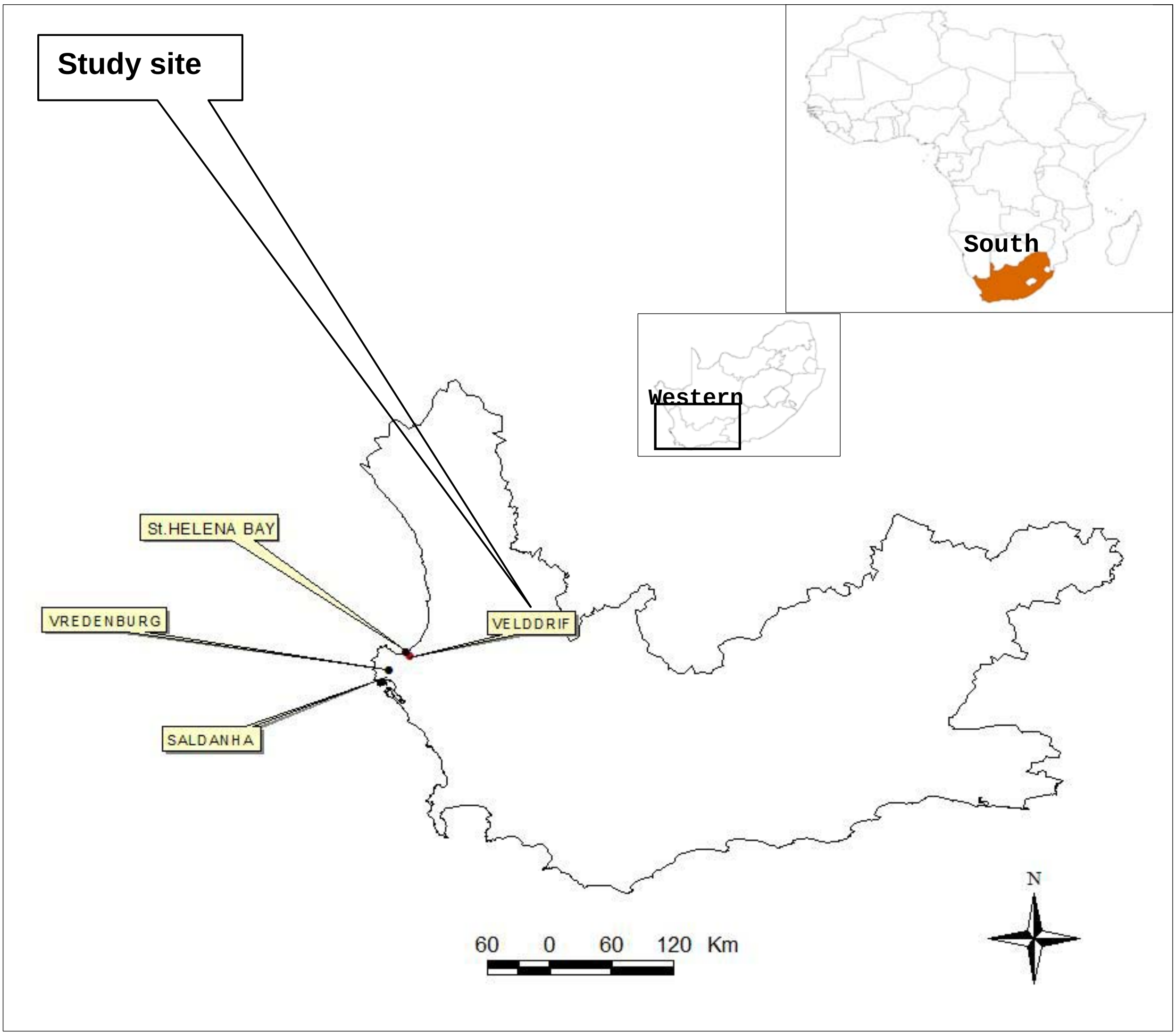


Figure 2.1. Map of the Western Cape of South Africa showing location of study site at Velddrif.

The fishing harbour is located in the estuary where the Berg River flows into St Helena Bay, which is a site noted for high concentrations of gillnet and seine-net fishing (Freer and Griffiths 1993, Hutchings and Lamberth 2002a/b, Hutchings et al.

2002). Clarke et al. (2002) categorised Velddrif as a subsistence fishing community within the Benguela Current Large Marine Ecosystem (BCLME).

2.2.2 Sampling procedure

In total 173 frozen specimens of *C. capensis* were available for examination. Laboratory analysis of these specimens involved morphometric and reproductive analysis of both sexes. Each specimen was left to be thawed before commencement of measurements and dissections. Primary measurements included the weight (g), total length (TL), precaudal length (PCL), inner clasper length (ICL), dorsal origin to precaudal pit (DOPCP) and dorsal origin to caudal tip (DOCT) (Figure 2.2). Total lengths (TL, mm) are used throughout this study. The relationship between precaudal length (PCL, mm) and total length (TL, mm) for *C. capensis* was calculated as:

$$\mathrm{TL} = 1.34(\mathrm{PCL}) + 67.27 \quad (n = 163,\ r^2 = 0.970) \qquad \text{Eqn 2.1}$$

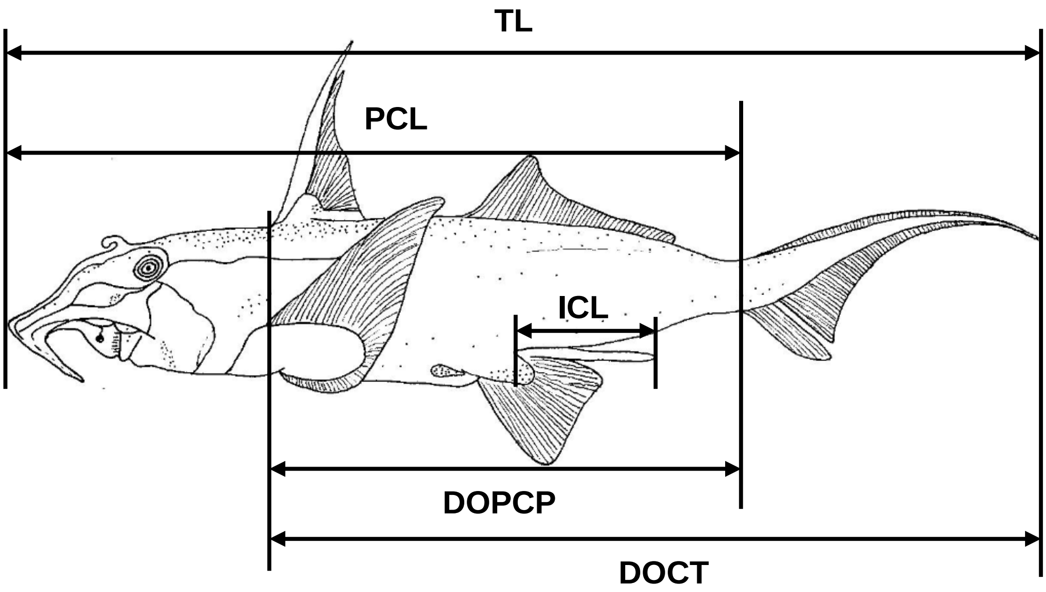


Figure 2.2. Diagram of a male *C. capensis* showing morphometric dimensions.

2.2.3 External examination

The fish was sexed externally prior to dissection and weighed to the nearest 0.1 g. Shark specimens were sexed visually by the presence or absence of male claspers. The sexual maturity for male St. Josephs were determined on the basis of inner clasper length (ICL). Clasper elongation, articulation and calcification for these males were examined following Pratt (1979) and Compagno (1984). Claspers were assigned a clasper state value, ranging from 1 to 3 (1 – clasper soft, uncalcified and shorter than pelvic fin, 2 – clasper soft, uncalcified and longer than pelvic fin, 3- clasper hard and calcified). Additionally, clasper articulation (ability to rotate anteriorly) was scored by as yes or no. Inner clasper lengths as well as basal width were recorded to the nearest 0.1 mm using callipers.

Females do not develop external sexual characteristic but the presence of seminal plugs in sexually mature females was checked and noted.

2.2.4 Internal examination

The body cavity of the sharks was opened by cutting through the body wall from the cloaca to slightly anterior of the pectoral girdle, to expose the internal organs. The testes were removed and weighed to the nearest gram and the presence or absence of sperm in the seminal sac was noted (Yano 1995). The developmental stages of gonads, as indicated by size, colour and texture was noted.

The maturity of females was assessed by visual inspection of reproductive organs. Females were considered mature by the presence of well-developed oocytes within the ovaries and widening of the uterus (with a wider terminal end). All oocytes larger than 10 mm were counted and the length of the two largest oocytes per ovary was measured and recorded to the nearest 0.1 mm with callipers. The ovaries, uteri and nidamental glands were removed and weighed to the nearest gram. Sexually matured females were examined for egg cases in the nidamental gland. The egg case was removed and the length measured to the nearest 0.1 mm and weighed to the nearest 0.1 g, and recorded against the corresponding fish.

Freer and Griffiths (1993) categorised the sexual maturity of *C. capensis* in four stages as: newborn, juvenile, adolesent and adult. For this study, both the males and females were divided into two reproductive stages; immature (newborn and juvenile) and mature (adolescent and adult) (Figure 2.3). Macroscopically, sexual maturity of gonads (ovaries and testes) was classified according to indices modified from Walker (2005) (see Tables 2.1 and 2.2).

Table 2.1. Ovary, uterus and nidamental gland indices used to assess sexual maturity in female *C. capensis* (modified from Walker 2005).

	Index	Maturity	Description
Female			
Ovary index	1	Immature	Small clear lobes, largest follicles not yolked and diameter < 5 mm, ovary weight < 0.1 g (pre-vitellogenic).
	2	Mature	Largest oocytes with yolk and diameter of oocytes 4-10 mm, ovary weight > 0.5 g (vitellogenic).
	3	Mature	Largest oocytes with yolk, yellowish, diameter of oocytes > 10mm, ovary weight > 1 g (vitellogenic).
Uterus index	1	Immature	Uterus is a uniformly thin tubular structure/ not widened / partly enlarged posteriorly / uterus weight < 0.4g.
	2	Mature	Uterus is a uniform enlarged tubular structure/ uterus weight > 0.4g.
Nidamental gland	1	Immature	Nidamental gland is distinct from its anterior oviduct, weighs < 0.4 g.
	2	Mature	Nidamental gland is distinct /enlarged/ lack clear internal zonation/ has clearly defined internal zonation/weighs > 0.4g

Table 2.2. Clasper calcification status and testis index used to assess sexual maturity in male *C. capensis* (modified from Walker 2005).

	Index	Maturity	Description
Male			
Clasper calcification	Uncalcified (1)	Immature	Clasper completely soft and flexible. No articulation.
	Partially calcified (2)	Immature	Clasper partially rigid, but still flexible. No articulation.
	Fully calcified (3)	Mature	Clasper fully rigid. Articulated.
Testis	1	Immature	Testis not macroscopically differentiated from epigonal gland.
	2	Immature	Testis thin (width <5 mm) with epigonal organ dominant.
	3	Mature	Testis enlarged, thickening (width ≥ 5 mm) and distinct seminal sac present; sperm.

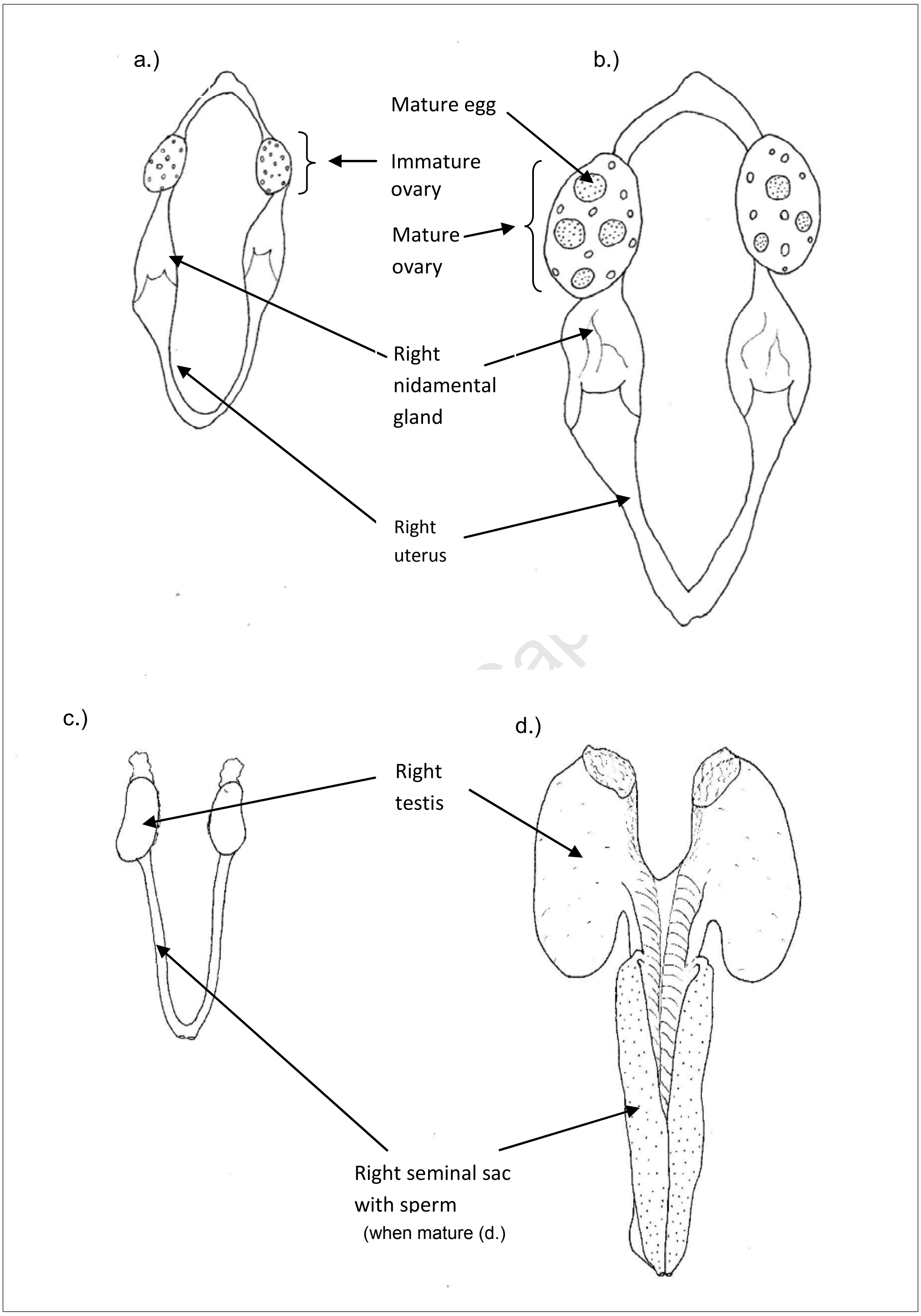


Figure 2.3. Drawing showing reproductive organs of male and female *C. capensis* at different stages of maturity; immature (a-female and c- male) and mature (b-female and d-male) (Drawing by author).

Other measurements recorded for each fish were the weights of the liver, heart and stomach. Fecundity for the females was estimated macroscopically by counting the number of developing oocytes in the ovary and the relationship between fecundity and total length of each mature female was assessed. The Gonadosomatic Index (GSI), Hepatosomatic Index (HSI) and Le Cren's (1951) relative condition factor (K) were calculated. Each of these three indices was defined as follows:

$$GSI = \frac{GW}{M_T} \times 100 \qquad \text{Eqn 2.2}$$

$$HSI = \frac{M_L}{M_T} \times 100 \qquad \text{Eqn 2.3}$$

$$K = \frac{M_T}{aTL^b} \times 100 \qquad \text{Eqn 2.4}$$

Where M_T = total ungutted body weight (g), GW = gonad weight (g), M_L = liver weight (g) and TL = total length (mm). The parameters *a* and *b* were calculated by least-squares regression from a log-transformed data. The mean of these indices during reproductive period were compared between species sex, maturity and size .

2.2.5 Gut content examination

The diet of *C. capensis* was studied by examination of the stomach contents of each specimen after morphometric and reproductive data were recorded. Before opening each stomach, the stomach was weighed to the nearest 0.1 g using an electronic scale. Prey items were identified, and classified to the highest possible taxonomic resolution and quantified for each opened stomach. The number and state of the prey found in each opened stomach was recorded. In this study, prey items found in each fish stomach was evaluated as percentage frequency of occurance (% F). Frequency of occurrence uses the formula below as described by Hyslop (1980):

$$F_i = \frac{n_i}{n} \times 100 \qquad \text{Eqn 2.5}$$

where:

F_i: frequency of occurrence of the *i* food item in the sample;

n_i: number of stomachs in which the *i* item is found;

n: total number of stomachs with food in the sample.

Percentage frequency of occurrence (%F) is the proportion of shark stomachs containing a specific prey item.

2.2.6 Data analysis

The length-mass relationships for both sexes of *C. capensis* were calculated using the function described by Ricker (1973):

$$M_T = aTL^b \qquad \text{Eqn 2.6}$$

Where M_T is the body mass or weight (g), TL is the total length (mm), *a* is a coefficient related to body mass or weight (g) and *b* is the exponent indicating fish growth rate (Beverton and Holt 1996).

The parameters of *a* and *b* of M_T vs TL relationship were estimated by the least-square method from logarithmically transformed data (log M_T = log*a* + *b* logTL), The statistical significance level of r^2 and 95% confidence limits of the parameters *a* and *b* were estimated (Santos et al. 2002).

The isometric increase in fish weight are given by the exponent $b = 3$. When the value of *b* is other than 3, growth is hypo allometric ($b<3$) or hyper allometric ($b>3$). The null hypothesis of the isometric growth (H_0: $b = 3$) was tested by *t*-test, using the statistic: $t_s = (b-3)/S_b$, where S_b is the standard error of the slope, for α=0.05 for testing significant differences among slopes (*b*) between two regressions for the same species (Morey et al. 2003).

The sex ratio was expressed as the proportion of females (males) to total numbers of females and males:

$$\text{Sex ratio} = \frac{\text{number of females (males)}}{\text{number of females} + \text{number of males}} \qquad \text{Eqn 2.7}$$

The chi-square goodness of fit test was used to examine the homogeneity of sex ratio using Yates correction to find deviation from the expected 1:1 sex ratio. Also, chi-square statistics using 2 x 2 and 2 x 3 contingency tables were used to evaluate the association between sexes, dependency of maturity on fish sex and the dependence of fish size on sex. Other data noted and analysed were the length or size frequency, maturity stage analysis and the gut content analysis.

A paired sample student *t*-test was used to test the asymmetry between right and left reproductive organs in matured males and females (Zar 1984). Once samples of all sizes were obtained, a graph of the relationship of total body length to organ length or mass was constructed to find the inflection at the point of maturity. This showed a similar approximation for all reproductive organs measured per sex. The length-at-maturity estimation for both sexes was calculated for the length at which 50% of each sex matured. Data were fitted for each sex to a logistic model:

$$PM_i = \left(1 + \exp - \frac{(L_i - Lm_{50})}{d_L}\right) \qquad \text{Eqn 2.8}$$

Where: PM_i = the proportion of mature fish in the i^{th} length class

L_i = i^{th} length class

Lm_{50} = length-at-50% maturity

d_L = the width of the logistic ogive, or the rate at which the population changes from 0% to 100% mature.

Maximum likelihood estimates of the parameters were obtained by minimizing the binomial likelihood through routine use of SOLVER in Microsoft Excel (Cerrato 1990). The calculations of the likelihood of immature and mature individuals were 1 - PM_i and PM_i respectively. The effect of sex was compared using χ^2-tests of likelihood ratios. Other calculated estimates obtained were the length at which the population is mature for both sex of St. Joseph (i.e., median length-at-maturity) and the size-at-50% maturity. The determination of length-at-maturity was fitted into the logistic model using maximum likelihood and the effect of sex was compared using χ^2-tests of likelihood ratios.

Other calculations included the oocyte size-frequency distribution, and seasonal trends in GSI, HIS and K per sex. Sexual dimorphism in liver mass was assessed by performing a Student's *t*-test, to test the null hypothesis that there was no difference in the slopes of the linear regressions TL and M_L between the sexes.

Differences in the mean of biological indices for adult males and females were tested using one-way ANOVA, and dietary differences between sex and fish size tested using paired sample student *t*-test. When differences were detected, the post-hoc Turkey's test for unequal sample sizes was used to locate the differences.

Chapter 3: Results

3.1.1 Sex ratio

According to examination from dissections and secondary sex characteristics, a total of 173 specimens of *C. capensis* were sexed, of which 113 (65.3%) and 60 (34.8%) were females and males, respectively. Overall female/male (F/M) sex ratio was 1.88 : 1.00, showing a significant different from an expected 1:1 ratio (χ^2=16.23, d.f. = 1, $p = 5.6 \times 10^{-5} < 0.05$). Samples showed an unequal sex ratio between sexes (Table 3.1). The overall sex ratio (F/M) of mature fish greatly favoured the females; sex ratio = 3.71:1.00 ($p < 0.05$).

Table 3.1. Table showing unequal sex ratio of *C. capensis***.**

Sex	Mature	Immature	**TOTAL**
Females	52	61	113
Males	15	45	60
TOTAL	67	106	

The ratio of mature to immature fish was 1.00:1.58. The difference was significant ($p < 0.05$). On application of chi-square test with Yates's correction, the female to male sex ratio statistics were modified as thus: overall (χ^2=15.63, d.f. = 1, $p < 0.05$), mature (χ^2=19.34, d.f. = 1, $p < 0.05$) and immature (χ^2=2.12, d.f. = 1, $p < 0.05$). The proportion of mature individuals was dependent on sex (χ^2 = 6.437, d.f. = 1, $p < 0.05$). A 2 x 3 contingency analysis that grouped fishes in the sizes; small (300 – 499 mm TL), medium (500 – 699 mm TL) and large (700 – 899 mm TL) revealed that the occurrence of fish size was independent on sex (χ^2 = 10.542, d.f. = 2, $p > 0.05$).

3.1.2 Length-frequency distribution

According to the length-frequency histogram of *C. capensis* sampled (Figure 3.1), it shows that females in the range from 400 to 499 mm TL were caught in highest abundance, whereas males in the range from 500 to 599 mm TL were most abundance. The size composition data showed a domination of small fishes. The females were generally caught at larger sizes than the males.

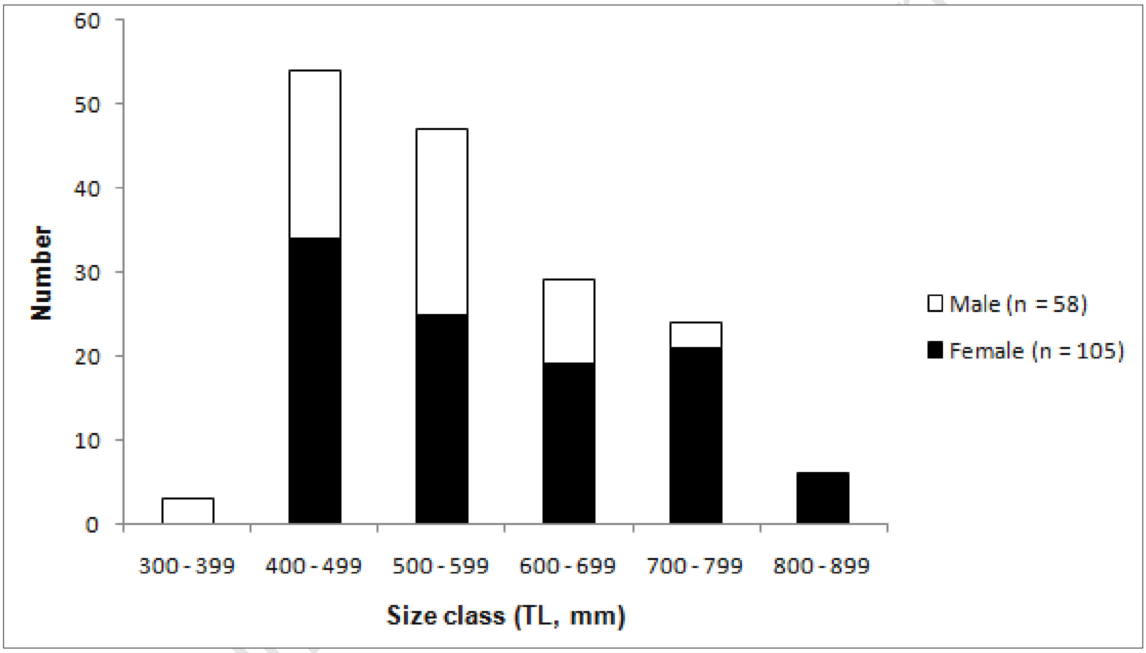


Figure 3.1. Length – frequency distribution of 58 males and 105 females of *C. capensis*.

Size class ranges were 361 - 632 mm TL and 588 – 740 mm TL for immature and mature males while that of females were 403 – 614 mm TL and 440 – 852 mm TL respectively (Figure 3.2). The smallest mature male was 588 mm TL (ICL = 62 mm) while the largest immature male was 632 mm TL (ICL = 46 mm). For females, the smallest mature fish was 440 mm TL while the largest immature fish was 614 mm TL. For the smallest mature and largest immature female samples, their ovaries, uteri and nidamental glands weighed < 0.1 g. The distribution of males is approximately normal but that for females is not (Figure 3.2).

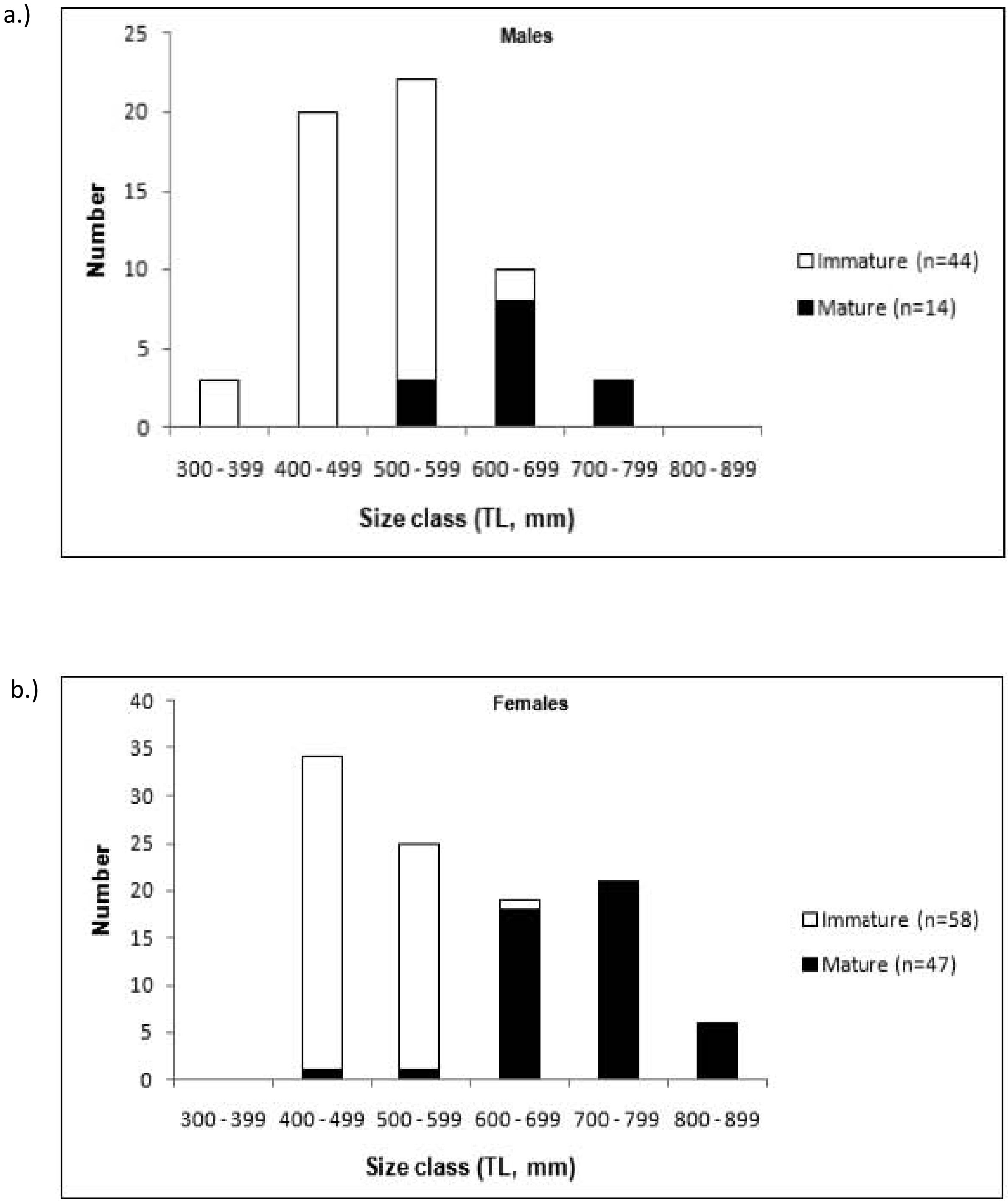


Figure 3.2. Size – frequency distribution by maturity for males (5a) and females (5b) *C. capensis*.

3.1.3 Length – mass relationship

Overall lengths ranged from 361 – 852 mm TL (569.3 ± 119.59, n = 163). Males ranged from 361 to 740 mm TL with mean of 534 mm TL (s.d. = 90.8, n = 58) and females ranged from 403 to 852 mm TL with mean of 588.8 mm TL (s.d. = 129.1, n = 105). Overall body weights ranged from 179.8 – 2800 g (852.1 ± 610.2, n = 172). The total body mass of males ranged from 182.3 to 1666 g with mean of 659.8 g (s.d. = 380.2, n = 60) and females ranged from 179.8 to 2800 g with mean of 954.2 g (s.d. = 682.2, n = 113). The weight of adult females (mean = 1510.73 g) was heavier at a given length than that of males (mean = 1208.97 g) (Figure 3.3). Significantly different length (TL) to mass (M_T) relationship was identified between males and females ($t = -2.51$; d.f. = 114; $p < 0.013$) (Figure 3.3). The values of the constants in the equation $M_T = a\mathrm{TL}^b$ that describes the length – mass relationship were as follows: for males $a = 5e^{-0.7}$, $b = 3.329$, $r^2 = 0.952$ and for females, $a = 4e^{-0.6}$, $b = 2.983$, $r^2 = 0.902$.

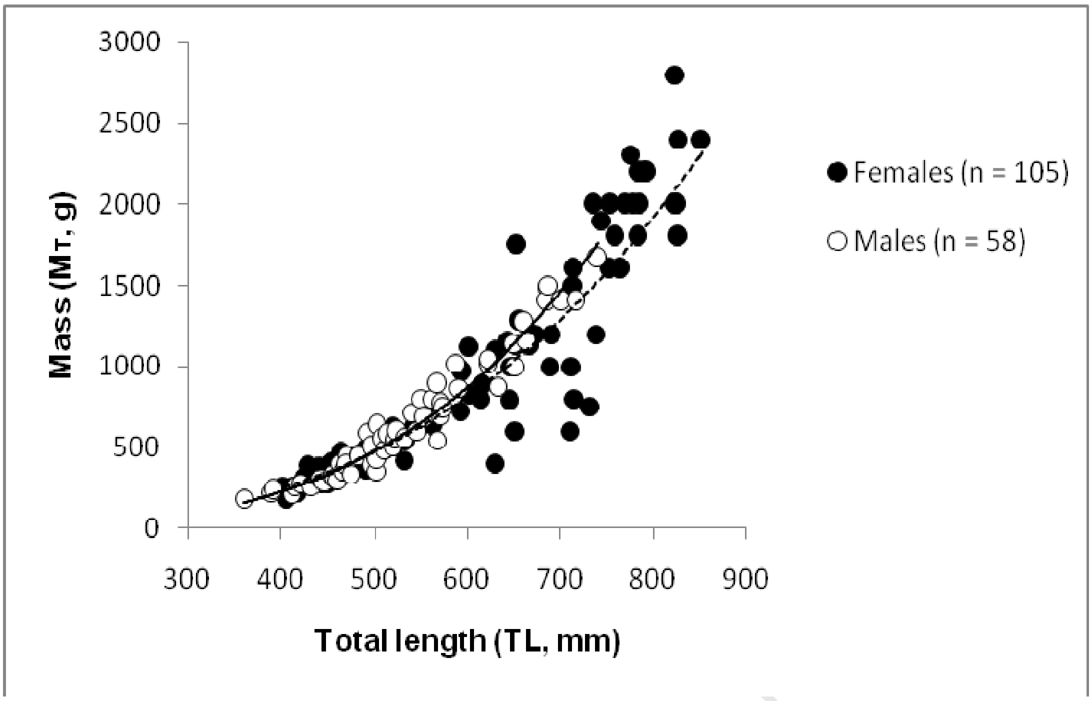


Figure 3.3. Length – mass relationship of *C. capensis* from a single catch in Velddrif, west coast of South Africa. Females (filled circles); n = 105 and Males (open circles); n = 58;. Both solid (males) and dashed (females) regression lines represent non linear fit.

The estimate of the intercept *a* for combined sexes of *C. capensis* was $3e^{-0.6}$, the correlation coefficient r^2 was 0.916 and the slope *b* was 3.053 (Figure 3.4).

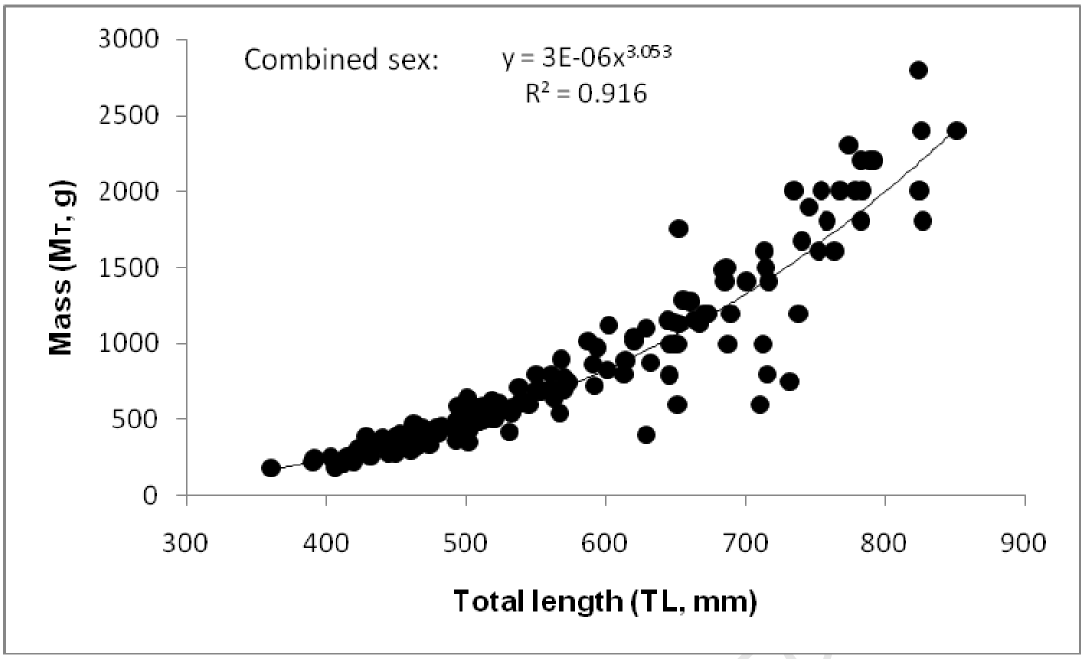


Figure 3.4. Length – mass relationship of *C. capensis* from a single catch at Velddrif, west coast of South Africa for combined sex.

Females attained greater lengths and masses than males (Figure 3.3). The heaviest male was 740 mm TL and weighed 1666 g and the heaviest female was 824 mm TL and weighed 2800 g. The values of the exponent *b* for males (3.329) was significantly ($p < 0.05$) higher than 3.0, showing a positive allometric growth. The exponent *b* value for females (2.983) was close to 3.0 ($p > 0.05$). Thus the females showed an isometric growth pattern (i.e. changing the body form following the cube law (volume = L^3) (Table 3.2).

Table 3.2. Length-weight (TL- M_T) linear relationship of *Callorhinchus capensis*. Slope of log-transformed data significantly different from 3 using *t*-test ($p < 0.05$).The slopes only differ from 3 in those cases where the growth type was allometric

TL - M_T	*a*	*b*	r^2	n	Growth type
Combined sex	$2.72 \times 10^{-6} \pm 0.2001$	3.053 ± 0.0728	0.916	163	isometric
Males	$4.93 \times 10^{-7} \pm 0.2719$	3.329 ± 0.0999	0.952	58	allometric
Females	$4.22 \times 10^{-6} \pm 0.2674$	2.983 ± 0.0968	0.902	105	isometric
Males: *Mature*	$1.99 \times 10^{-5} \pm 0.6812$	2.761 ± 0.2421	0.915	14	isometric
Immature	$5.27 \times 10^{-7} \pm 0.4487$	3.317 ± 0.1667	0.904	44	allometric
Females: *Mature*	$2.43 \times 10^{-6} \pm 0.9987$	3.065 ± 0.3504	0.629	47	isometric
Immature	$2.72 \times 10^{-6} \pm 0.4630$	3.087 ± 0.1723	0.851	58	isometric

3.1.4 Sexual maturity: Males

All male *C. capensis* smaller than 531 mm TL had a clasper state of 1, whereas clasper state of 3 started occurring at a TL of 621 mm. There were a large number of males with clasper state 2 between total length 533 mm and 632 mm (Figure 3.5). There were a few overlaps in male transition from one clasper state to another.

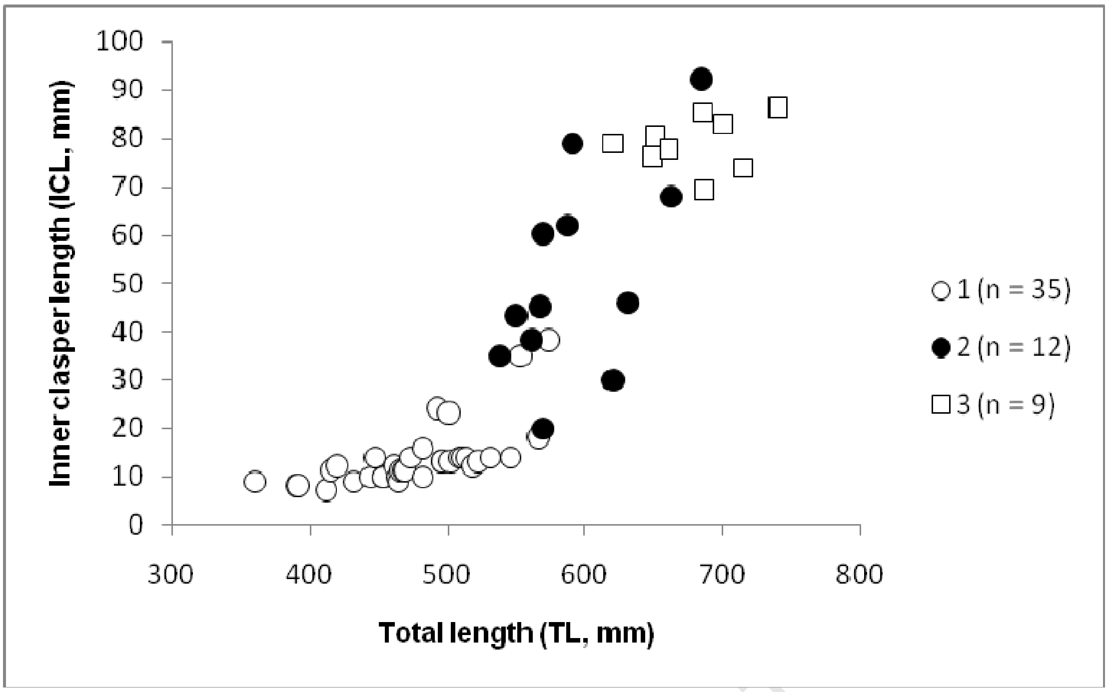


Figure 3.5. Clasper states (1, 2 or 3) of male St. Joseph sharks (*Callorhinchus capensis*) examined relative to their total length (mm) and inner clasper length (mm) (n = 56).

Articulation of the claspers was present in 17 (41.5%) of the sharks (Figure 3.6). Apart from a lone male of 621 mm TL lacking an articulated clasper, all males of size class from 621 mm of total length and above had articulated claspers. In the size class of 500 - 599 mm TL, most of the sharks examined were lacking articulated claspers. In the size class of 600 – 699 mm TL, majority of specimens had articulated claspers.

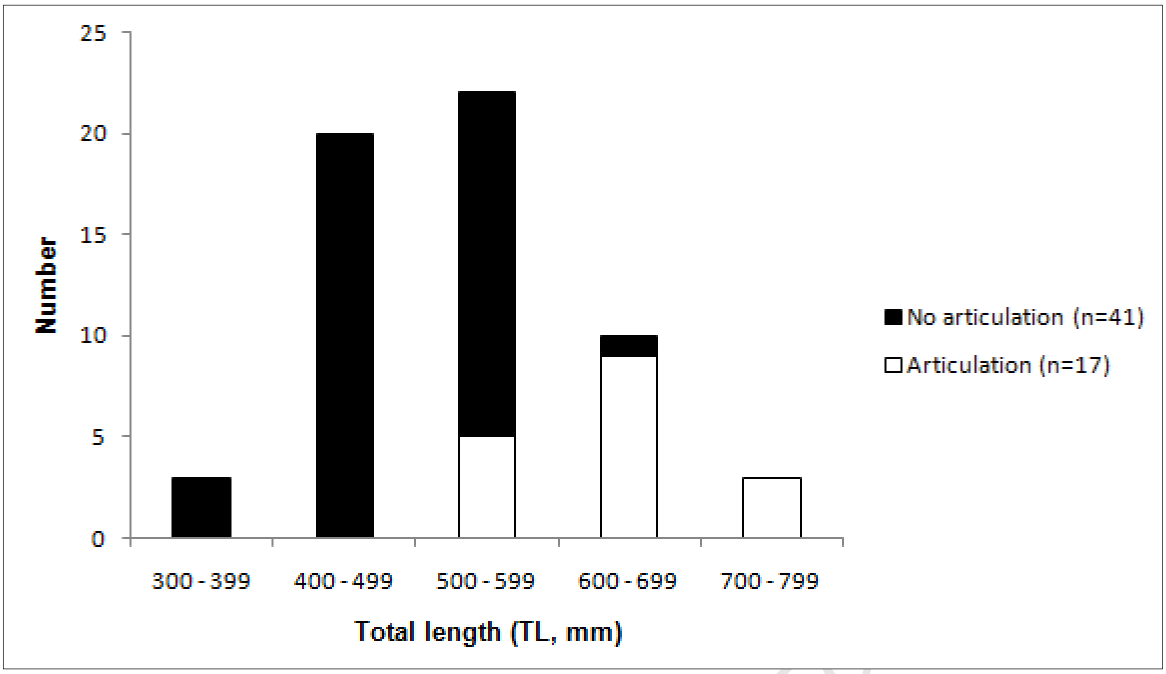


Figure 3.6. Size frequency distribution and articulation status of male St. Joseph shark, *Callorhinchus capensis* (n= 58).

Development of claspers was gradual. They appeared flaccid in immature specimens and began to grow rapidly once males reach 588 mm TL (Figure 3.7). The calcification of claspers was observed from 588 mm TL upwards. The relationship between inner clasper length (ICL) and total length (TL) was described as:

$$ICL = 2e^{-11}TL^{4.462}(n = 58, r^2 = 0.812) \qquad \text{Eqn 3.1}$$

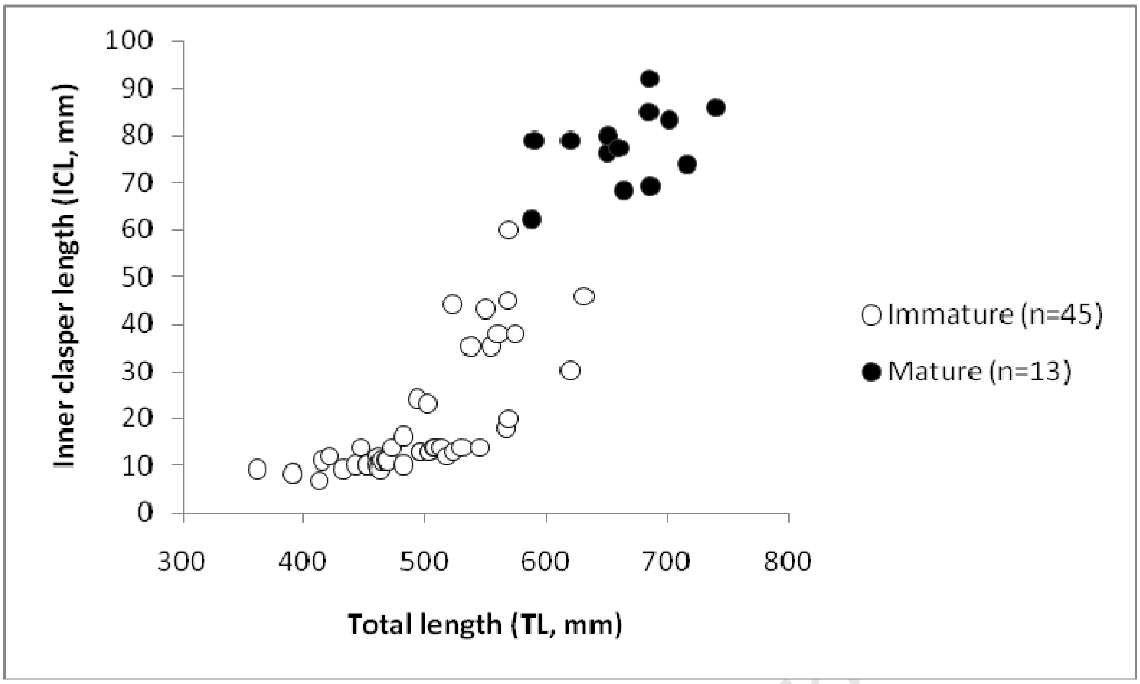


Figure 3.7. Relationship between clasper length and total length of *C. capensis* (n = 58).

The basal width for the immature male specimens ranged from 2 mm to 12 mm (mean = 3.8, s.d = 2.12, n = 45), while those of mature males were between 4 mm and 15 mm (mean = 11, s.d = 2.91, n = 14). For inner clasper length, immature males ranged from 7 mm to 60 mm (mean = 20.0, s.d = 13.18, n = 45), while claspers of mature males ranged were between 62 mm and 92 mm (mean = 73.2, s.d = 18.74, n = 14). There was significant increase in both the basal width and length of clasper with TL. The small immature male specimens had small claspers that lacked calcification.

Of the 60 male St. Josephs sampled, sperm was found in 11 (18.3%) individuals (Figure 3.8). The smallest male with sperm was 588 mm in total length. A transition stage for sperm presence started from the size class of 500 – 599 mm TL though a few large males of between the size class (600 – 699 mm TL) had no sperm.

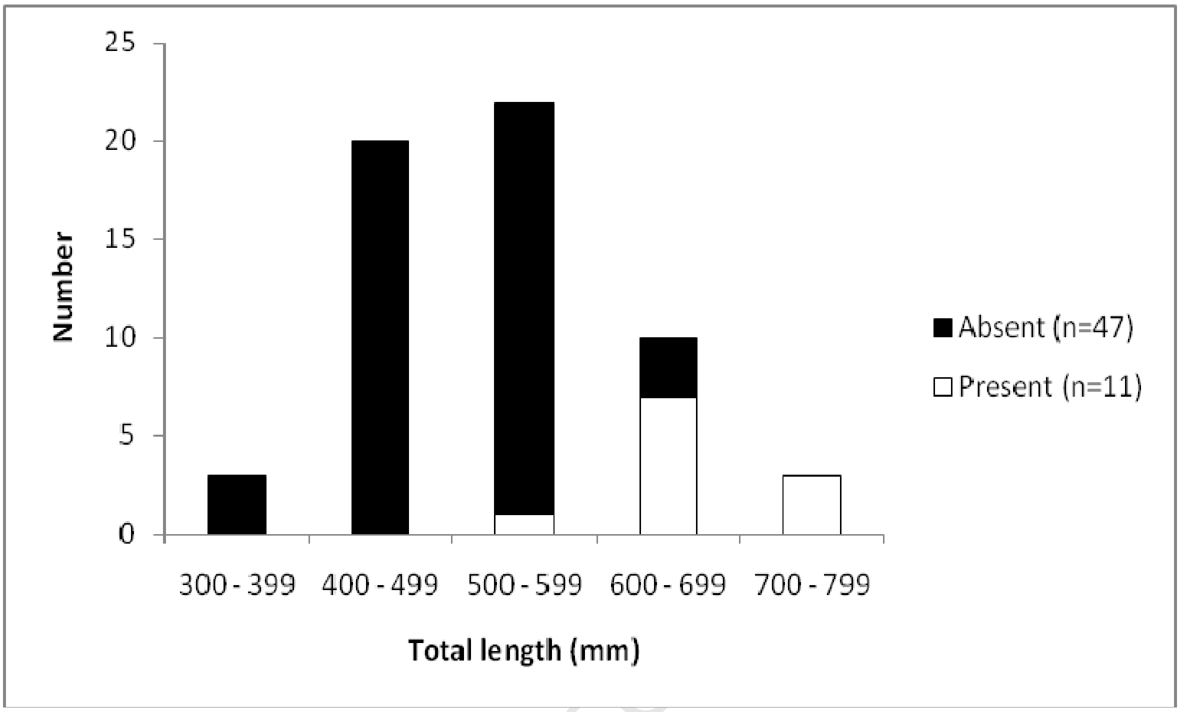
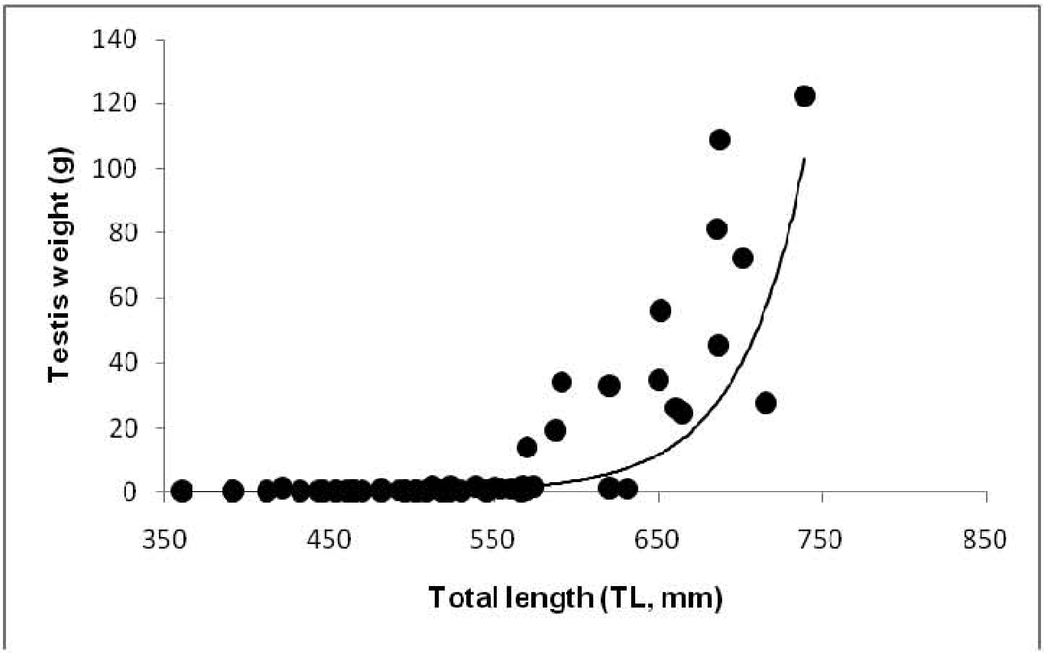


Figure 3.8. Size frequency distribution and sperm presence in male St. Joseph shark *Callorhinchus capensis* (n= 58).

Sperm presence by males was more dominant in the size class 600 – 699 mm TL compared to the other size classes.

There was no difference between the mean mass of right and left testes (t = -0.06, d.f. = 104, p = 0.95 > 0.05). Testis weight (TW) was exponentially related to both the total length TL and total weight (M_T) for male specimens following their respective relationship as shown in Figure 3.9. Testis weight (TW) of the mature males ranged from 26.3 to 122 g (mean = 60.6, s.d = 34.40, n = 10) (Figure 3.10). Growth of testes is gradual with a positive trend of the scatter diagram as a function of TL; $TW = 4e^{-15}\ TL^{5.697}$ (Figure 3.10).

a.)



b.)

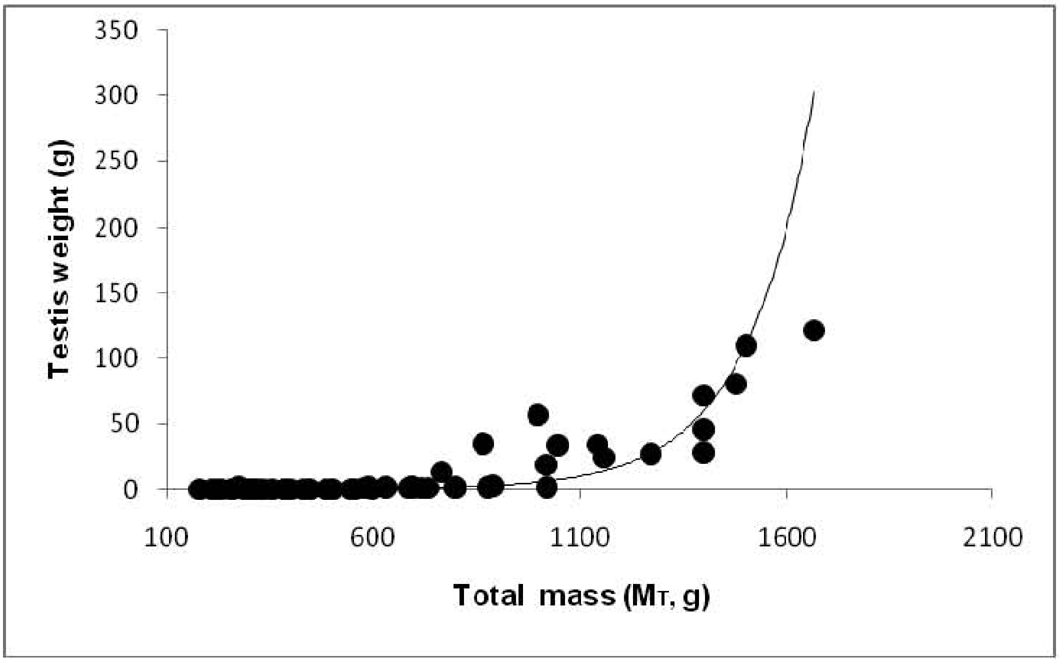


Figure 3.9. Regression for combined mature and immature male *Callorhinchus capensis* (a) testis weight and total length (TL) ($y = 2E^{-0.6}e^{0.024x}$; n = 54; $r^2 = 0.738$) and (b) testis weight against total mass (M_T) ($y = 0.013e^{0.006x}$; n = 58; $r^2 = 0.842$).

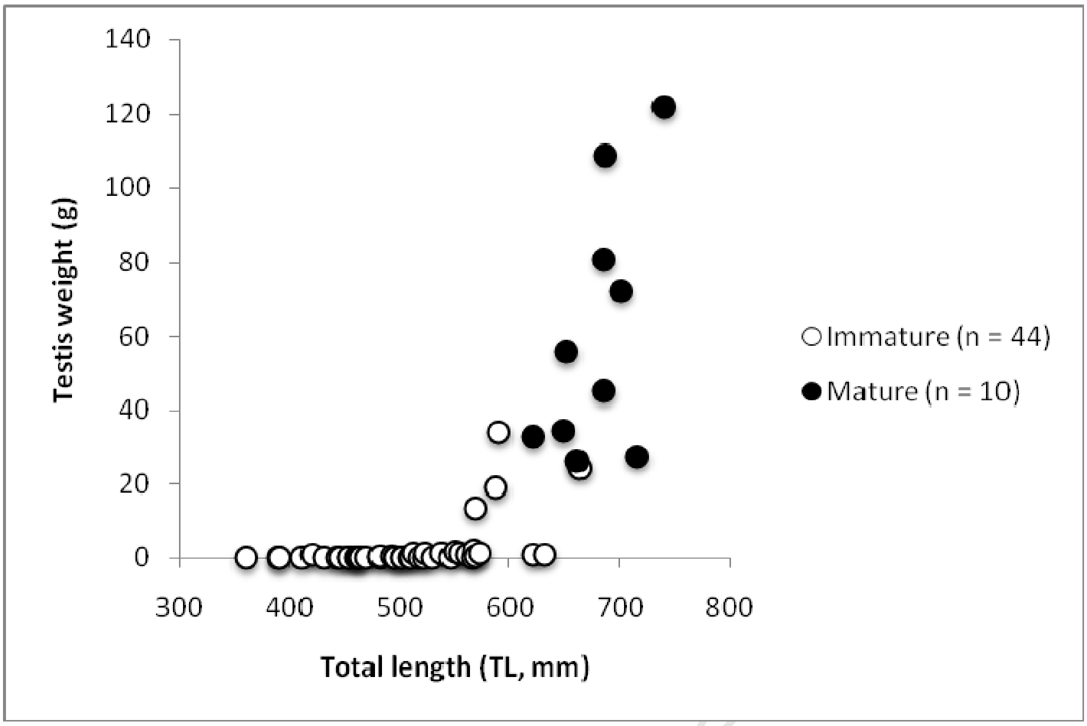


Figure 3.10. Relationship between testis length and total length of males of *C. capensis* (n = 10).

Mature male with clasper state 3 and claspers with full articulation more often presented sperm in the seminal sac. The total length-at-50% maturity (Lm_{50}) of the males was estimated at 593 mm TL (Figure 3.11).

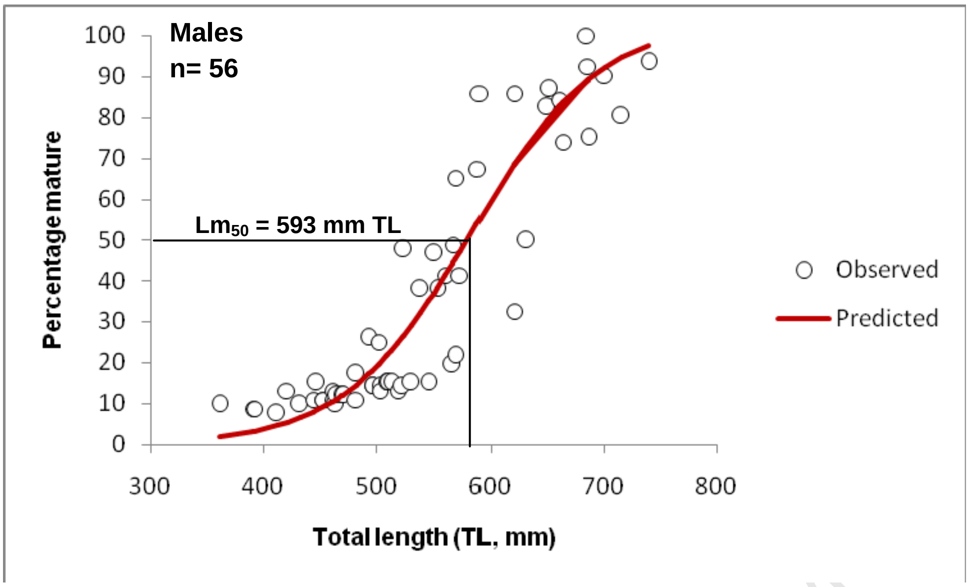


Figure 3.11. Logistic ogive showing Length-at-50% maturity (Lm_{50}) for male St. Joseph *Callorhinchus capensis* from Velddrif, west coast of South Africa.

3.1.5 Sexual maturity: Females

The nidamental glands, uterus and ovary weights were the best indicators of maturity in females. The nidamental glands of females less than 0.1 g of weight were recorded as underdeveloped (immature). These glands were difficult to distinguish from the thread-like uteri for immature females. The nidamental gland was coloured white for mature females. There was a positive correlation between the total length ($n = 104$; $r^2 = 0.86$) and total mass ($n = 102$; $r^2 = 0.76$) of female St. Joseph against the weight of the left and right nidamental glands. No significance difference in mass ($t = 0.178$, d.f. = 206, $p = 0.859 > 0.05$) of the right and left nidamental glands of female species was noticed. Mature female specimen ranged from 0.4 to 42.9 g for left nidamental gland weight (mean = 12.9; s.d = 10.6) while those of the right ranged from 0.4 g to 43.3 g (mean = 12.4; s.d. = 10.6). Paired nidamental gland weights for mature females ranged from 0.8 g to 86.2 g (mean = 25.1; s.d. = 20.08) (Figure 3.12).

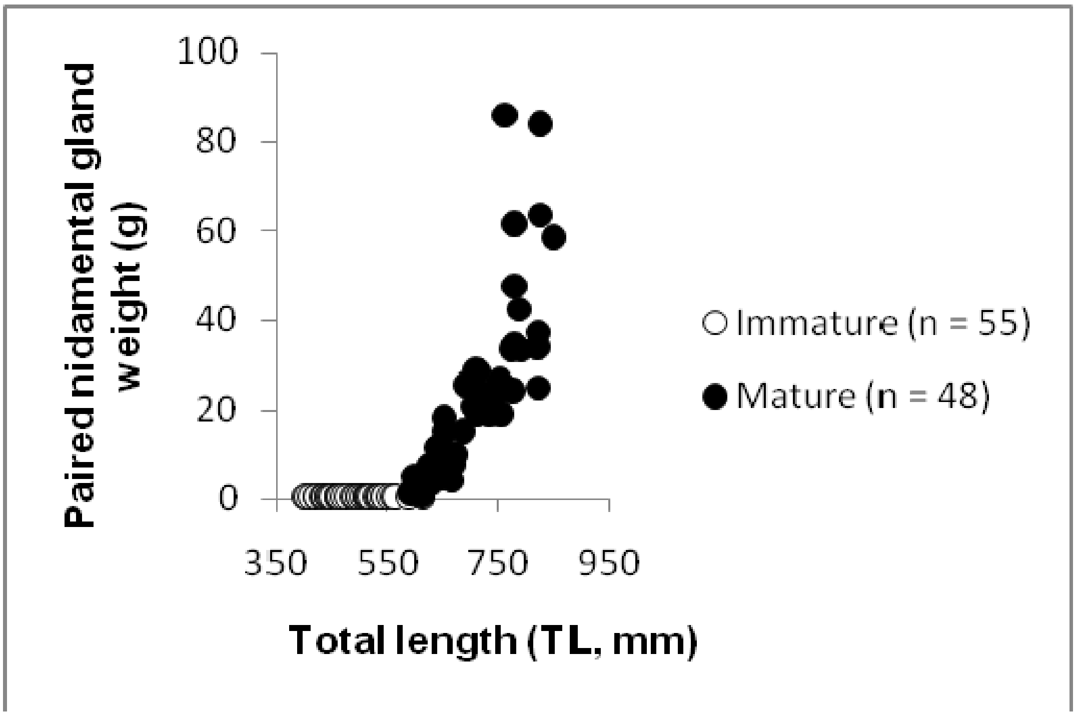


Figure 3.12. Relationship between total length and paired nidamental gland weight for female *C. capensis* from Velddrif, west coast of South Africa.

The uteri were found widened in all the mature females sampled in this study. Uterine weight remained fairly constant with increasing length in immature females and increased with sexual maturity during ovary development (Figure 3.13). Paired uteri of mature females varied between 0.6 and 22.5 g in weight (9.0 ± 6.25).

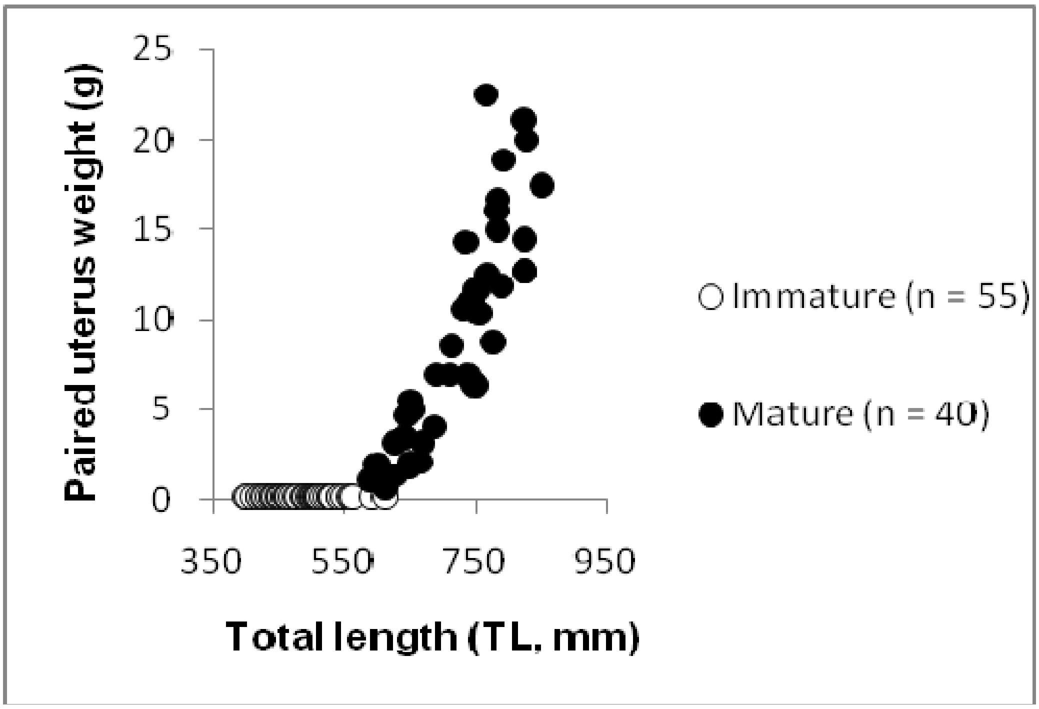


Figure 3.13. Relationship between total length and paired uterus weight for female *C. capensis* from Velddrif, west coast of South Africa.

All ovaries of weight less than 0.1 g were considered as underdeveloped (immature). Ovary weight showed clear variations with sampled species maturity; immature (n = 59) and mature (n = 45) females had two unequal developed ovaries. The paired ovary weight for immature females were all less than 0.1 g while those of the mature females ranged from 0.7 to 61.9 g (mean = 12.9 , s.d = 15.1, n = 45) (Figure 3.14). Matured females did not have symmetrical gonads, as shown by the significant differences in mass between right (mean ± s.d., 7.1 ± 8.9 g) and left (6.3 ± 7.5 g) ovaries (t = - 0.496; d.f. = 102; p = 0.621).

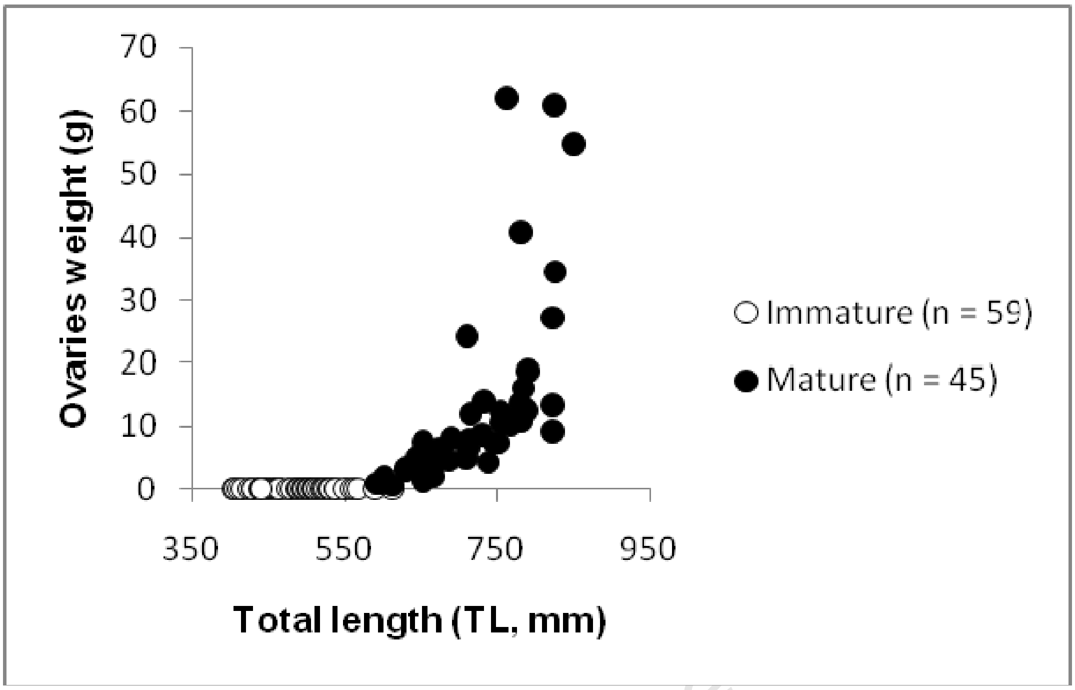


Figure 3.14. Relationship between paired ovary weight (g) and total length (mm) with respect to maturity of female *Callorhinchus capensis* (n = 104).

At 594 mm TL, female maturity was indicative as the nidamental glands, uterus and ovary began to enlarge (Figure 3.12, 3.13 and 3.14). Paired uterus weight (UW), nidamental gland weight (NG) and ovary weight (OW) for matured female specimens increased with total length (mm) according to the following respective equations:

$$UW = e^{-22}TL^{7.944};\ r^2 = 0.812 \qquad \text{Eqn 3.2}$$

$$NG = e^{-24}TL^{8.831};\ r^2 = 0.860 \qquad \text{Eqn 3.3}$$

$$OW = 2e^{-26}TL^{9.283};\ r^2 = 0.726 \qquad \text{Eqn 3.4}$$

3.1.6 Maximum oocyte inspection

For the oocytes inspected, only the more advanced ones (size > 10 mm) were used for fecundity (F) estimates. Both the paired ovary weight (g) and the number of oocytes > 10 mm showed a steady rise with increase in total length (mm) of sampled species. Most of the females between the total length of 403 and 688 mm had no oocyte greater that 10 mm, while a majority of female specimens larger than 690 mm had oocytes larger than 10 mm. The greatest numbers oocyte with diameters > 10 mm were found in the larger females of total length 827 mm (11), 852 mm (13) and 783 mm (14) respectively (Figure 3.15). The total length of oocyte-bearing females (≥ 1 oocyte), each with diameter > 10 mm was between 653 mm and 852 mm (763.1 ± 49.09 mm); n = 27. The estimated fecundity of oocytes > 10 mm for mature female *C. capensis* (n = 27) ranged from 1 to 14 oocytes (5.3 ± 3.79 oocytes). The total ovary weight and ovarian fecundity (number of oocytes > 10 mm) were significantly related ($t = 4.136$, d.f. = 52, $p = 0.0001 < 0.05$) (Figure 3.15). Number of oocytes > 10 mm overlapped for some mature-active females irrespective of total length and ovary weight for the sampled specimens (Figure 3.15). The fecundity and total length for female *C. capensis* was generally described as:

$$F = 0.038TL - 24.21,\ r^2 = 0.483,\ n = 44. \qquad \text{Eqn 3.5}$$

A significant relation between the paired ovarian weight and their corresponding hepatosomatic index were not clearly evident for the sampled female specimens of this study ($t = 2.635$, d.f. = 52, $p = 0.011 < 0.05$). The shape of the female sharks' ovaries examined varied with fish size.

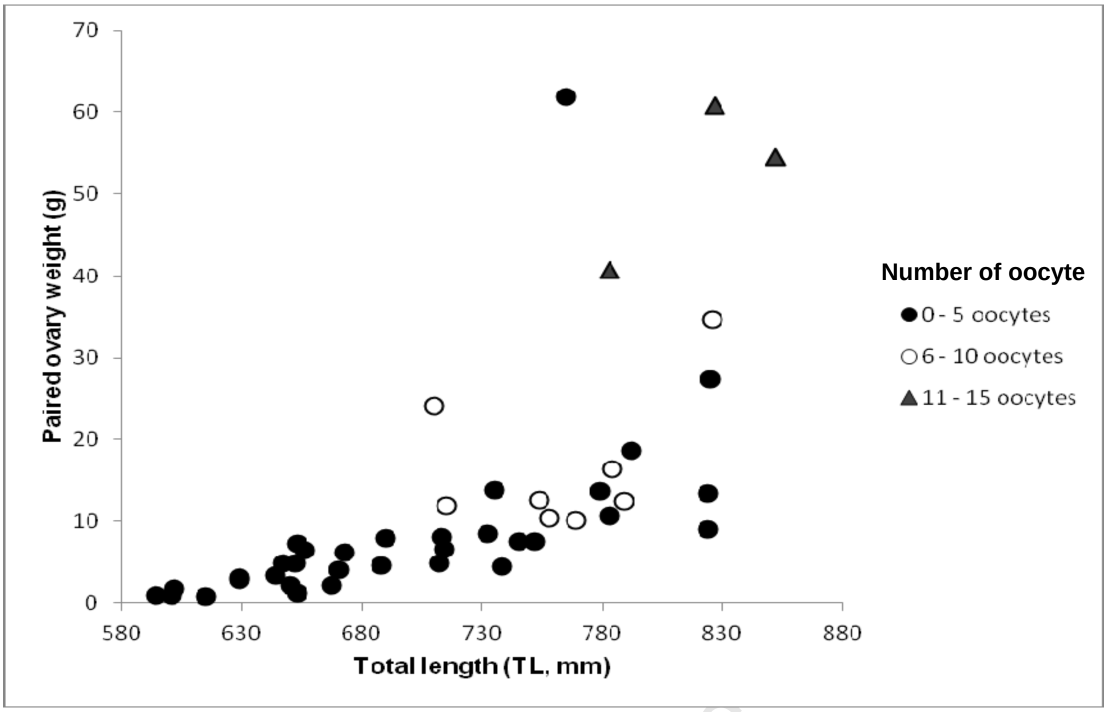


Figure 3.15. Relationship between paired ovary weight (g) and total length (mm) with respect to the number of oocytes > 10 mm for mature female *Callorhinchus capensis*(n = 44).

Gonad weight increased with ovary development and oocyte maturation. Sexually reproductive females with the highest average values of paired ovary weight and oocyte diameter respectively was 52 g with a mean number of 13 oocytes per ovary each with average oocytes diameter > 10 mm. Maximum oocyte diameter (MOD) was not a clear indicator for female maturity as there was an overlap in oocyte sizes at some lengths of shark (Figure 3.15, 3.16). An egg-bearing female of 826 mm TL weighing 2400 g with egg cases reached a high uterus weight of 21 g due to the presence of egg-cases (Figure 3.17). Mucus plugs were found in a mature female of mass 2200 g.

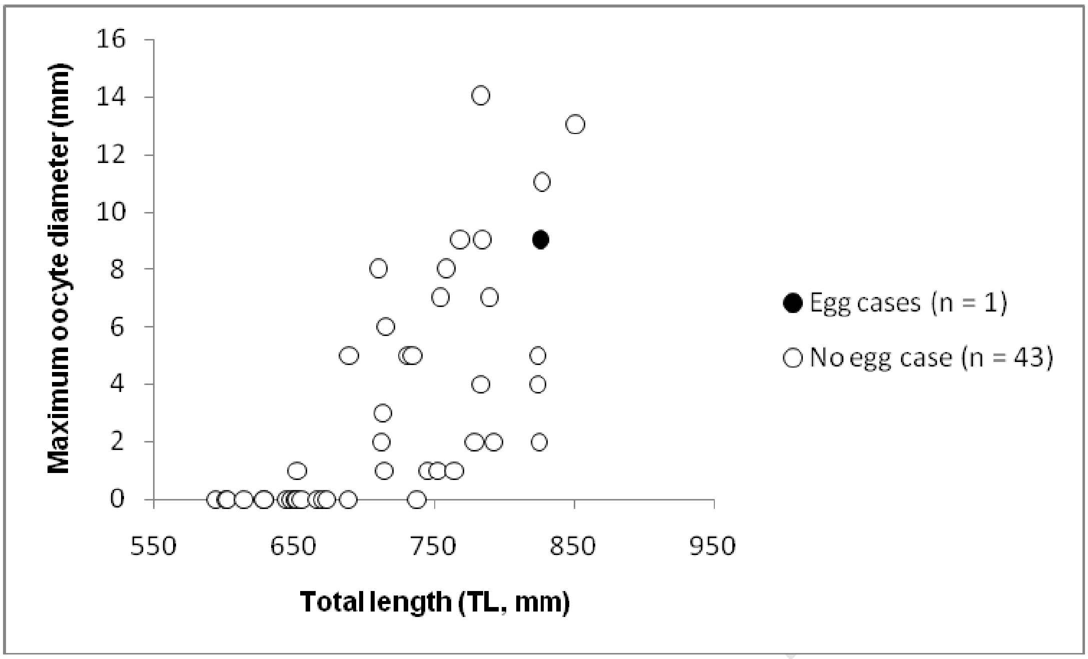


Figure 3.16. Maximum oocyte diameter versus total length of female *C. capensis* from Velddrif, west coast of South Africa (n = 44).

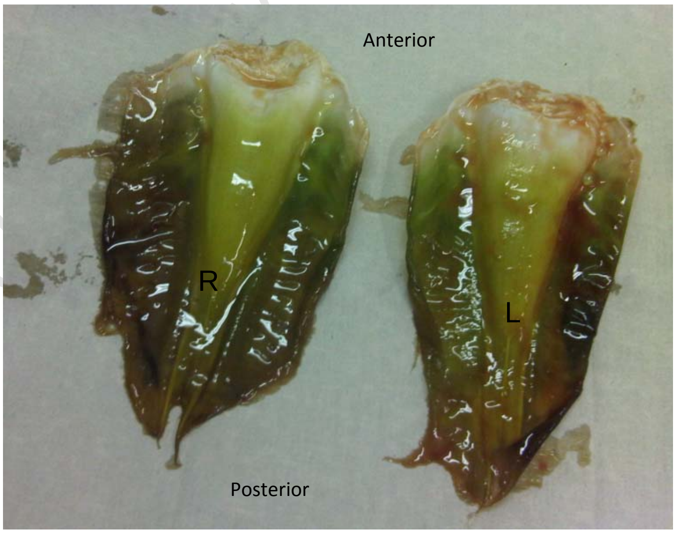


Figure 3.17. Egg-cases of a mature females *C. capensis* at the actively spawning stage. Left (L): 130 mm and Right (R): 135 mm; total length 826 mm and mass 2400 g.

Figure 3.18 shows the oocyte size-frequency trend determined from macroscopic examination for adult female *Callorhinchus capensis* ovaries (n = 50). Oocytes in all stages of development were present. The graph showed a continuous oocyte size-frequency distribution pattern of sampled ovaries. This observation indicates that the species exhibit an asynchronous ovarian development organisation. In asynchronous ovulators, oocytes recruited and ovulated from the population of yolked oocytes in several batches over a protracted period during spawning season (Murua and Saborido-Rey 2003). The different sizes or modes in the continuous oocyte size-frequency distribution indicate the presence of several batches.

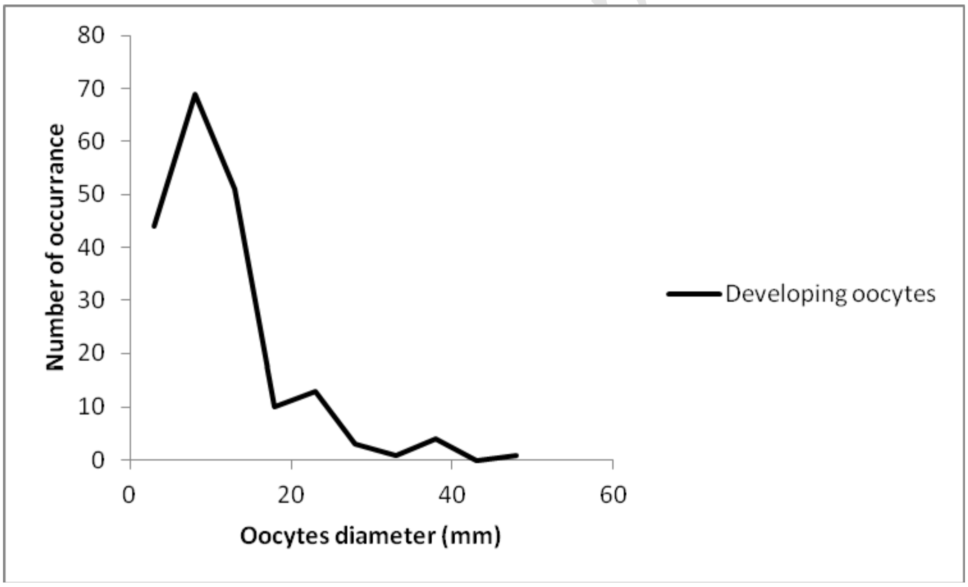


Figure 3.18. Size-frequency distribution of oocytes determined from macroscopic measurement from the ovaries of mature female *Callorhinchus capensis* (n = 44).

The length-at-50% maturity (Lm_{50}) for female *C. capensis* was estimated at 754 mm TL (Figure 3.19). Females mature at a considerably larger size than males when compared with Figure 3.11.

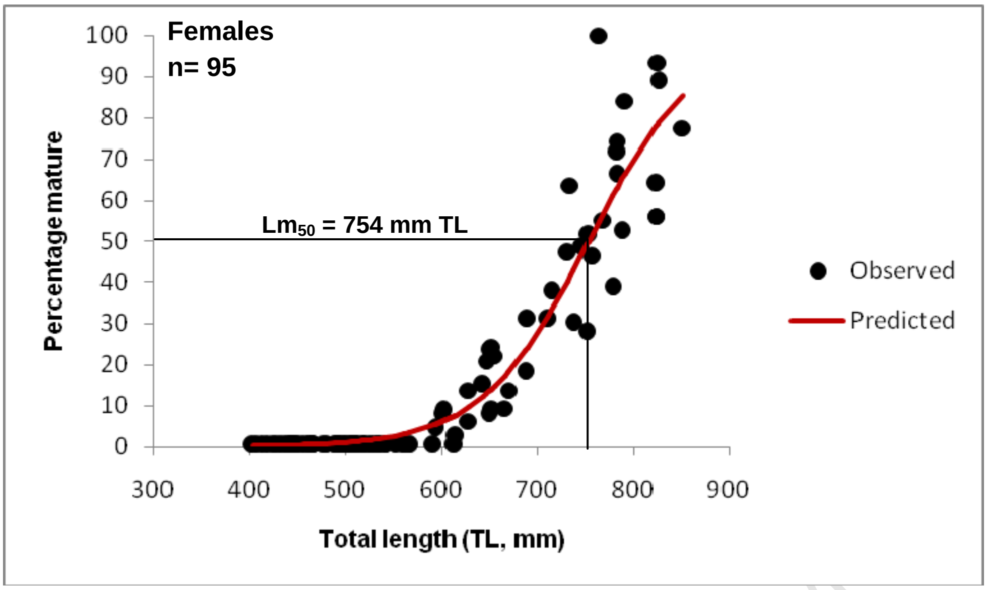


Figure 3.19. Length-at-50% maturity for female *Callorhinchus capensis* from Velddrif, west coast of South Africa.

3.1.7 Biological indices

The relationship between gonad weight (GW) and gonadosomatic index (GSI) of matured specimens of St. Joseph and fish size are respectively shown in Figure 3.20. The gonad weight and body length for both sexes were each given by the relationship below.

The equation for females was:

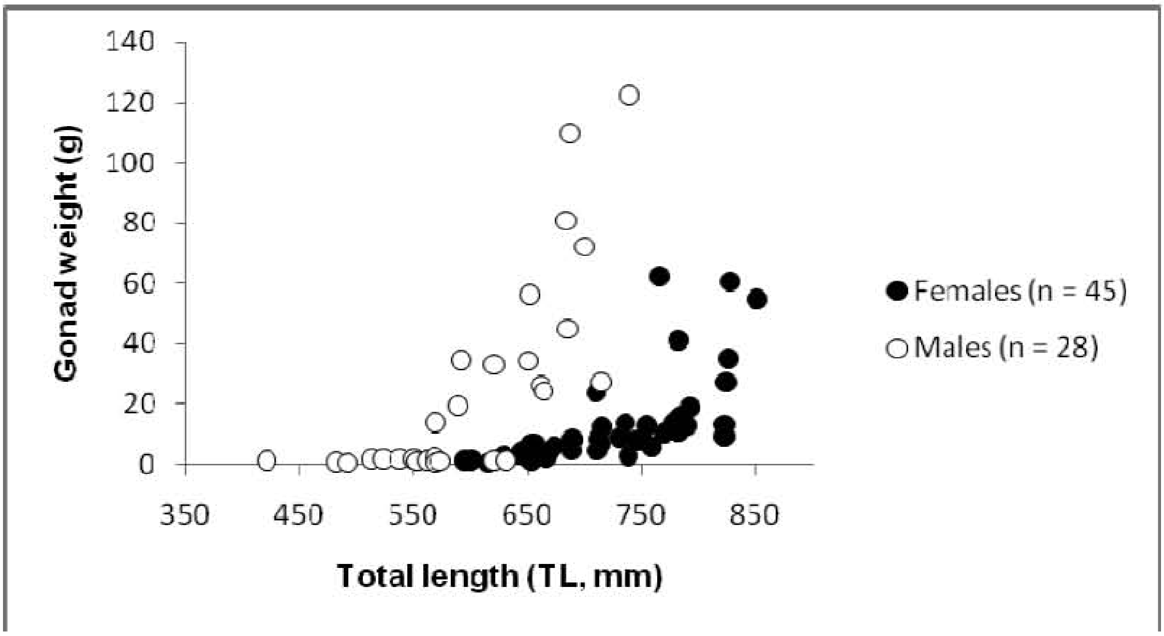
$$GW = 5\,e^{-26}TL^{9.160}\ (n = 45;\ r^2 = 0.694). \qquad \text{Eqn 3.6}$$

and for males was:

$$GW = 2\,e^{-32}TL^{11.75}\ (n = 28;\ r^2 = 0.644). \qquad \text{Eqn 3.7}$$

The GSI was correlated with fish size for both sexes (Figure 3.20b). Large specimens had relatively larger gonads compared to body weight. However, the data were more variable and showed a poor linear fit (Figure 3.20b).

a)



b)

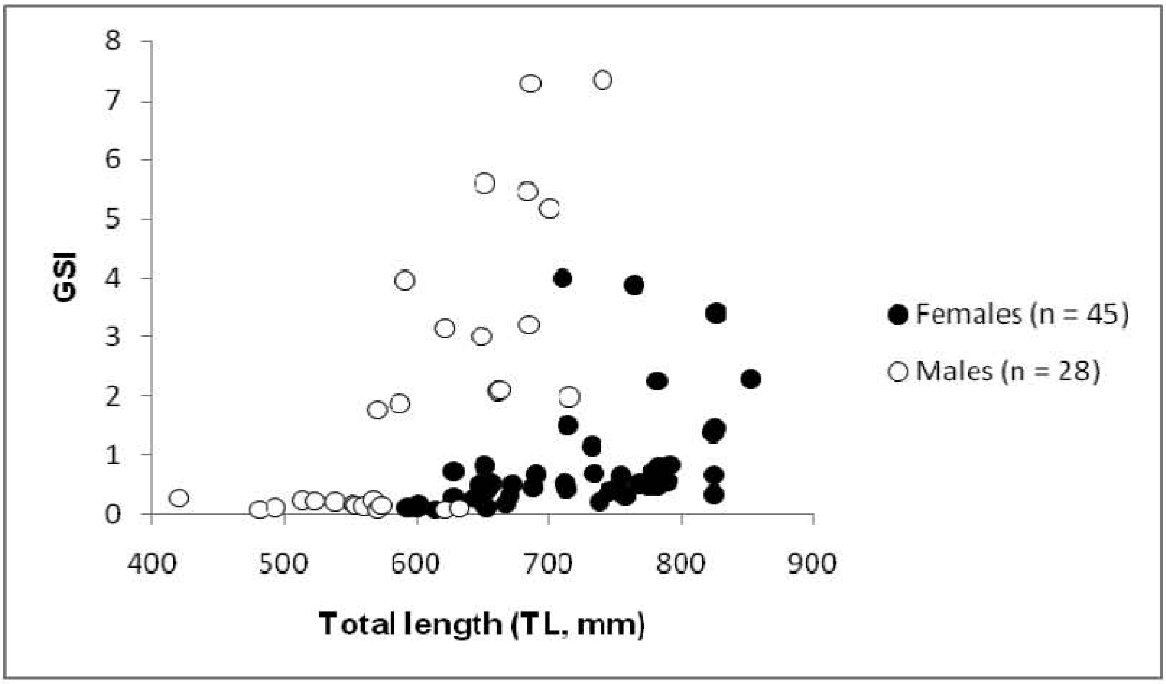


Figure 3.20. a) Relationship of total length and gonadal weight for males (empty circles) and females (full circles). b) Relationship of total length and gonadosomatic index (GSI) for males (empty circles) and females (full circles) for *Callorhinchus capensis* from Velddrif, west coast of South Africa.

The liver weight (M_L) of *C. capensis* increased equally in both sexes up to about 700 mm TL, from where females began to show higher values than males. Liver size at a given mass was sexually dimorphic with females having livers that were significantly heavier than those of males as from 600-700 mm TL ($t = 3.197$; $p < 0.002$; d.f. = 156) (Figure 3.21). The livers of female *C. capensis* ranged from 8 – 278 g (77.2 ± 67.71) while those of the males ranged from 8.6 – 121.6 g (46.7 ± 27.39). The M_L - TL relationships that describe both sexes of *C. capensis* were given by the equations: (for males) $M_L = 8e^{-0.9}TL^{3.546}$ ($r^2 = 0.802$) and (for females) $M_L = 3e^{-0.9}TL^{3.715}$ ($r^2 = 0.829$). The M_L – TL relationship for combined sex was given by $M_L = 4e^{-0.9}TL^{3.683}$ ($r^2 = 829$).

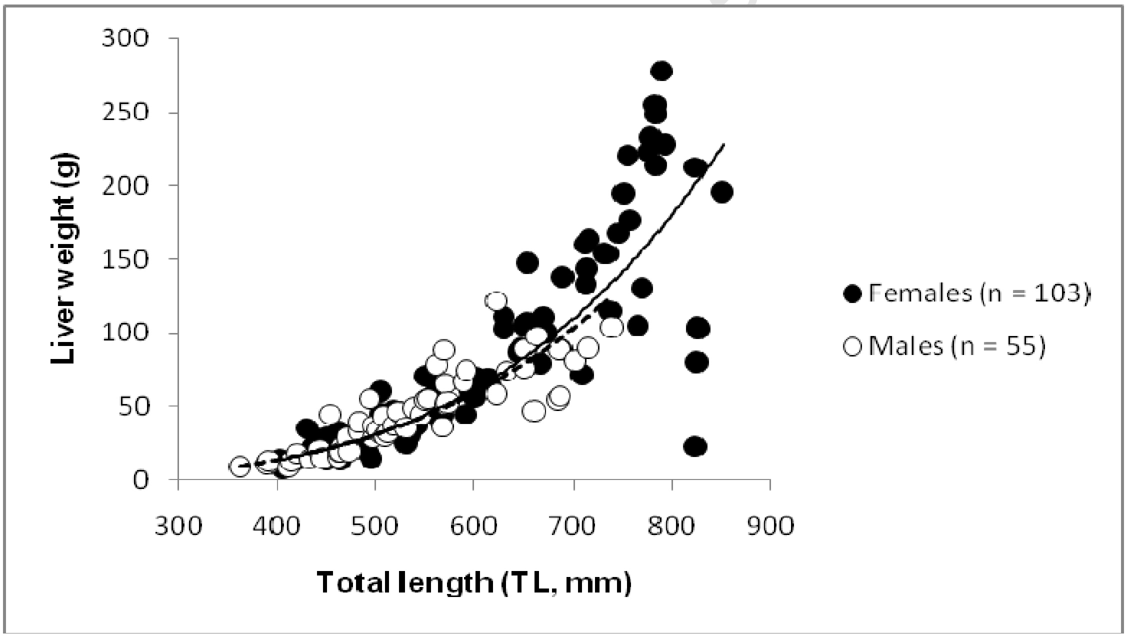


Figure 3.21. Relationship between total length and liver mass for *Callorhinchus capensis* from Velddrif, west coast of South Africa. Both solid (females) and dashed (males) regression lines represent non linear fit.

As shown in above, female species of *C. capensis* had significantly heavier livers than males from the examined specimens. HSI is often referred to as the liver index that correlates with the lipid content of liver, and it varies according to the energy content of the fish (Lambert and Dutil 1997, Pope and Kruse 2007). In this study,

$HSI-M_L$ relationship for combined sex of *C. capensis* was described by $HSI = 0.031M_L + 5.5103$ ($r^2 = 0.345$).

The mean HSI was significantly higher in females compared to males ($t= 2.3$; $p = 0.02 < 0.05$; d.f = 156) (Figure 3.22). HSI for females specimens ranged from 1.16 to 25.63 (mean = 7.96, s.d. = 3.51) while those of males ranged from 0.07 to 14.07 (mean = 6.73, s.d. = 2.18).

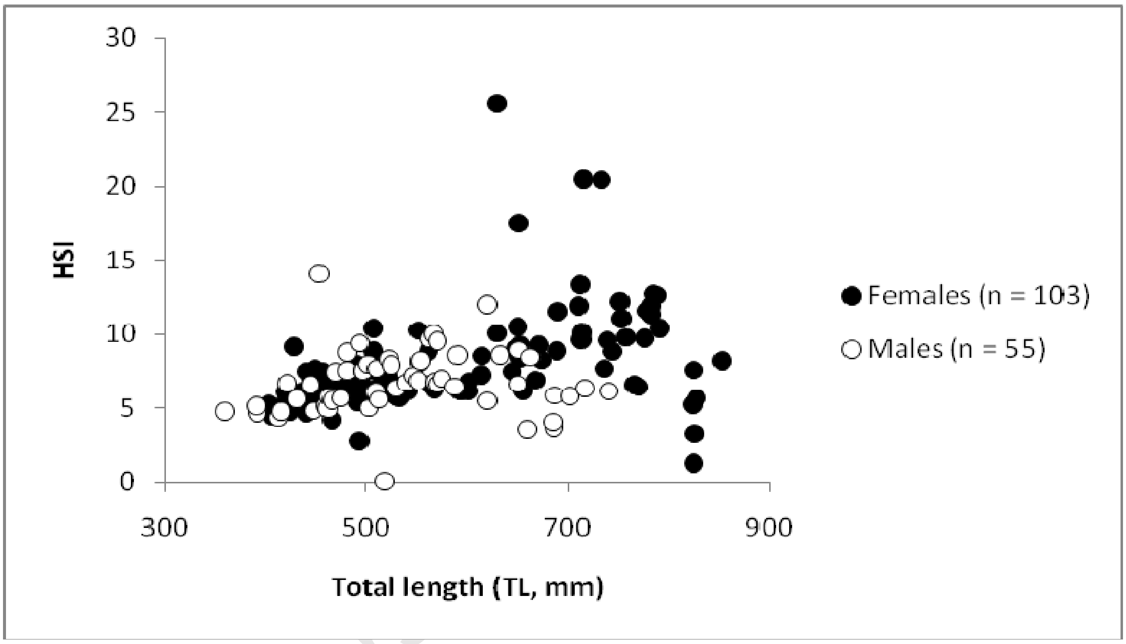


Figure 3.22. Relationship between hepatosomatic index (HSI) and total length (mm) for females (full circles) and males (empty circles) of *Callorhinchus capensis*.

The plot of the condition factor (K) against total length of sampled *C. capensis* generally had greater variability with increasing total length for females than males at larger fish sizes (Figure 3.23). The regression parameters of condition factor (K) on the total length and body mass for a combined sex of St. Joseph are presented below:

$$K = 97.28 + 0.006\ TL\ (r^2 = 0.002) \quad \text{Eqn 3.8}$$

$$K = 93.47 + 0.009\ M_T\ (r^2 = 0.111) \quad \text{Eqn 3.9}$$

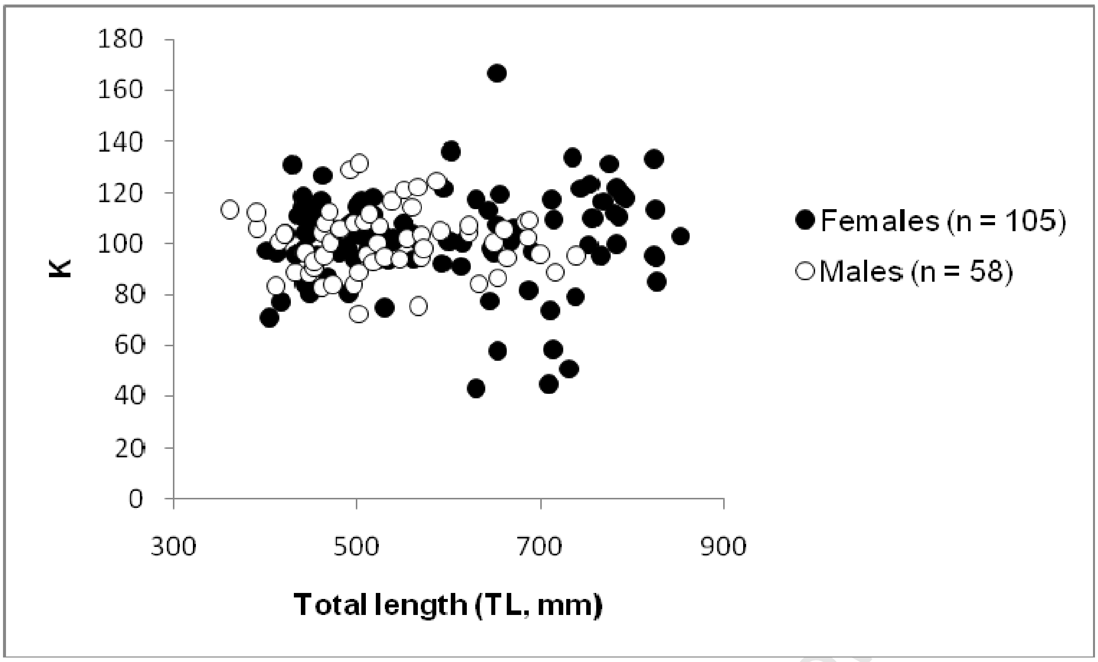


Figure 3.23. Relationship between condition factor (K) and total length (mm) for females (full circles) and males (empty circles) of *Callorhinchus capensis*. Females; K = 97.28 + 0.007 TL (r^2 = 0.002); Males; K = 101.6 – 0.001 TL (r^2 = 0.000).

The variability in body mass is greater in larger fish. The mass of sampled fishes increased faster than length as K increased with size of fish. The condition factors for males and females were not significantly different from each other (t = 0.345; p = 0.730 > 0.05; d.f = 161). For females of *C. capensis*, K ranged from 42.5 to 166.75 (mean = 101.81, s.d. = 18.92), while those of males ranged from 72.58 to 131.17 (mean = 100.86, s.d. = 12.58) (Figure 3.23). GSI values showed a rise with fish size up to a maximum, with peak value significantly higher for males (F = 5.306; d.f. (5, 26); p = 0.0017) than that of females (F = 3.286; d.f. (5, 44); p = 0.0132) (Figure 3.24). HSI values per fish size varied significantly (males: F = 4.285, d.f. (5, 51), p = 0.0025; females: F = 16.42, d.f. (5, 99), p < 0.0001). According to Table 3.3, both the average HSI and K for female *C. capensis* were generally greater than those of males. However the average GSI for males were higher than those for females. The development of K for each fish size was different for both sexes (males: F = 39.51, d.f. (5, 55), $p < 0.0001$; females: F = 16.72, d.f. (5, 102), $p < 0.0001$). K values for females and males > 600 mm were inversely related.

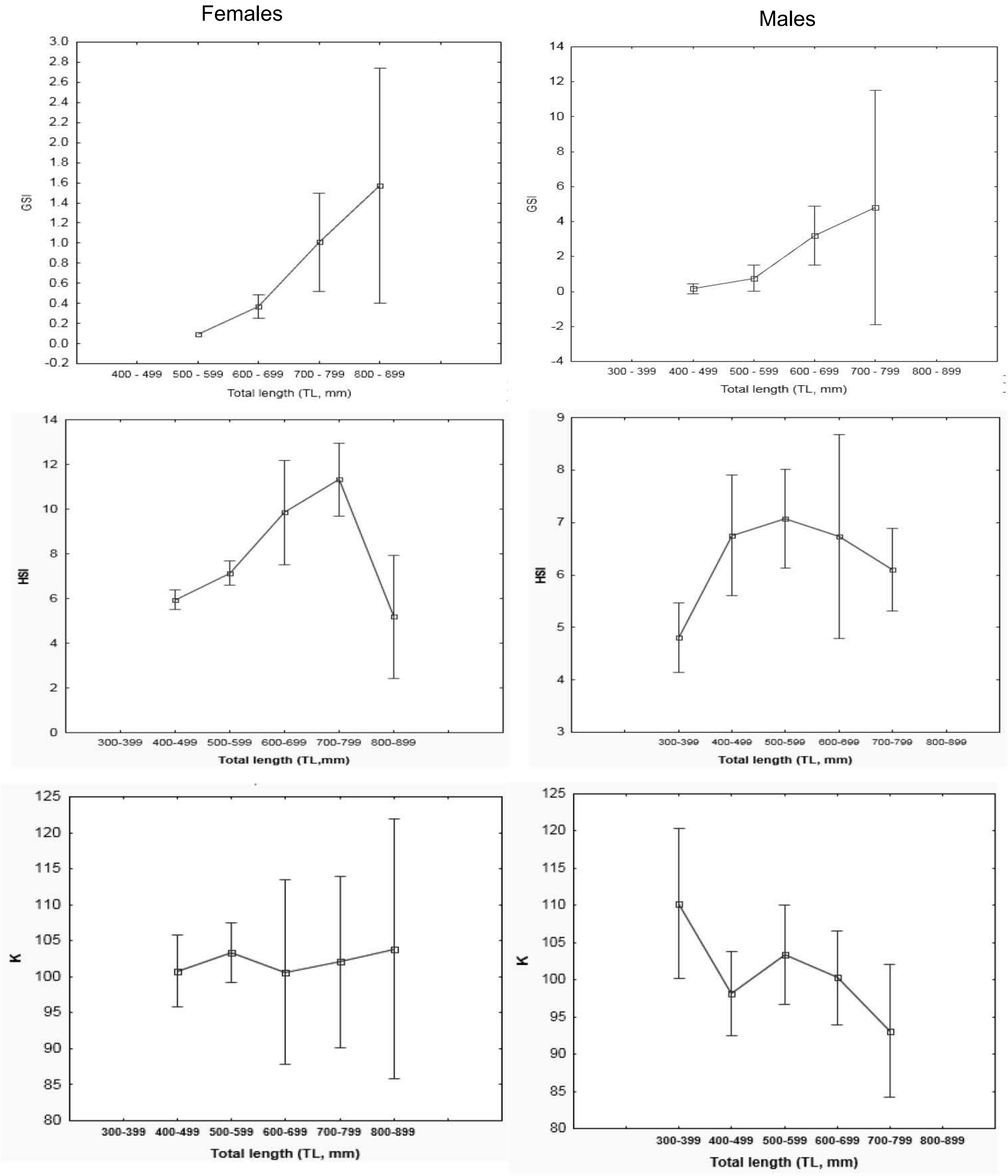


Figure 3.24. Trends of gonadosomatic index (GSI), hepatosomatic index (HSI) and condition factor (K) against sizes for both sexes of *C. capensis.*

Table 3.3. Variation in GSI, HSI and K by maturity stage for male and female *C. capensis.*

Index	Sex	Maturity	Range	Mean	n	S. D.
Gonadosomatic index (GSI)	Female	Mature	0.1 – 4.0	0.8	45	0.9
	Male	Mature	0.2 – 7.3	3.7	14	2.1
Hepatosomatic index (HSI)	Female	Mature	3.3 – 25.6	8.0	46	4.5
		Immature	1.2 – 12.6	7.3	57	2.3
	Male	Mature	5.5 – 9.4	7.2	14	1.1
		Immature	2.9 – 17.5	7.5	41	2.7
Condition factor (K)	Female	Mature	42.5 – 166.8	102.7	47	24.9
		Immature	70.5 – 130.7	101.1	58	12.3
	Male	Mature	86.8 – 124.8	102.5	14	10.0
		Immature	72.6 – 131.2	100.3	44	13.4

3.1.8 Gut content analysis

Of the 173 stomach of examined macroscopically, 172 (99.4%) contained food, from which 3 (1.7%) contained more than one prey item. For stomach with > 1 item, the number of prey items ranged from 2 to 3. For the fishes landed and used for this study, 87.9% of stomachs were un-gutted while 12.1% of examined species stomachs were gutted. The stomach content for female fishes were very much similar to those of males. Both females and males however, showed different frequencies in each stomach item (Figure 3.25). This difference in the number of individual prey items for males was statistically not significant when compared to females for the examined specimens (t = - 0.74; p = 0.47, d.f = 16). Crushed black mussels (either *Choromytilus merdionalis* or *Mytilus galloprovincialis*) and un-identified digested materials dominated the stomach content by frequency in all length classes of males and female *C. capensis* sampled (Figure 3.25 and 3.26).

Smaller individuals with total length between 400 to 599 mm had greater feeding activity compared to fishes in larger length classes (Figure 3.26).

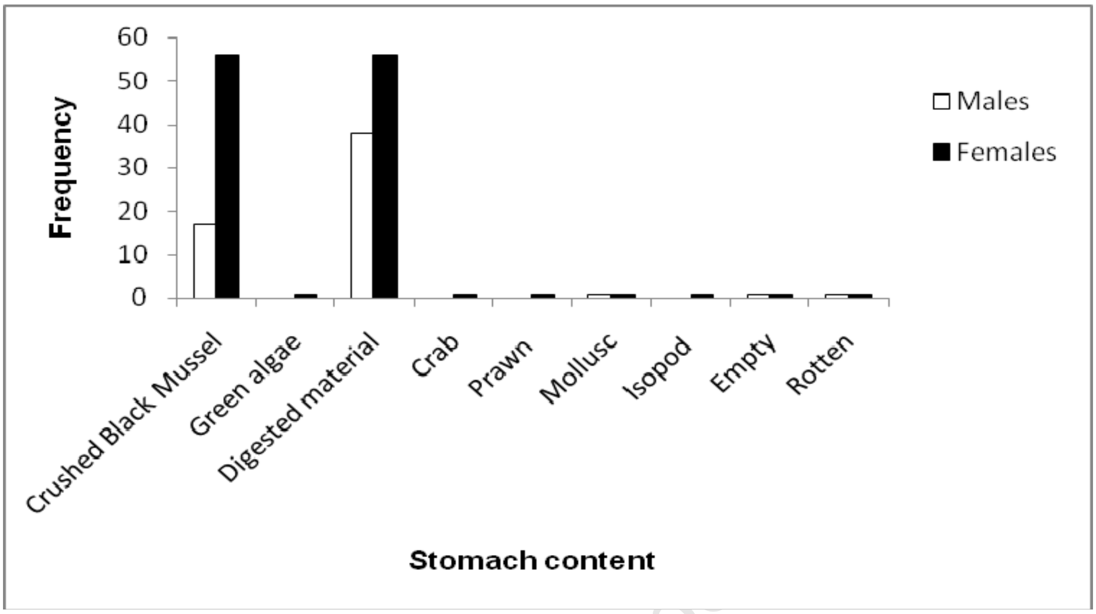


Figure 3.25. Frequency distribution of stomach content item for 60 males and 113 females of *C. capensis*.

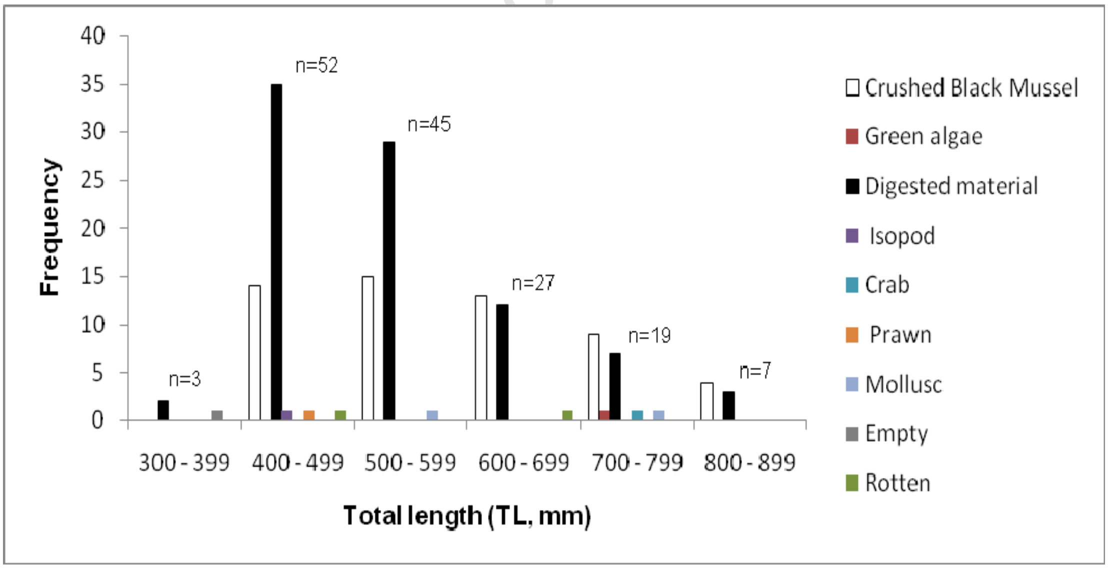


Figure 3.26. Distribution of ingested stomach content items per length class for combined sex of *C. capensis*. n: number of fish in each length class.

Above the size class length of 400-499 mm TL, the number of fishes with digested stomach materials and crushed black mussels decreased with increasing sizes of *C.*

capensis sampled (Figure 3.26). There was no appreciable dietary difference between mature and immature *C. capensis* (t = - 0.444, d.f. = 14, p = 0.664 > 0.05). However, females (mature and immature) had a higher percentage of stomachs with food items than males, 65.4% and 34.6% respectively (Figure 3.27). Feeding periodicity was however, not within the scope of this study.

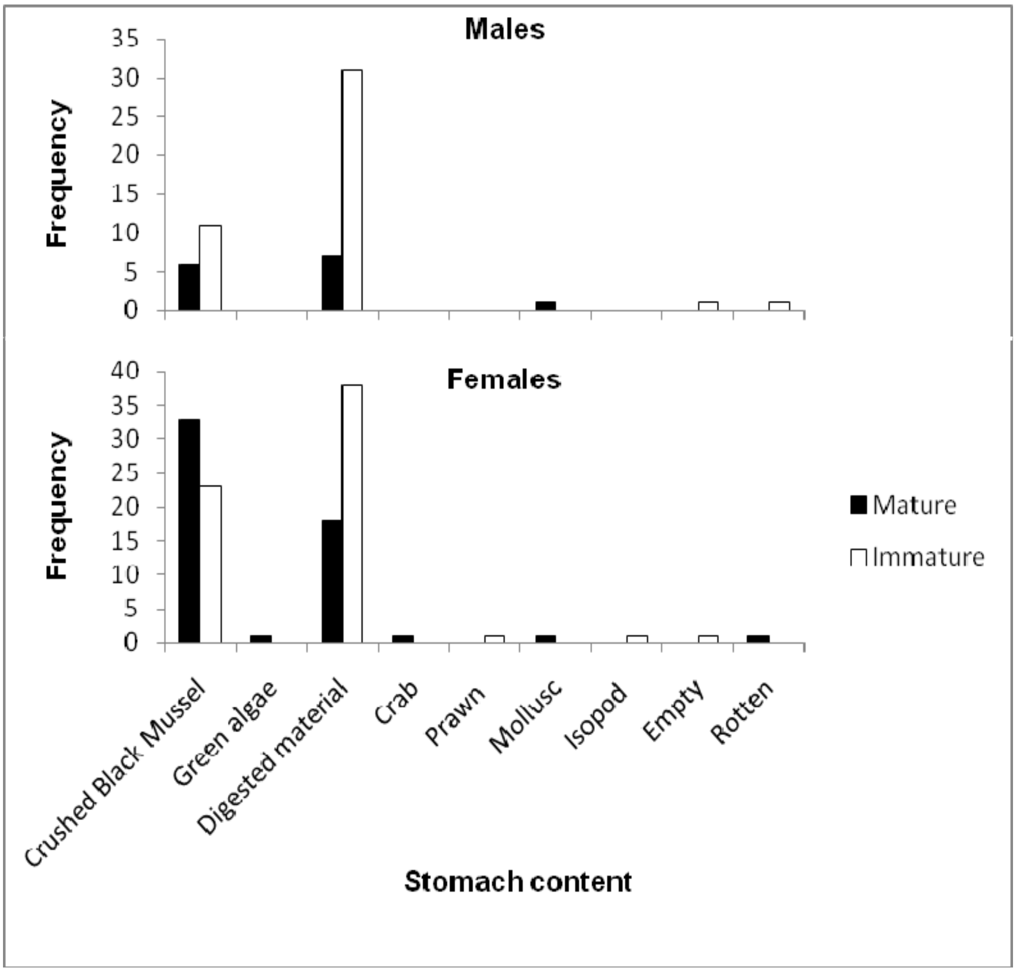


Figure 3.27. Distribution of ingested stomach content items for male and female *C. capensis*.

The stomach mass (M_S) of males *C. capensis* ranged from 2.5 to 63.3 g with mean of 25.5 g (s.d. = 12.96, n = 55) while those of females ranged from 5.5 to 134.5 g with mean of 38.3 g (s.d. = 27.57, n = 104) (Figure 3.28). For combined sex of sampled specimens, stomach mass ranged from 2.5 g in the smallest shark sampled to more than 134.5 g in the largest specimen.

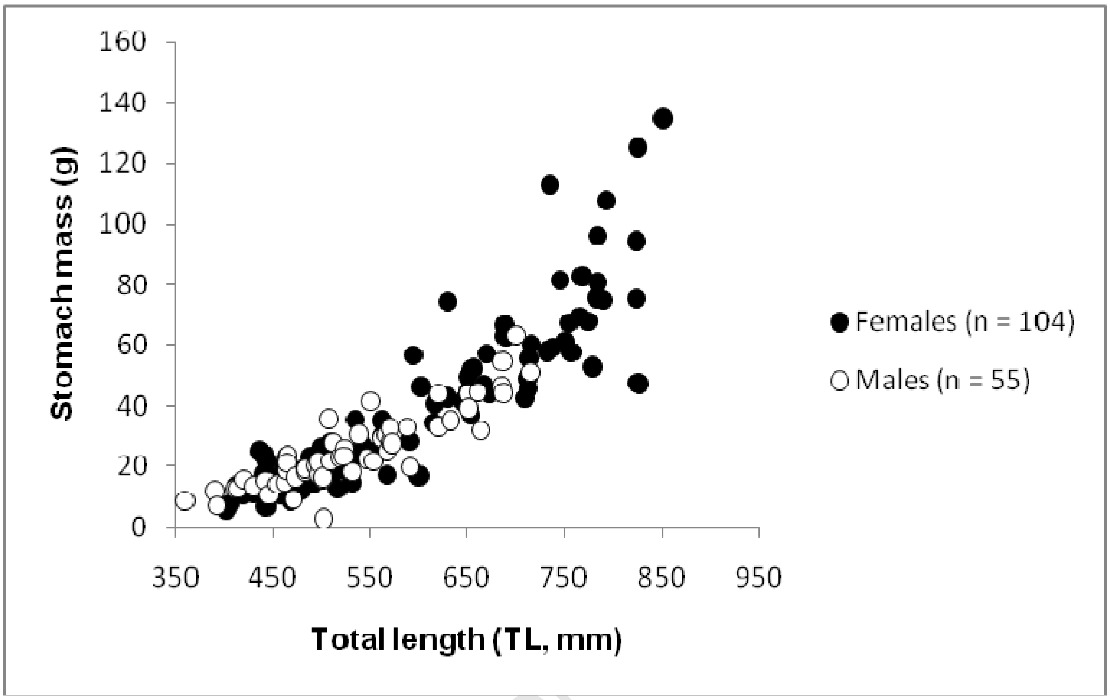
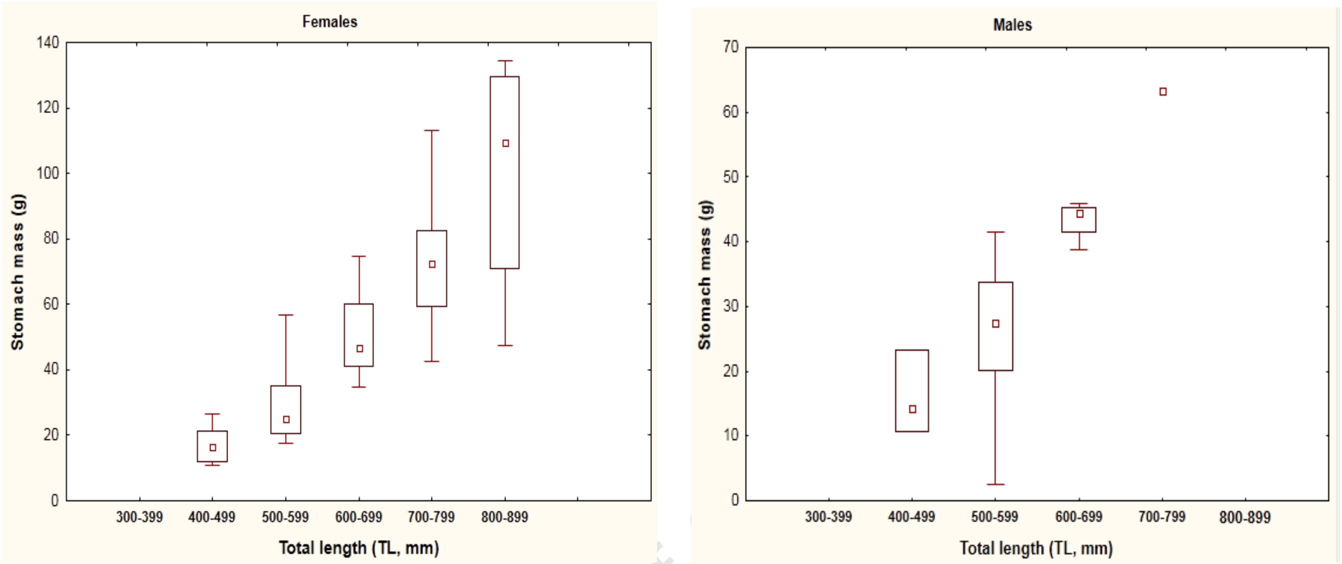


Figure 3.28. Stomach mass plotted against total length of *C. capensis* from Velddrif, west coast of South Africa. The M_S - TL relationship were described for (Males): $M_S = 6e^{-0.7}TL^{2.770}$, $r^2 = 0.630$, n = 55; (Females): $M_S = e^{-0.7}TL^{3.025}$, $r^2 = 0.842$, n = 104 and (Combined sex): $M_S = 2e^{-0.7}TL^{2.984}$, $r^2 = 0.796$, n = 159.

Stomach weight with its constituent item increased with fish size for each sex. Average un-gutted stomach weight for all stomachs (n = 168) was 35.4 g, 4.2% of the average body weight (852.1 g). For stomachs containing digested food materials (n = 94) average stomach content weight was 26.6 g, or 3.1% of the average body weight. Stomachs containing crushed black mussels (n = 72) gave an average stomach content weight of 47.1 g, 5.5% of the average body weight.

According to changes in mean stomach mass for both sexes of *C. capensis*, stomachs with the main crushed black mussel diet for females (F = 29.62; d.f. (4, 46); $p < 0.0001$) was higher than males (F = 3.34; d.f. (4, 16); p = 0.0273). Similarly, changes in mean stomach mass containing digested food materials for females (F = 25.41; d.f. (4, 46); p < 0.0001) was higher than males (F = 13.78; d.f. (4, 35); p < 0.0001) (Figure 3.29).

Stomachs with crushed black mussels



Stomachs with digested materials

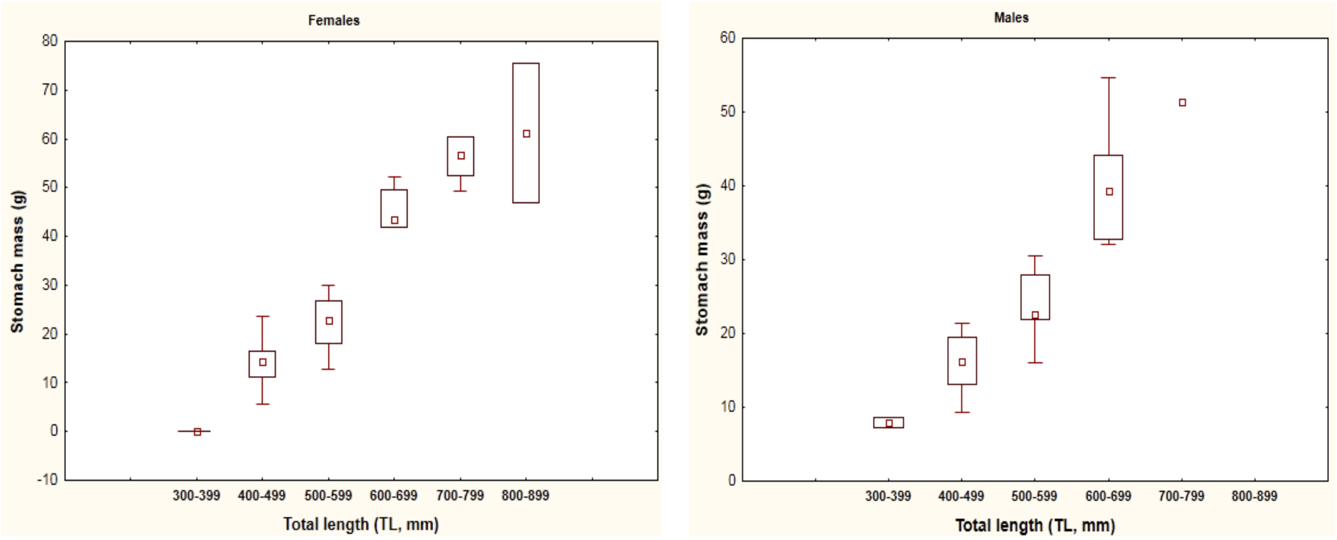


Figure 3.29. Changes in mean stomach mass with fish sizes of each sex of *C. capensis* containing main stomach diet; crushed black mussels and digested materials.

3.2 Discussion

3.2.1 Sample size

A similar study carried by Freer and Griffiths (1993) sampled 841 specimens of *C. capensis* throughout the year, whereas only 173 animals were sampled in this study. This study was done on fish sampled in October which according to Freer and Griffiths (1993) coincided with the breeding season.

The samples from the present study show that females were about three times as numerous as males. The analysis of such an unequal sex proportion can assist in predicting which portion of the population is more frequently caught (Bonfil 2004). Possible explanations for the unequal sex ratio in the sample are that it either reflects the actual sex ratio in the fish stock or is a result of a sampling caused by the size-specific gear selectivity from the gillnet fishing method used by the commercial fishermen.

Springer (1967) attributed unequal sex ratio and size composition of such species as a consequence of sexual segregation. Other species of chondichthyans had also been reported to show similar variations in sex ratio. For example, females of *Centrosyllium fabricii* were more abundant than males in deeper waters off Greenland (Yano 1995). Other deviations from unity had been reported for *Centroscymnus coelolepis* and *Deania calceus* from the continental slopes of the Rockall Trough and Porcupine Bank (Clarke 2000), the deep-sea squaloid shark *Centroscymnus owstoni* in Suraga Bay, Japan (Yano and Tanaka 1988) and the copper shark *Carcharhinus brachyurus* from north Patagonia, Argentina (Lucifora et al. 2005). The explanation for these differences in sex ratio for most of the mentioned species have been reported to be associated with the influence of depth distribution, habitat, season and temperature on reproductive requirements

(Compagno et al. 1991, Clarke et al. 2001). Freer and Griffiths (1993) reported monthly catch fluctuations of male and female *C. capensis* in largely discrete aggregations at the St. Helena Bay, west coast of South Africa. In summer, female *C. capensis* usually migrate inshore (in nursery areas) to breed where they are caught by fishermen, while adult males remain at greater depths (Freer and Griffiths 1993). It is likely that the *C. capensis* samples were taken in shallow water at a time when females were more abundant than males. It may be important for young fish to remain inshore, where there is an abundant supply of black mussels, the preferred prey of young *C. capensis*.

3.2.2 Morphometrics

This study recorded important variation in maximum size-at-maturity and weight between sexes of *C. capensis.* Females were larger than males and the sexes displayed different length-mass relationships. Freer and Griffiths (1993) also observed a similar difference for *C. capensis*. Other deep-sea sharks have also been reported to show morphometric differences between males and females. These include, *Deania calcea* (Clarke et al. 2002), *Centrophorus* cf. *uyato* (Rafinesque 1810) (McLaughlin and Morrissey 2005) and skates such as the zipper sand skate, *Psammobatis extenta* (Braccini and Chiaramonte 2002), the smallnose fanskate, *Sympterygia bonapartii* (Mabragaňa et al. 2002), and the shortfin sand skate, *Psammobatis normani* (Mabragaňa and Cousseau 2004). In every case the female is larger than the male.

This difference is related to the production of oocytes. Females grow larger to hold the egg case within their body cavity. In contrast males attain maturity earlier. Size difference between sexes could also be explained by differences in growth rates and longevity (Chauvet 1991). The large liver (*t*-test, $p < 0.05$) of mature females might also suggest the difference in the length-mass relationships. Other causes such as differences in environmental conditions (habitat), food availability, food resources (quantity, quality and size), time of year, stock density, fishing pressure and water temperature and salinity also influences growth and age at first maturity (Tormosova 1983, Pauly 1984a, Sparre and Venema 1992).

In Velddrif, the St. Joseph as presented in this study exhibits significant positive allometric growth for males ($b = 3.329 > 3$), isometric growth for both females ($b = 2.983$) and combined sex ($b = 3.053 \approx 3$) with length when considering total weight of species. Allometric growth with ($b > 3$) means that the shark becomes more rotund when length increases, and at the same time, condition factor increases with increasing length (Jones et al. 1999). On the other hand, isometric growth ($b \approx 3$) occurs when length increases in equal proportions with body weight for constant specific gravity (Gayanilo and Pauly 1997). The change of "*b*" value depends primarily on the shape and fatness (size) of the species. Comparison of the "*b*" value for both sexes of *C. capensis* suggests notable growth differences. Differences in growth rates exist between males, females and the combined sexes of *C. capensis*.

Studies on Soupfin shark *Galeorhinus galeus* have reported differences in growth rates between males and females, where it was found that males grow slightly faster than females, but reach smaller asymptotic size (Walker 1997). Similar sexual dimorphic characteristics has been reported in *Centrophorus cf. uyato* (McLaughlin and Morrissey 2005), *Apristurus microps* (Ebert et al. 2006), *Raja eglanteria* (Gelsleichter 1998), *Isurus oxyrinchus* (Compagno 1984) and *Heterodontus portusjacksoni* (Powter and Gladston 2008) and is typical of elasmobranchs (Ebert 2003). Freer and Griffiths (1993) sampled in St. Helena Bay and found that female *C. capensis* mature at larger sizes than males. Information on length-weight relationship is required for stock assessment of commercially harvested species. The value of the constants of this relationship is useful for fisheries management because biomass estimations depend on such parameters.

3.2.3 *Male maturity parameters*

The inspection of reproductive traits and the growth of secondary sexual structures provided an easy means for assessing maturity in sampled species. Conrath (2005) defined a sexually mature shark as one that has the ability to mate and produce viable offspring. A fully functional reproductive system with the ability to deliver reproductive products is required for a species to be sexually mature (Francis and Duffy 2005). Thus, a sexually mature male *C. capensis* should be able to produce sperm as well as having means to transfer sperm using their fully functional claspers. An accurate estimation for assessing male maturity is based on both the presence of sperm and development of fully functional claspers (Conrath 2005). The development of clasper length can either increase gradually or abruptly as individuals reach sexual maturity depending on the species (Pratt 1979). In this study, claspers with articulation and sperm presence indicated that a male was mature. Almost all males with advanced clasper stage also had sperm presence. Just two males with calcified and articulated claspers did not have sperm. There was a distinct transition in sperm presence between 588 mm TL and 687 mm TL, hence the consequential transition to male maturity. This observation is supported by the estimated length-at-50% maturity for males (593 mm). Above length at which males first mature (621 mm TL), there was abrupt increase in testis weight with increase in total length. Abrupt increase in gonad weight immediately after the onset of sexual maturity has also been reported for species such as *R. wallacei*, *R. pullopunctata*, and *Atlantoraja cyclophora* (Walmsley-Hart et al. 1999, Oddone and Vooren 2005). The length-at-50% maturity for males was calculated to be 593 mm TL. Freer and Griffiths (1993) reported 434 mm FL for length-at-50% maturity for males *C. capensis*.

3.2.4 *Female maturity parameters*

Measurements of internal female reproductive organs; maximum oocyte diameter, the ovary, uterus and nidamental gland weights were used to draw general conclusions about female maturity in *C. capensis*. These reproductive organs have widely been used as indicators for the assessment of female maturity in other sharks (Conrath 2005, Manning and Francis 2005). Maximum oocyte diameter, however, has not been used as a clear indicator of maturity, with its values for immature sharks commonly overlapping with those for mature sharks. St. Josephs may not reproduce annually and females in resting phase often carry small oocytes which causes oocyte diameter to be a poor indicator of maturity. This type of reproductive strategy is practised by tiger sharks *Galeocerdo cuvier* (Whitney and Crow 2007). Weights of nidamental gland, uterus and ovary begins to show drastic increases when mature female sharks reach 594 mm TL until they attain the length of 852 mm. The class size range for mature female *C. capensis* (594 – 852 mm) was comparatively larger than those of mature males. This range is supported by findings from Freer and Griffiths (1993) whose observation found that females mature at larger sizes than the males. The length-at-50% maturity for females was calculated at 754 mm TL. Freer and Griffiths (1993) obtained 496 mm FL as length-at-50% maturity for female *C. capensis.*

St. Josephs tend to mature at above 88% (for females) and 78% (for males) of their maximum total length due to their late maturation. This observation is also supported by late maturing of large skate species at a large size relative to their maximum total length (Dulvy et al. 2000). Large size-at-maturity is commonly the case in viviparous sharks (Holden 1974, Pratt and Casey 1990). The late maturation range observed for *C. capensis* is due to their life-history traits although relatively less compared to other deep-water chondrichthyans; slower growth, later age at maturity and higher longevity. This indicates that *C. capensis* could be particularly sensitive to fishing pressure and overexploitation, a conclusion supported by their age-at-maturity of 4.2 years for females and 3.3 years for males (Freer and Griffiths 1993).

3.2.5 Fecundity

In this study, fecundity was estimated by counting the number of mature follicles in the both ovaries of mature female *C. capensis*. The macroscopic assessment of the gonad data revealed that *C. capensis* is an iteroparous, gonochoristic and serial batch-spawning species (Murua and Saborido-Rey 2003) (Figure 3.18). They are known to be serial batch-spawners because only a portion of the yolked oocytes is spawned in each batch during hydration process. Oocytes developmental pattern was indicated in the frequency distribution as all stages of development can be distinguished at any one time, which is the definition of an asynchronous ovary (Wallace and Selman 1981). Mature-active batch spawning female species often release their egg batches over a period (Murua et al. 2003). In this study, successive cohorts of oocytes in different stages of development were distinguished in ovaries of female *C. capensis*. Like in many Chimaeras, estimation of fecundity from this type of continuous spawning patterns is usually difficult (Kokuho et al. 2003). Previous authors have reported discrepancies in the methods used to enumerate mature oocytes for single oviparous chimaeroids, and other chondrichthyans (Holden et al. 1971, Moura et al. 2004, Tovar-Avila et al. 2007). In this study, fecundity of *C. capensis* was estimated between 1-14 oocytes (5.3 ± 3.79 oocytes), similar to that estimated for *Chimaera monstrosa* (mean = 6; Moura et al. 2004) and much less than *Callorhinchus milii* (16-24; Bell 2003). The number of fully developed oocytes increased with mature female *C. capensis* length, providing evidence for increased fecundity with fish size (Conrath 2005). Females larger than 780 mm produced 11-15 eggs > 10 mm diameter while fish between 710 -789 mm produced 6-10 eggs (or oocytes). The increase in fecundity with increase in female size has also been reported in a *Callorhinchus milii* (Bell 2003), and other chondrithyans, including Alaska skates *Bathyraja parmifera* (Matta 2006), Tiger sharks *Galeocerdo cuvier* (Simpfendorfer 1992) and Black dogfish *Centrosyllium fabicii* (Yano 1995). Larger females are known to provide more nutrients toward oocyte formation and greater investment in gonadal tissues, potentially increasing offspring fitness (Berkeley et al. 2004a). It should however be recalled that fecundity estimates in this study was done through the simplest and most rapid method; external appearance of ovary as opposed to the most accurate technique, namely histological analysis (West 1990).

3.2.6 Indicators of fecundity

The liver weight (M_L) of *C. capensis* increased equally in both sexes up to 600-700 mm TL, from where females began to show higher weight values. Such sexual dimorphism of the liver is a common phenomenon in the bonnethead sharks and skates (Radidae) (Silva and Lessa 1991, Mabragaňa et al. 2002). The energetic expense of females is related to this dimorphism as lipids are stored in the liver during oocyte production and maturation in their reproductive cycle, thus accounting for the high weights (Lucifora et al. 2002). The liver is involved in the production of vitellogenin, the precursor of egg yolk protein (Gelsleichter 2004). Thus, it is apparent that the size of the liver varies depending on the reproductive stage of *C. capensis.*

The relationship of the gonad size with respect to fish body size (gonad indices) is used to complement results from changes in oocyte sizes (West 1990). As male and female *C. capensis* matured, the GSI increased. There were differences in the process of development of testes of the sampled species (Figure 3.9). The testis development in *C. capensis* with respect to weight is gradual until a certain stage (mature) when development becomes rapid (Figure 3.9). This goes to show that *C. capensis* apportion differing amounts of resources to gonadal development. According to observations from this study, ovaries of female *C. capensis* account for about 1.5% of total body weight, while male *C. capensis* testes account for 1.9 %. Thus male *C. capensis* devotes higher amount of resources to gonadal development than the females. This observation was reflected in the greater variation in the GSI of males that females, thus indicating peaks in the reproductive cycle of *C. capensis*. The GSI vary between sexes where mean value for males being higher than those of females. In this study, the higher mean GSI of males probably account for the differences in growth and aggregation by sexes. This observation is supported by results of Freer and Griffiths (1993) which show that the GSI for males were greater than those of females in the same month when this study was conducted. Higher peak values of mean GSI for large females could be related by their spawning activities. In this study, it was deduced from HSI values that gonadal development was preceded by depletion of protein and lipid reserves of the fish since it took place at a stage of low or no food intake.

This study also found that HSI varied significantly with size of fish. The variation in HSI for females was greater than males (Table 3.3). This is attributed to the increase in liver mass to the accumulation of hepatic lipids for females than males. Liver contributes lipids to the formation of egg yolk during reproduction. The HSI increases with maturation in female *C. capensis* with mean value of 7.3 and 8 for immature and mature females respectively. Although the mean values of HSI for mature females (8) and mature males (7.2) were different, the GSI showed a greater difference between the sexes. Variations in high and low values in the HSI range of the females *C. capensis* simply reflect the presence of sexual resting females with ovaries that are no longer producing vitellogenic follicles (Oddone and Vooren 2005). Hussey et al. (2009b) also found that HIS in dusky sharks varies according to reproductive state. In as much as these variations are involved in vitellogenesis, they are also linked to the deposition of lipid at times of food abundance and utilisation of reserves when food is scarce. In general, GSI and HSI of *C. capensis* showed an inverse association especially in larger fish sizes as in the case of *Sciaenops ocellatus* studied by Craig et al. (2000) (Figure 3.24).

The condition factor (K) reflects information on the physiological state of the fish. Highest K values are generally reached in female *C. capensis* that have accumulations of fat and advanced gonad development (Le Cren 1951). Average condition factors for female *C. capensis* were slightly greater than for males. The development of each fish condition factor was inversely related between sexes (Figure 3.24). Heavier female fishes were in better state than smaller female fishes whereas smaller male fishes had a better condition than those of larger sizes. The developmental decrease in K for male fishes revealed that they reach their maximum length at maturity earlier than females. K gave a good indication of the fish well-being in its natural habitat with greater retard of body weight and length in males than females. Thus as observed in this study, variations in gonad developments and hepatosomatic index of the fish did influence fish condition. The variation of K with fish size could apparently be attributed to the fluctuation in food availability and consumption as well as fish reproductive cycle of the sampled species (Weatherley 1972). Females had more feeding activities and undergo much reproductive development than males, hence an apparent reason for their higher K values (Figure 3.24, 3.25, 3.27, 3.38 and 3.29).

3.2.7 *Diet*

The diet of *C. capensis* is important in understanding food availability in the natural habitat. Information from dietary analysis contributes significantly to an understanding of variations in fisheries yield as it indicates the state of fish growth. Although no particular method of analysing stomach contents of predators is able to give a complete description of diet composition (Hyslop 1980). The present study based on frequency of occurance of a particular prey, showed that the diet of the sampled specimen of *C. capensis* was mainly composed of black mussels. Unidentified digested stomach materials were also dominated the sampled stomachs. According to Freer and Griffiths (1993) the diet was mainly bivalves, gastropods and a dominant crustacean diet. The feeding ecology of *C. capensis* is similar to that of some species of Soleidae (Darnaude et al. 2001). Sampled specimens of *C. capensis* presented variations in diet according to sex and length of fish. Based on sampled stomachs in this study, stomach weights of *C. capensis* revealed that females' stomach had higher stomach contents than males, and the larger fishes had lower feeding activity than smaller fishes (Figure 3.26).

The variations on feeding activity of *C. capensis* can be attributed to many factors such as changes in space and time of benthic prey, shifts due to life-history patterns of prey and predation patterns (Wootton 1998). This feeding variation for *C. capensis* was shown as their dominant crustaceans diet (Freer and Griffiths 1993) shifted to black mussels observed in this study (Table 3.4). Reproductive processes in *C. capensis* could also account for it feeding variations. In serial spawning species such as *C. capensis*, large fish spawn more frequently and need to forage more frequently than smaller fish (Wootton 1999). The more feeding activity observed in smaller fishes was related to growth. Temperate areas usually have highest productivity in summer which increases prey availability in account for seasonal variation. Also, females have higher energetic needs for growth and reproduction which could explain their higher stomach weight (Lozán 1992). Smaller sizes of fish often present higher growth rates during the first years of life and are often related to more intense feeding activity to maximize growth (Vassilopoulou and Ondrais 1999).

Similar sex related differences in diet have also been reported for *Callorhinchus callorhynchus* and *Chimaera monstrosa* (Mauchline and Gordon 1983, Di Gia´como and Perier 1996).

Table 3.4. Comparison on some biology and life-history traits of *Callorhinchus capensis* drawn from this study and previous work.

Characteristic	**Freer and Griffiths (1993)***	**This study**
Geographic area	St. Helena Bay	Velddrif
Sex ratio (F/M)	1.00:1.21	3.71:1.00
Largest fish	900 mm FL	852 mm TL
Smallest mature male	429 mm FL	588 mm TL
Smallest mature female	464 mm FL	440 mm TL
Reproductive organ		
Males		
Testis		
- Percentage body weight	1.3%	1.9%
- Mean weight of mature testis	15.4 g	60.6 g
- Range of mature testis weight	6.7 – 53.8 g	26.3 – 122 g
Females		
Ovary		
- Percentage body weight	n/a	1.5%
- Mean weight of mature ovary	n/a	12 g
- Range of mature ovary weight	n/a	0.7 – 61.9 g
Nidamental gland		
- Percentage body weight	1%	2.6%
- Mean weight of mature NG	29.4 g	25.1 g
Sample size (n)	841	173
Principal diet (% by number)	Crustaceans	Black mussels
Percentage body mass		
• Liver	5.5%	8.1%
• $GSI_{Females}$	0.8%	0.08%
• GSI_{Males}	3.7%	0.6%
Length of eggcase	180 mm	Left= 130 mm Right= 135 mm
Maxaimum oocyte diameter	35 mm	50 mm
Largest number of viable oocytes	22	14
Length-at-50% maturity:		
Males	434 mm FL	593 mm TL
Females	496 mm FL	754 mm TL

***NB**/ Some of the values from Freer and Griffiths (1993) work were extrapolated from graphs in the same month (October) of this study.
n/a = Not Available

Chapter 4: Conclusion and Future work

4.1 **Conclusion**

This study has provided some important information on the reproductive biology and diet of the St. Joseph which is currently exploited by commercial gillnet in Velddrif, on the west coast of South Africa. *C. capensis* have reproductive strategies that cannot support intensive fishing. For instance, they have slow growth and their distributions are disaggregated by sex, which has important implications for fisheries management; regulation of effort and mesh sizes and seasonal / area closures from fishing. Other life-history parameters which this work has shed light are size-at-50% maturity, size-at-100% maturity, fecundity, egg size, gonad indices and dietary patterns. Size-at-100% maturity relative to maximum total length- and size-at-50% maturity were both indicative of the size at which maturity was achieved on *C. capensis*. These differences in the life-history traits between sexes of *C. capensis* emphasize the need to collect sex-specific information on *C. capensis* as part of monitoring programmes.

Many mature-active females rely on inshore and shallow-water for egg-laying and nursery grounds on a seasonal basis, usually in summer (Freer and Griffiths 1993). Newborns and juveniles remain in these productive shallow areas for food and shelter from predators. Over-exploitation on a fish species can be accompanied by several other threats such as loss of habitat and pollution (Camhi et al. 1998, Reynolds et al. 2005). Also, changes in mean size of a targeted species have often been reported as effects of fishing, and as good indicators of fish exploitation rates (Steven et al. 2000, Smith et al. 2007). The few sample size for this study was however not enough to provide the expected evidence of a decrease in mean size of the exploited *C. capensis* species when compared to work done by Freer and Griffiths (1993).

In the food habit study, it was revealed that *C. capensis* as in the study carried out by Freer and Griffiths (1993), take a wide spectrum of prey species depending on the food availability in the environment. A clear difference in frequency of occurrence in prey categories was observed between mature male and mature females. It is hypothesized that this relates to the different feeding and energetic requirements.

The results and methods presented in this dissertation were subject to the following limitations:

Some of the estimates of the reproductive traits of *C. capensis* such as fecundity may be influenced by factors such as a lack of size class representation of mature active females. This may have been caused by selectivity. Previous studies on a similar effect of mesh size in a gillnet fishery have been reported by Walker et al. (1998) and Márquez-Far□as (2005).

The small sample size of biological data used in this study when compared to that used by Freer and Griffiths (1993) (e.g. n = 841 fish stomachs examined) might not be enough to improve results, hence variations in estimates for biological and life-history parameters (Table 3.4).

Data used in this study came from two single catches of *C. capensis* by commercial gillnetters. As such trends over time in the frequencies of length, weight, sex, age (if possible), maturity, fecundity as well as dietary data were not monitored throughout the year and therefore could not give a good understanding of the variability of life-history parameters exhibited by sampled species.

Despite the limitations of this study, it should be evident that *C. capensis* is vulnerable to over-fishing, and that there is a clear need for management in the St. Joseph fishery. The current size / area- distribution as well as the potential variations in sex-ratio of *C. capensis* makes it is advisable for fishing activities to be recorded at a higher spatial resolution. Also, there is a need to re-evaluation on the current minimum legal mesh size of the gillnets especially as 61.3% of species sampled were mostly immature females. These measures as well as the establishment of a fishing prohibition at nursery sites will help to protect recruitment grounds.

4.2 **Future research.**

In order to augment estimates of life-history parameters stated in this study, the following research is recommended for the future:

1. *Analysis of growth rings of spines*. This will provide assistance in correlating estimates from this study with present age of *C. capensis.* Growth rate estimates are often determined from size-at-age curves. The growth curve needs to be re-estimated at regular interval. The last study was conducted in 1993.
2. *Periodic data collection*. Since the data recorded for this study refer to only one month sampling (October 2010), it was not possible to properly study the defined breeding season for *C. capensis*. Thus, further studies should consider a large time interval covering the whole reproductive cycle for at least two years as referred by Yano and Tanaka (1988) for two *Centroscymnus* sharks.

3. *Histological analysis of gonads*. This will assist in providing more precise estimates in fecundity of *C. capensis*. The staging method used in this study was based on inspection of the external appearance of ovaries, and could be improved upon.

4. *Gillnet mesh selectivity of C. capensis*. An understanding of the gear selectivity will help to interpret catch data accurately, determine the size structure of *C. capensis* population, and assess the effects of gillnet fishing on the exploited stock. Catch efficiency has often been reported to be dependent on the ratio between mesh size and fish length (Emmanuel and Chukwu 2010).

5. *Experimental gillnet fishing surveys*. This will assist in augmenting the life-history parameters of *C. capensis* through the collection of information on maximum length, egg size, fecundity and size at maturity data from different areas at the study site. Also, experimental gillnet fishing provides catch per unit effort (CPUE) by area and by sex, and can be used for stock assessment.

6. *Spatial distribution of fishing effort on C. capensis*. Studies on the spatial and temporal distribution patterns of *C. capensis* will assist in providing knowledge about the resource partitioning among species and the nature of inter-specific interactions in a multi-species fisheries (Wootton 1990).

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