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The parasites of *Callorhinchus capensis* (St. Joseph elephant fish)

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ABSTRACT

Parasitic infestation of the commercially important fish *Callorhinchus capensis* (St Joseph shark or elephant fish), from the south west coast of South Africa was investigated. The extent of parasitism by macroscopic parasites was assessed and the relationships between the parasites and their fish hosts in terms of sex, size and the condition factor of the fish were investigated. A total of 173 fish, comprising 115 females and 58 males was dissected. Five species of macroparasites were identified: *Gyrocotyle plana*, *Callorhynchocotyle callorhynchi*, *Callorhynchicola multitesticulatus*, *Branchellion* sp. and *Anilocra capensis*. The prevalence of *G. plana* and *C. multitesticulatus* were both independent of sex (χ^2=0.659, df=1, P=0.417), (χ^2=0.010, df=1, P=0.315) and size (χ^2=5.024, df=2, P=0.081), (χ^2=0.659, df=2, P=0.948) respectively. The prevalence of *C. callorhynchi* was independent of sex (χ^2=0.321, df=1, P=0.571), but dependent on size (χ^2=7.401, df=2, P=0.025). The intensity of infestation by each of the three most common macroparasites was similar for the three size classes of *C. capensis*. Also, parasite burden was similar between male and female *C. capensis*. Small (200 – 350 mm) and medium-sized (350 – 500 mm) fish were in a good condition, whereas large fish (500-650+ mm) were in a fair state.

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CHAPTER 1

Introduction

The cartilaginous fishes (Class Chondrichthyes), which comprise chimaeras, sharks, skates and rays, diverged from a common ancestor of bony vertebrates (Osteichthyes: ray-finned fishes, coelacanths, lungfishes, and tetrapods) about 420 Ma (Benton *et al*. 2009). Two major subgroups of modern chondrichthyans are currently recognised: the Holocephalan fishes, represented by three genera (*Hydrolagus* (ratfishes), *Chimaera* (rabbit fishes) and *Callorhinchus* (elephant fishes)) and the Elasmobranchii, represented by sharks, skates and rays. The genus *Callorhinchus* is restricted to shallow temperate waters in the southern hemisphere, occurring in New Zealand (Gorman 1963), Chile, Argentina, Australia and southern Africa (Smith and Heemstra 1986). Three species occur in these regions: the southern African species *Callorhinchus capensis*, the New Zealand/Australian species *C. milii* and the Chilean/ Argentinian species *C. callorhynchus*.

Calorhinchus milii is a target species for the trawl and gillnet fisheries off the coasts of New Zealand and Australia, with average landings of close to 1000 tonnes per year off the coast of New Zealand in the late 1970s (McClatchie and Lester 1994, Francis 1997). In contrast, *C. callorhynchus* is mostly exploited off the coast of Chile as part of the by-catch of artisanal fisheries, with low landings ranging between 57 and 65 tonnes for 2007 and 2008, respectively (Alarcon *et al*. 2011). *Callorhinchus capensis* was the most common chondrichthyan landed by gillnets off the south western coast of South Africa in the early 1980s and was also very common as a by-catch in demersal trawl operations (Freer and Griffiths 1993a).

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Callorhinchus capensis off South Africa inhabit shallow sandy bottoms in depths up to 366m, with frequency of occurrence decreasing with increasing depth (Freer and Griffiths 1993a). They have a geographical distribution from KwaZulu-Natal on the east coast (Van Der Elst 1988), where they are not very common, to at least northern Namibia on the west coast (Compagno 1988). Their distribution may extend into Angolan waters, although no confirmed records currently exist for the area.

Callorhinchus capensis were of very little or no value until the early 1980s when large numbers were accidentally caught in seine nets meant for *Liza richardsonii* (mullet) on the west coast, which was the main target catch at the time (Freer and Griffiths 1993a). Gradually, the species started gaining commercial importance on the west coast. The first gillnet catches made in 1981, amounted to 263 tonnes (Freer and Griffiths 1993a). Annual landings by gillnets increased up to 1983 and thereafter stabilized between 700-900 tonnes (Freer and Griffiths 1993a). Commercial catches off the south western Cape extend from Mossel Bay to Elands Bay. The largest fishery for *C. capensis* by 1993 existed in St. Helena Bay on the west coast, where the greatest number of net permits was held (Freer and Griffiths 1993a). This is still the case today.

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The concept of `stock' in fisheries biology is important in fisheries management. Stocks are arbitrary groups of fish large enough to be essentially self-reproducing, with members of each group having similar life history characteristics (Hilborn and Walters 1992). Differences in stock centre around varying nursery, feeding or spawning grounds (Williams *et al.* 1992). To manage a fishery effectively, it is important to understand the stock structure of the species and how fishing effort and mortality rates are distributed (Grimes *et al*. 1987).

Recent interest in the exploitation of holocephalans, along with a number of associated deepwater species of sharks, for their meat and liver oil (Hardy and Mackie 1971, Brennan and Gormley 1999), has focussed attention on the scarcity of information available on the life history of these species upon which to base fisheries management advice. It is important that the stock structure of *C. capensis* be identified, to allow sustainable management of the coastal fishery in South Africa.

The populations of *C. capensis* that exist on the west, south and east coasts of South Africa live under different environmental conditions. The west coast forms part of the Benguela upwelling region, which is characterized by high productivity, low species diversity and relatively cold water temperatures (van der Lingen *et al*. 2006). The east coast is less productive than the west coast, with high species diversity and relatively warm water temperatures. This presents two environments with different biological and ecological activities, especially when it comes to nursery, feeding and spawning grounds for *C. capensis*, and as a result, there might exist different stocks of *C. capensis* on the west and east coasts of South Africa.

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Callorhinchus capensis is one of the least-studied commercially exploited fish in South Africa and no information about stock composition currently exists. At present only age, growth, diet and reproductive biology of the species have been documented (Freer and Griffiths 1993 a and b). The research presented in this dissertation sets a base for further investigation into the macro parasite species infesting *C. capensis* from the south and east coasts of South Africa. In this only the west coast (St Helena Bay) was sampled. Hence stock structure cannot be addressed at this point, but by identifying the species of parasite commonly found on St Joseph from the west coast, the potential usefulness will be identified of certain of the parasite species for future stock discrimination studies.

Parasites infecting holocephalan fishes around the world

Several parasitic species have been described from holocephalans (Table 1.1). Cestodes and monogeneans appear to be the most commonly occurring parasites infecting these fish. Chimaeroid fish, the only surviving holocephalans, contain in their spiral valves and stomachs the gyrocotylideans, which are specific to these hosts (Colin *et al.* 1986). They are a small group of flatworms with ten known species within two genera: *Gyrocotyle* and *Gyrocotyloides* (Xylander and Poddubnaya 2009). Most holocephalan species so far examined are said to be parasitized by one prevalent and one rare species of *Gyrocotyle* (Xylander 2005). Most authors who have recognised two sympatric *Gyrocotyle* species have noted that only one species infects a fish at a time and never, or very rarely, would you find more than one species infecting the same fish (Lynch 1945, van der Land and Templeman 1968, Simmons and Laurie 1972). An exception was found by Simmons and Laurie (1972), who found that two species of *Gyrocotyle* infected the same fish, but differed statistically in their distribution along the spiral valve.

There are differences, as well as some striking similarities, in the biology of the *Gyrocotyloides* species from holocephalans studied thus far. Host species from deep water in the North Atlantic (*Chimaera monstrosa*), shallow water in the North East Pacific (*Hydrolagus colliei*), and shallow water in the South West Pacific (*Callorhinchus milii*) (Colin *et al*. 1986) have been studied. In South Africa, Linton (1924) described a new species of *Gyrocotyle*, *G. plana,* from the stomach of *Callorhinchus capensis* from Table Bay.

Manter (1955) described another monogenean from South Africa, *Callorhynchichola multitesticulatus,* found in *C. capensis* caught off the coast of South Africa. These are the only two parasitic species identified on *C. capensis* prior to this study.

Table 1.1 Parasitic cestode and monogenean species described from holocephalan hosts around the world.

Parasite species	**Host species**	**Organ**	**Locality**	**Reference**
Cestodes				
Gyrocotyle plana	*Callorhinchus capensis* (elephant fish)	Stomach	South Africa	Linton (1924)
Gyrocotyle rugosa	*Callorhinchus milii* (elephant fish)	Stomach	New Zealand	Manter (1951)
Gyrocotyle nybelini	*Chimaera monstrosa* (rabbit fish)	Spiral valve	Norway	Fuhrmann (1930)
Gyrocotyle fimbriata	*Hydrolagus colliei* (ratfish)	Spiral valve	California	Watson (1911)
Gyrocotyle urna				Wagener (1852)
Gyrocotyle rugosa	*Hydrolagus colliei* (ratfish)	Spiral valve	California	Hungerbuhler (1910)
Monogeneans				
Callorhynchicola branchialis	*Callorhinchus callorynchus* (elephant fish)	Gills	Chile	Brinkmann (1952) Beverly-Burton *et al.* (1993)
Callorhynchicola multitesticulatus	*Callorhinchus capensis* (elephant fish)	Gills and facial musculature	South Africa	Manter (1955), Beverly-Burton *et al.* (1993)
Callorhynchicola multitesticulatus	*Callorhinchus milii* (elephant fish)	Gills and facial musculature	New Zealand	Manter (1955), Beverly-Burton *et al.* (1993)
Callorhynchocotyle sagamiensis	*Chimaera phantasma* (Ginzama)	Gills	Japan	Kitamura *et al.* (2006)

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In South Africa, the parasite species associated with many economically important marine fishes have not been studied in great detail. The objectives of this study were to examine selected organs of *Callorhinchus capensis* from the south west coast of South Africa for the presence of macroscopic parasites. The aims were to identify the parasite species to as high taxonomic levels as possible, to calculate summary statistics of prevalence and intensity of infestation related to host size and sex for each parasite species identified, and to determine if one or all parasite species found infecting *C. capensis* could be suitable for use as biological tags for host stock assessment.

Parasites as biological tags

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Several techniques of discriminating fish stocks exist and the use of parasites merely represents one of these methods. Since the parasites infecting St Josephs will be discussed in this dissertation it presents the opportunity to document the presence of potential parasite tags for future studies. Parasites present some advantages over other tagging methods in certain fish species as will be highlighted in the subsequent paragraphs.

Fish parasites have been used successfully in stock identification of several commercially-important marine and fresh-water fishes throughout the world. This approach has also been used successfully to provide information on movements and population structure of fish hosts of parasites (Lester 1990, Williams *et al*. 1992, MacKenzie and Abaunza 1998, Oliva and Ballon 2002). Although parasites have been used as biological tags in mainly fish population studies (MacKenzie 2002, MacKenzie and Abaunza 2005), they have also been used for other vertebrates, such as marine mammals, and for some invertebrates (Balbuena *et al*. 1995, Pascual and Hochberg 1996).

In the South Atlantic, the whitemouth croaker *Micropogonias furnieri* was a very important source that supported both industrial and local fisheries in Venezuela, Argentina, Uruguay and Brazil. This species was considered a unitary stock, but the stock structure was poorly known. Several studies on the Brazilian coast indicated two groups of this fish, but not two stocks, until Vasconcellos and Haimovici (2006) suggested the existence of at least two stocks in southern Brazil. There was a need for the investigation of the southern Brazilian stocks and the exploited stock in the common fishing zone of Uruguay and Argentina. Due to the importance of *M. furnieri* in both Brazilian and Argentinean fisheries, the status of the population along the coast of Brazil needed to be investigated. Luque *et al.* (2010) subsequently used metazoan parasites to distinguish three stocks of this species: the northern, south-eastern and southern populations.

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The Brazilian sandperch (*Pinguipes brasilianus*) had little importance in the regional fisheries, but was caught as an incidental catch over its distribution range and therefore was being indirectly exploited. Its biology, diet, migration and population sizes were poorly known, and consequently the number and distribution of stocks was unknown and required further investigation. Timi *et al.* (2009) identified two stocks of *P. brasilianus* using monogeneans, digeneans, cestodes, nematodes, acanthocephalans and crustaceans from the northern Argentine sea.

The Brazilian flathead (*Percophis brasiliensis*) was exploited commercially within a multispecies fishery. Despite the differences in their population dynamics, all the species were exploited as a single resource. Since 1997, the capture of these species increased progressively (Carozza *et al*. 2004), and for this reason it was important that stock delineation for each of the species be identified to allow sustainable management of the coastal fishery in

Argentina. Braicovich and Timi (2008) used metazoan parasites in the south-west Atlantic from the coast of Argentina and Uruguay to identify three stocks of *P. brasiliensis*.

The striped weakfish (*Cynoscion guatucupa*) was of great importance in the regional fisheries of Brazil and Argentina, yet the number of populations or stocks in this area was poorly known and needed to be investigated. Timi *et al.* (2005) identified two stocks of *C. guatucupa*, using metazoan parasites, in the south-west Atlantic Ocean.

The Argentine hake (*Merluccius hubbsi*) is an important fishery resource in the seas of Argentina and Uruguay. The fishery faced danger of collapsing due to overexploitation of the resource, with huge declines in fish catches. There was substantial uncertainty about the identity of Argentine hake populations in Argentine waters, and knowledge of stock composition was therefore important to allow the recovery of the resource. Sardella and Timi (2004) identified three stocks of *M. hubbsi* using anisakids in the south-west Atlantic.

In North Atlantic waters, the Atlantic cod (*Gadus morhua*) was exploited commercially from the Gulf of St. Lawrence and Cape Breton Shelf for close to four centuries and the stock collapsed in the early 1990s, which led to closure of the fishery in 1993, yet the stocks continued to decline (Swain *et al*. 2009). Assessment of 4T cod (North Atlantic Fisheries Organization division 4T) and 4Vn cod (North Atlantic Fisheries Organization division 4Vn) was confused by seasonal migrations and it was difficult to determine accurate exploitation rates of migrant 4T and local 4Vn cod during the 4Vn winter fishery. Prior to the closure of the fishery, catches from the 4Vn winter fishery were often attributed to the 4T total allowable catch. The possibility remained that declines in 4Vn cod were obscured when migrant 4T cod were harvested in winter. Lambert (1993) carried out tagging experiments

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which revealed that 4T cod could be further separated into two distinct populations, one occupying the south-western Gulf off the Gaspe Peninsula, and the other residing in the eastern Gulf between Prince Edward Island and Western Cape Breton. In this regard, stock identification was needed for delineation of stock boundaries for efficient management of the fishery. McClelland and Melendy (2011) used nematodes and acanthocephalan parasites of *G. morhua* from the southern Gulf of St. Lawrence to show that the western and eastern 4T cod were discrete and different from 4Vn cod from the Smokey Channel and Cape Breton Shelf.

Several studies have been carried out on bluemouth (*Helicolenus dactylopterus*), including age, growth and reproductive biology. Population structure was investigated using genetic markers, but information on their population structure was still contradictory. *Helicolenus dactylopterus* was the most important species captured on the continental Portuguese slope and its stock structure in Portuguese waters needed clarification. Sequeira *et al.* (2010) identified three stocks of *H. dactylopterus* using anisakid parasites as tags in Portuguese waters.

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A population structure study was carried out on the Atlantic horse mackerel (*Trachurus trachurus*) from the coast of Morocco to south-west Norway and throughout the Mediterranean Sea, as part of a multidisciplinary international project aimed at clarifying the stock structure of *T. trachurus* in European waters. Mackenzie *et al.* (2008) examined the stock structure of *T. trachurus* using nematodes to show that the western, central and southern populations of the Mediterranean stock were separate, and also different from the North Sea stock.

The sciaenid fish (*Micropogonias undulates*) was exploited both commercially and recreationally in the United States of America. A study by Lankford *et al*. (1999) showed that separate stocks existed in the Gulf of Mexico and in the western North Atlantic. However, historical fluctuations in *M. undulatus* landings from the east coast of the USA led to an increased concern for the fate of the fishery. There was, therefore, the need to understand *M. undulatus* stock structure in the western North Atlantic Ocean. Baker *et al*. (2007) used turbellarians, monogeneans, digeneans, acanthocephalans, aspidogastreans and copepods to identify two stocks of *M. undulatus* in the North West Atlantic Ocean.

Before 1994, the flatfish fisheries on the Breton and Scotian shelves and in the north-east Gulf of Maine were managed as a single stock, excluding winter flounder (*Pleuronectes americanus*) from management considerations. Winter flounder were included in the stock complex in 1994 and the fishery was divided into two management units. Harvesting levels of winter flounder from this point started increasing, although they were still below historical levels. Aquaculture then became established to diversify and expand the world's market for non-salmonid species to counterbalance the short comings from traditionally captured fish. It was discovered that winter flounder were loyal to spawning areas and had many physiological and life-history characteristics which made them suitable for future broodstock in North America.

McClelland *et al.* (2005) used adult digeneans and larval nematodes to delineate four stocks of winter flounder (*Pleuronectes americanus*) from the central and south-west Scotian Shelf and north-east Gulf of Maine.

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The Greenland halibut (*Reinhardtius hippoglossoides*) was heavily exploited along the eastern Canadian coast, in Davis Strait, in West and East Greenland and off Iceland, and the stocks throughout the area were declining considerably (Anon 1994, 1995). More detailed knowledge of stock structure was essential for effective management of the resource, especially considering the fact that the resource extended over several national boundaries and into international waters. Boje *et al.* (1997) used digeneans and nematodes of *R. hippoglossoides* in the North West Atlantic to identify and separate two populations on the east and west coast of Canada and Greenland.

In contrast, the Pacific herring was an important commercial fishery on the coast of California with separate feeding and spawning areas. The Californian Department of Fish and Game needed to distinguish between the two breeding stocks of herring. Moser and Hsieh (1992) used acanthocephalans, cestodes, copepods, digeneans, nematodes and protozoans from the Pacific herring (*Clupea arengus pallasi*) off northern California from San Francisco Bay and the nonspawning population in Monterey Bay to indicate that the two populations represent a single stock.

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In the North Pacific, a study on the life history of the starspotted dogfish (*Mustelus manazo*) from Japan and Taiwan was carried out and the results demonstrated great differences among the localities, particularly between the Aomori and Taiwan populations. Yamaguchi *et al.* (1998, 1999) found evidence of geographic variations in the maximum length and age, growth rate, size at birth, length and age at sexual maturity, and reproductive cycle among populations from Taiwan and Japan. These areas form a continuous slope with similar environmental conditions and there was suspicion that there was mixing of the two populations, thus population structure had to be verified. Yamaguchi *et al.* (2003) used the parasites of *M. manazo* (one nematode, two myxosporeans, two copepods and eight cestodes) from Japan and Taiwan to show that a single stock existed in Tokyo Bay and separate stocks in Aomori and Tokyo Bay.

The thumb grenadier (*Nezumia pulchella*) from the south-eastern Pacific coast of Chile was of no economic importance, but comprised about 80% of the by-catch associated with the deep-sea shrimp and squat lobster fisheries. The parasite fauna of *N. pulchella* across this geographical range in northern and central Chilean waters was assessed for use as potential parasite tags for the discrimination of host populations. Salinas *et al.* (2008) used copepods, monogeneans and larval acanthocephalans to distinguish three host populations of *N. pulchella*, from the south-eastern Pacific, off the coast of Chile.

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Anchoveta (*Engraulis ringens*) is one of the most important fish species in Chilean waters and the Chilean fishing regulations assumed that there was a single stock along the Chilean coast. An exact determination of its biological identity was therefore necessary for efficient management of the resource. Valdivia *et al.* (2007) distinguished two stocks of *E. ringens* using a monogenean and a copepod along the coast of Chile.

The main principle underlying the use of parasites of marine fish as biological tags is that a fish can become infected with a parasite only when it is within the endemic area of that parasite (MacKenzie *et al*. 2008). The endemic area is the geographical region in which suitable conditions exist for the transmission of the parasite, allowing it to complete its life cycle. The abundance and geographical distribution of parasites depend on the abundance and geographical distribution of all host species involved in their life cycles (MacKenzie 1987).

Therefore, sound knowledge of parasite diversity in a given geographical region can assist with environmental management and conservation of the fish resource (Poulin 2004). Understanding the dynamics of any commercially exploited population of fish begins by determining its biological identity in relation to neighbouring populations of the same species (MacKenzie and Abaunza 1998). For the evaluation and efficient management of a fish population, various techniques and methods are used to obtain information on stock structure: natural methods, including morphometric and meristic analyses, use of parasites as biological tags and genetic studies and studies of biological parameters in relation to life cycles (Anon 1993, MacKenzie and Abaunza 1998). These methods complement one another.

Biological tagging using parasites has many advantages over other tagging methods, such as the use of fin clips, where recapture has proven to be problematic. For genetic markers, preservation of blood samples and development of reagents and equipment can be complicated and costly. Where chemicals are used (immersion, injection, tattooing or feeding of fish), the retention of the mark can be difficult at times because growth can displace the marker.

In contrast, the use of parasites has a number of advantages, as indicated by Mosquera *et al.* (2003) and MacKenzie (2005). It involves little effort in relation to sampling procedures as fish are obtained from routine sampling and not necessarily dedicated tagging cruises. The use of parasites is cheaper than routine surveys and independent of fishing activities, unlike conventional tagging, for example. Tagging using parasites requires dissection of the organisms as the fish are killed and dissected once off, unlike the case with some artificial tags where some organisms suffer mortality after tagging as they are cut open and a tag

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placed. Lastly, the use of parasites is more suitable for crustaceans which lose artificial tags after moulting.

For these reasons, parasites have been used for a long time as biological indicators, tags, or markers to provide information on various aspects of host biology, including fish stock separation, fish recruitment, migration patterns, fish diet and feeding behaviour, and host phylogenetics and systematics (Williams *et al*. 1992, Arthur 1997).

In a review of parasites as biological tags, Williams *et al*. (1992) listed the commonly stated criteria required for fish population studies: the parasite should have varying levels of infection of the host in the study area, the length of time spent by the parasite in the host should be long enough, parasites with single host life cycles should be treated separately from those with complex life cycles which involve more than one host because further investigation is needed for the transmission modes from one host to the next, and the parasites should be easily detectable and identifiable, with dissection being a minimum requirement.

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CHAPTER 2

Macroscopic parasites of *Callorhinchus capensis* and their potential as biological tags

INTRODUCTION

The genus *Callorhinchus* is widely distributed in shallow temperate waters of the southern hemisphere, occurring off the coasts of South America, Australia and southern Africa. *Callorhinchus capensis* is found off the coast of South Africa in depths of less than 100 m (Freer and Griffiths 1993b). The range may also extend into Angolan waters, although no confirmed records are available for that area (Freer and Griffiths 1993b). The largest fishery for *C. capensis* is found in St Helena Bay (Figure 2.1), where it is caught by trawl and gillnet fisheries. *Callorhinchus capensis* was of little commercial value until the early 1980s when it was accidentally caught as a bycatch in gillnet catches in large quantities and subsequently started gaining some commercial importance on the west coast. Gradually the species was used by processors for salting and drying with larger fish processed into frozen fish fillets (Freer and Griffiths 1993 a and b).

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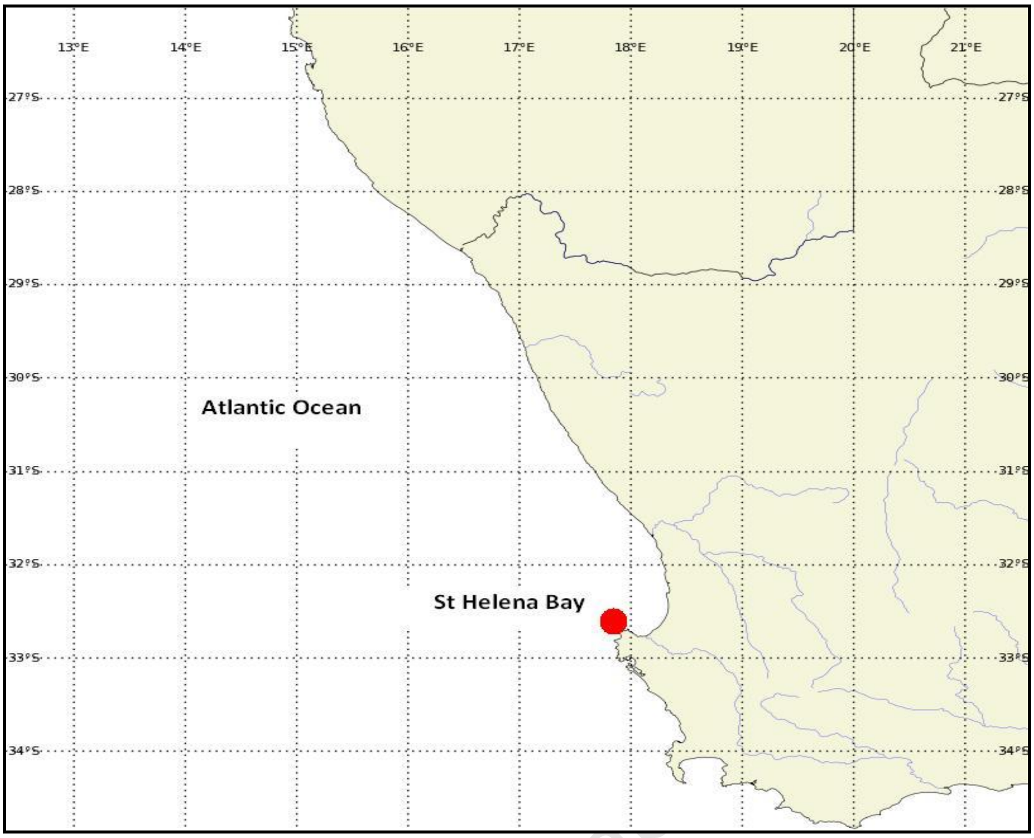

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Figure 2.1 Map of the south west coast of South Africa showing St Helena Bay where *Callorhinchus capensis* were captured in 2010.

Several methods have been used to distinguish different fish populations around the world. The use of naturally occurring parasites has proven to have some advantages over other tagging methods. The frequent occurrence of parasites in fish presents an opportunity for them to be used as biological markers to explore stock structure (MacKenzie and Abaunza 1998, MacKenzie 2002, Melendy *et al*. 2005, MacKenzie *et al*. 2008, Lester and MacKenzie 2009). Parasites have been used as biological tags in delineating demersal and pelagic fish stocks and in studying their migration and mixing (Williams *et al*. 1992). The use of parasites as biological markers has shown potential value in the allocation of quotas and in combating illegal fishing (Power *et al.* 2005). In theory, if the number and type of parasites of two groups of fish of different species are similar they are likely to have had a common history and, in contrast, if the parasites of one group of a particular species fish are significantly different from those of another group of the same species fish, they are likely to have had a different history (MacKenzie and Abaunza 1998). One population of fish may acquire a parasite and carry it to a region where the intermediate host does not occur. The parasite then acts as a tag, indicating the past movements of the individual fish (Speare 1995). Thus, in evaluating stock structure of fish, parasites that are 'permanent', that is they are resident in the fish for many years and possibly for the entire life of the fish, are likely to give more reliable results than 'temporary' parasites that remain in the fish for only a brief period of time (Lester and MacKenzie 2009).

Many studies have shown that parasites offer potential as biological tags for stock designation and fish migration studies which have contributed to management decisions, such as redefinition of stock boundaries and setting of catch limits for marine fishes. The aim of this study was to identify and quantify the various macroparasite species infesting *C. capensis* and to establish if some or all macro-species found could be used as suitable biological tags for future stock discrimination studies of *C. capensis*.

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MATERIALS AND METHODS

Fish were collected from commercial landing sites at St Helena Bay (Figure 2.1) on the west coast of South Africa. Gillnets used by commercial fishermen are standard commercial nets. Fish were frozen and taken to the Zoology Department, University of Cape Town where they were thawed at room temperature. Their total length (TL) and standard length (SL) were measured to the nearest millimetre (mm) on a measuring board with the fish placed on its right side, straightened, with the proboscis bent up against the base plate of the measuring board, as recommended by Coakley (1973). Immature fish were weighed on an electronic balance and mature fish on a spring balance to the nearest gram (g). A survey of the entire macroparasitic fauna was conducted, as recommended by MacKenzie (2005). The gills, skin, fins and mouth were examined for external macroparasites that were removed and stored in 10% formalin or 70% ethanol. The stomach of each fish was cut open and examined for internal parasites which were removed, flattened between glass slides and stored in 10% formalin or 70% ethanol. The stomach contents of each fish were examined and recorded.

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Summary statistics were calculated for levels of prevalence (the number of hosts infested with one or more individuals of a particular parasite species) and intensity (the mean number of a particular species of parasite found on each of the infested members of a particular host species), as recommended by MacKenzie and Abaunza (1998). The mean intensity was calculated as the total number of parasites of a particular species divided by the number of hosts parasitized by a particular parasite. Chi-squared statistics using 2 X 2 and 2 X 3 contingency tables were used to evaluate the dependence of parasite prevalence on sex and size of the host fish. The Mann-Whitney non-parametric test was used to evaluate whether male and female *C. capensis* had similar intensities of infestation/infection. The Kruskal-

Wallis non-parametric test was also used to evaluate the intensities of infestation of the three size classes of *C. capensis*. The condition factor K, of the fish was calculated as recommended by Williams (2000): $K = 100,000W/L^3$, where:

W= weight of fish in grams

L= standard length of fish in mm.

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RESULTS

A total of 173 *C. capensis* was dissected, comprising 115 females and 58 males. The fish were divided into three size classes: 200-350 mm SL representing juvenile fish, 350-500 mm SL representing maturing fish and 500-650+ mm SL representing matured fish (Freer and Griffiths 1993b). Five different species of macroscopic parasites, both internal and external, were recorded from these three size classes. These parasites were *Gyrocotyle plana* from the stomach (Figure 2.2a), two species of monogeneans (*Callorhynchichola multitesticulatus* (Figure 2.2b) and *Callorhynchocotyle callorhynchi* from the gills, a leech (*Branchellion* sp.) from the skin and an isopod (*Anilocra capensis*) from the skin and fins (Table 2.1). The three most common species were *Gyrocotyle plana*, *Callorhynchocotyle callorhynchi* and *Callorhynchichola multitesticulatus* (Table 2.1). Two leeches were found infesting one male and one female *C. capensis* respectively and three *Anilocra capensis* infesting two males and one female *C. capensis* (Table 2.1). The stomach content was mostly composed of crushed crustaceans (Table 2.2).

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Figure 2.2 Dorsal view of adult *Gyrocotyle plana* (a) from the stomach and *Callorhynchichola multitesticulatus* (b) attached to the gills of *Callorhinchus capensis* collected from the south west coast of South Africa in November and December 2010.

Table 2.1 Summary of parasite prevalence (%) showing the observed (and expected) numbers of the five macroparasite species in terms of sex and size of *Callorhinchus capensis* collected from the south west coast of South Africa in October and November 2010. X^2 = Chi squared values, df = degrees of freedom and P = probability of accepting null hypothesis.

Parasite species	**males**	**females**		χ^2	**df**	**p**
Gyrocotyle plana	40(42.2)	86(83.8)		0.659	1	0.417
Callorhynchocotyle callorhynchi	10(11.4)	24(22.6)		0.321	1	0.571
Callorhynchicola multitesticulatus	8(10.4)	23(20.6)		0.010	1	0.315
Branchellion sp.	1(0.7)	1(1.3)		0.246	1	0.620
Anilocra capensis	2(1.0)	1(2.0)		1.505	1	0.220
	small	**medium**	**large**			
Gyrocotyle plana	58(63.4)	45(43.7)	23(18.9)	5.024	2	0.081
Callorhynchocotyle callorhynchi	10(17.1)	17(11.8)	7(5.1)	7.401	2	0.025
Callorhynchicola multitesticulatus	16(15.6)	10(10.8)	5(4.7)	0.108	2	0.948
Branchellion sp.	1(1.0)	1(0.7)	0(0.3)	0.441	2	0.802
Anilocra capensis	2(1.5)	1(1.0)	0(0.5)	0.623	2	0.732

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Table 2.2 Diet of *Callorhinchus capensis* based on analysis of the stomach content of 173 fish dissected.

Size classes	**Crustaceans (%)**	**Gastropods (%)**	**Green algae (%)**
Small	88.9	11.1	0.0
Medium	75.5	15.7	8.8
Large	100	0.0	0.0

Gyrocotyle plana

The most common macroparasite was *G. plana* with an overall prevalence of 73%. Prevalence of *G. plana* was independent of sex ($\chi^2 = 0.659$, df = 1, P = 0.417) and size ($\chi^2 = 5.024$, df = 2, P = 0.081) (Table 2.1). They are hermaphrodites that usually occur in pairs, although in rare instances more than two or less than two can be found infesting the same fish (Lynch 1945, Van Der Land and Templeman 1968, Simmons and Laurie 1972). The stomach of *C. capensis* has a double layer and the *G. plana* were found lining both sides of the stomach. Three *G. plana* were found infesting three fish each and just one found infecting each of 29 fish specimens. In total, 158 *G. plana* parasites were found in the stomachs of 126 fish giving a mean intensity of infestation of 1.24 per fish (Figure 2.3). The parasites are about 15-20 cm in length (Figure 2.2a). There was no significant difference in infection between the three size classes of fish (Kruskal-Wallis = 4.351, df = 2, P = 0.113, $n_1 = 85$, $n_2 = 80$, $n_3 = 8$) (Table 2.1).

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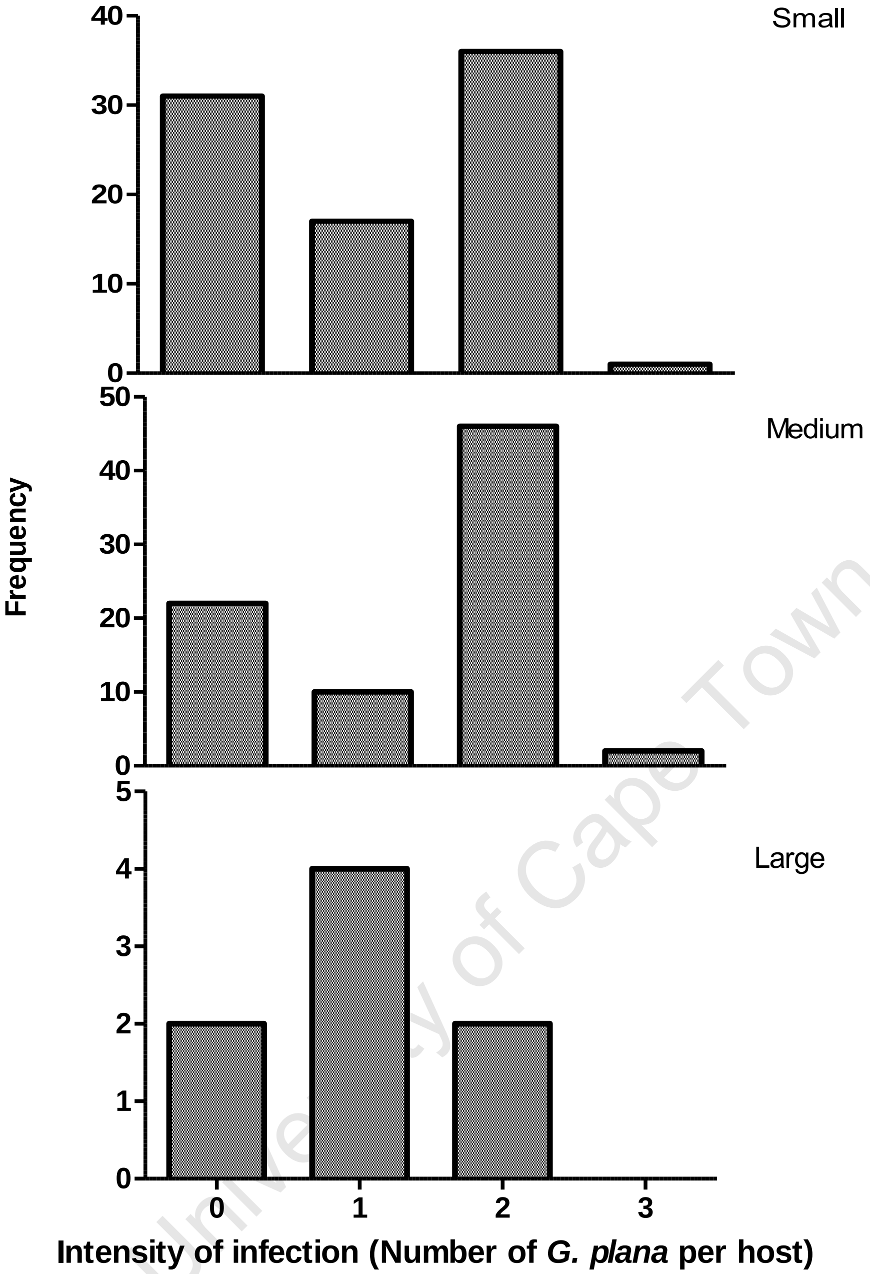

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Figure 2.3 The number of *Gyrocotyle plana* per individual (intensity of infection) for the three size classes of *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

The intensity of infection of females and males by *G. plana* was similar (Mann-Whitney U = 3105, n_{males} = 58, $n_{females}$ = 115, P = 0.370), (Figure 2.4).

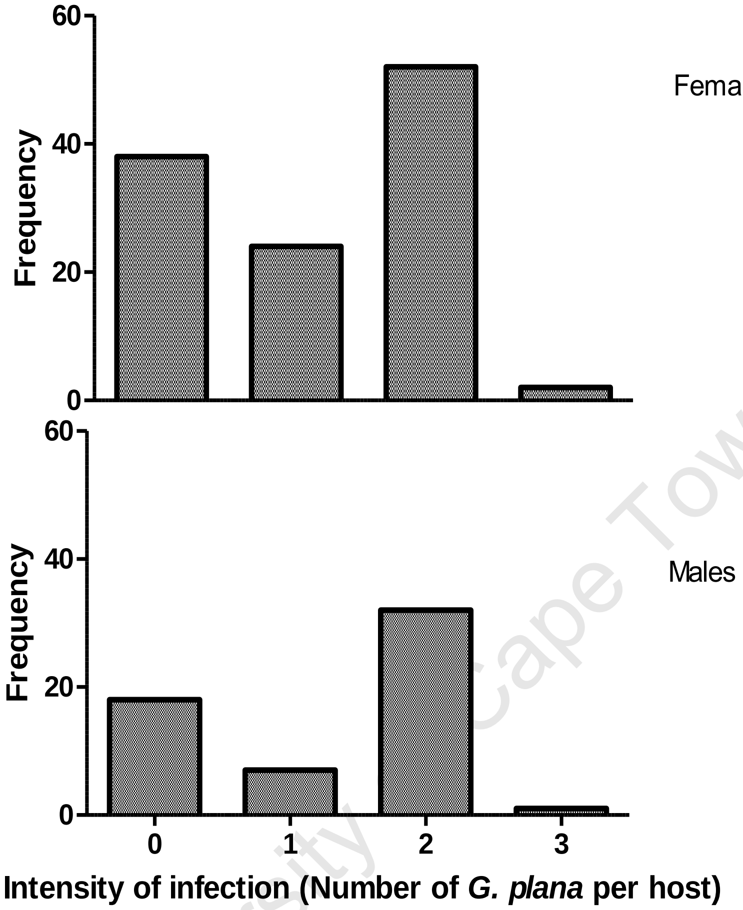

Figure 2.4 Frequency distribution of number of *Gyrocotyle plana* per host (intensity of infestation) in female and male *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

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Callorhynchocotyle callorhynchi

Callorhynchocotyle callorhynchi was the second most common macroparasite on *C. capensis* with an overall prevalence of 20%. In total 210 *C. callorhynchi* were found infesting the gills of 10 males and 24 females (Table 2.1). These are tiny thread-like organisms lining the gills. Prevalence of *C. callorhynchi* was independent of sex (χ^2 = 0.321, df = 1, P = 0.571), but dependent on size (χ^2 = 7.401, df = 2, P = 0.025) of the fish, with fewer parasites observed than expected in the small fish and more observed in the medium and large size classes (Table 2.1). The intensity of infestation by *C. callorhynchi* was also different among the three size classes (Figure 2.5) (Kruskal-Wallis H = 6.967, df = 2, P = 0.031, n_1 = 88, n_2 = 63, n_3 = 21). A post-hoc test indicated that the difference lay between the small/medium and large size classes with the large fish having a higher intensity than the small sizes.

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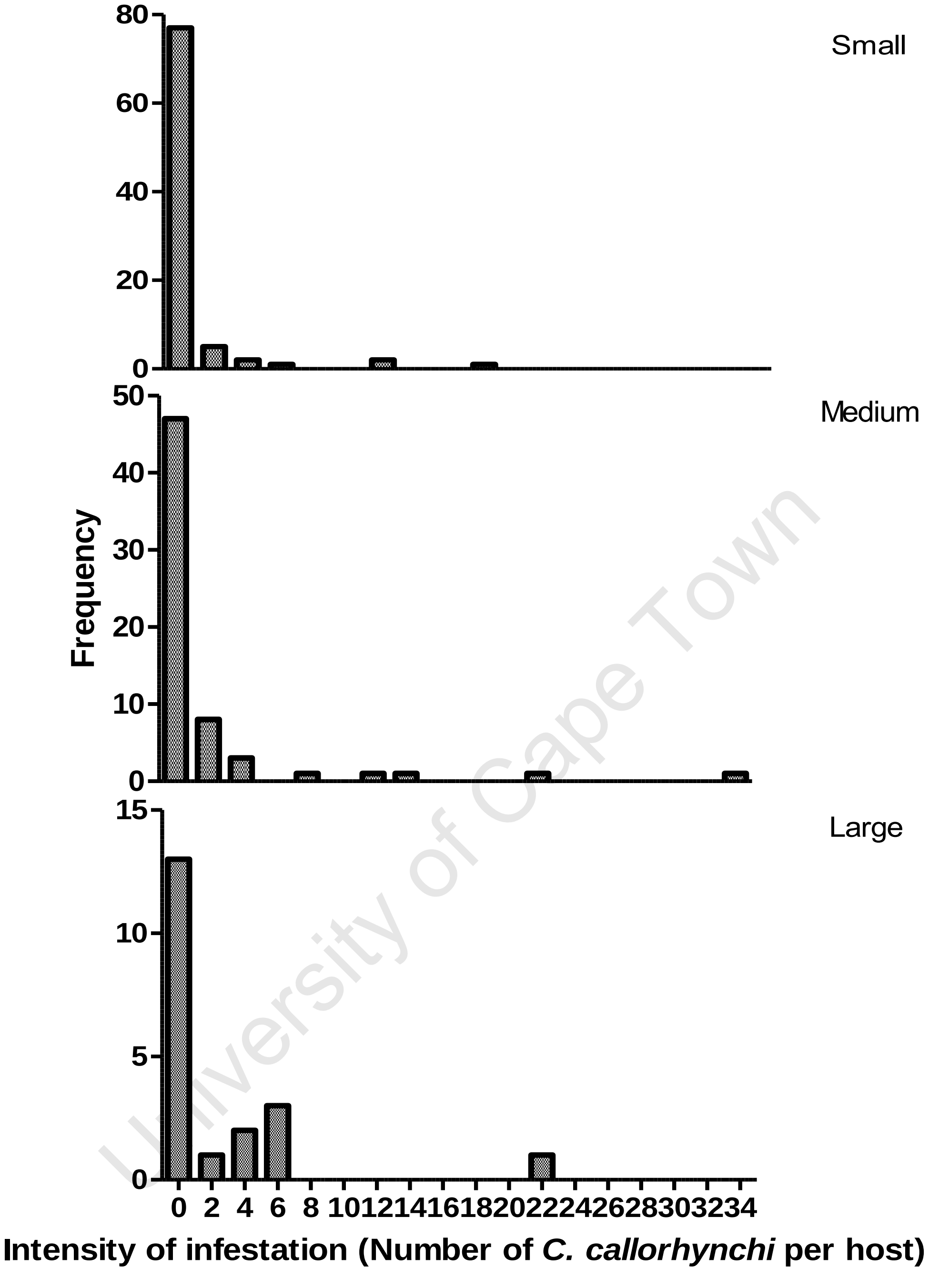

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Figure 2.5 The number of *Callorhynchocotyle callorhynchi* per individual found infesting the gills of three size classes of *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

The infestation of female and male *C. capensis* (Figure 2.6) was similar (Mann-Whitney U = 3064, n_{males} = 58, $n_{females}$ = 115, P = 0.228).

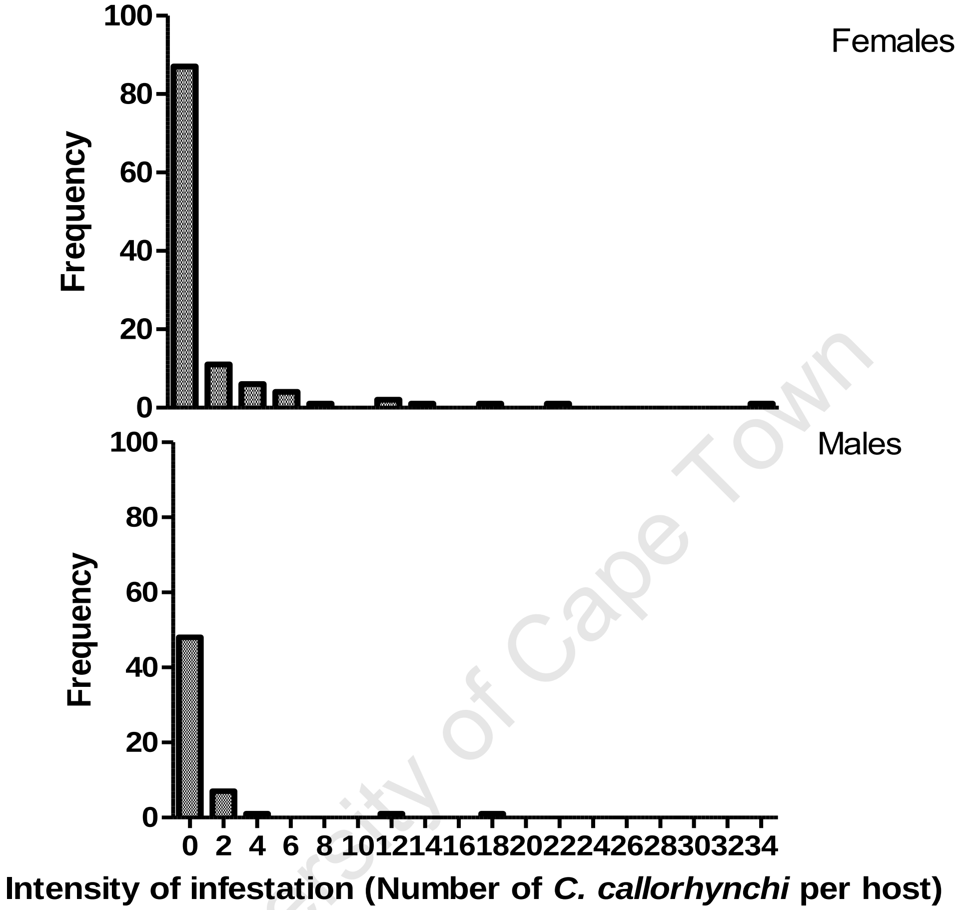

Figure 2.6 Frequency distribution of *C. callorhynchi* per host in female and male *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

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Callorhynchichola multitesticulatus

Callorhynchichola multitesticulatus was the third most common macroparasite infesting *C. capensis* with an overall prevalence of 18%. A total of 93 *C. multitesticulatus* were found infesting eight males and 23 females (Table 2.1). This prevalence was independent of sex ($\chi^2 = 0.010$, df = 1, P = 0.315) and size ($\chi^2 = 0.108$, df = 2, P = 0.948) of the fish. The intensity of infestation by *C. multitesticulatus* was similar among the three size classes (Kruskal-Wallis H = 0.153, df = 2, P = 0.926, $n_{small} = 89$, $n_{medium} = 60$, $n_{large} = 24$) and between males and females (Mann-Whitney U = 3167, $n_{males} = 58$, $n_{females} = 115$, P = 0.445) (Figure 2.7; 2.8).

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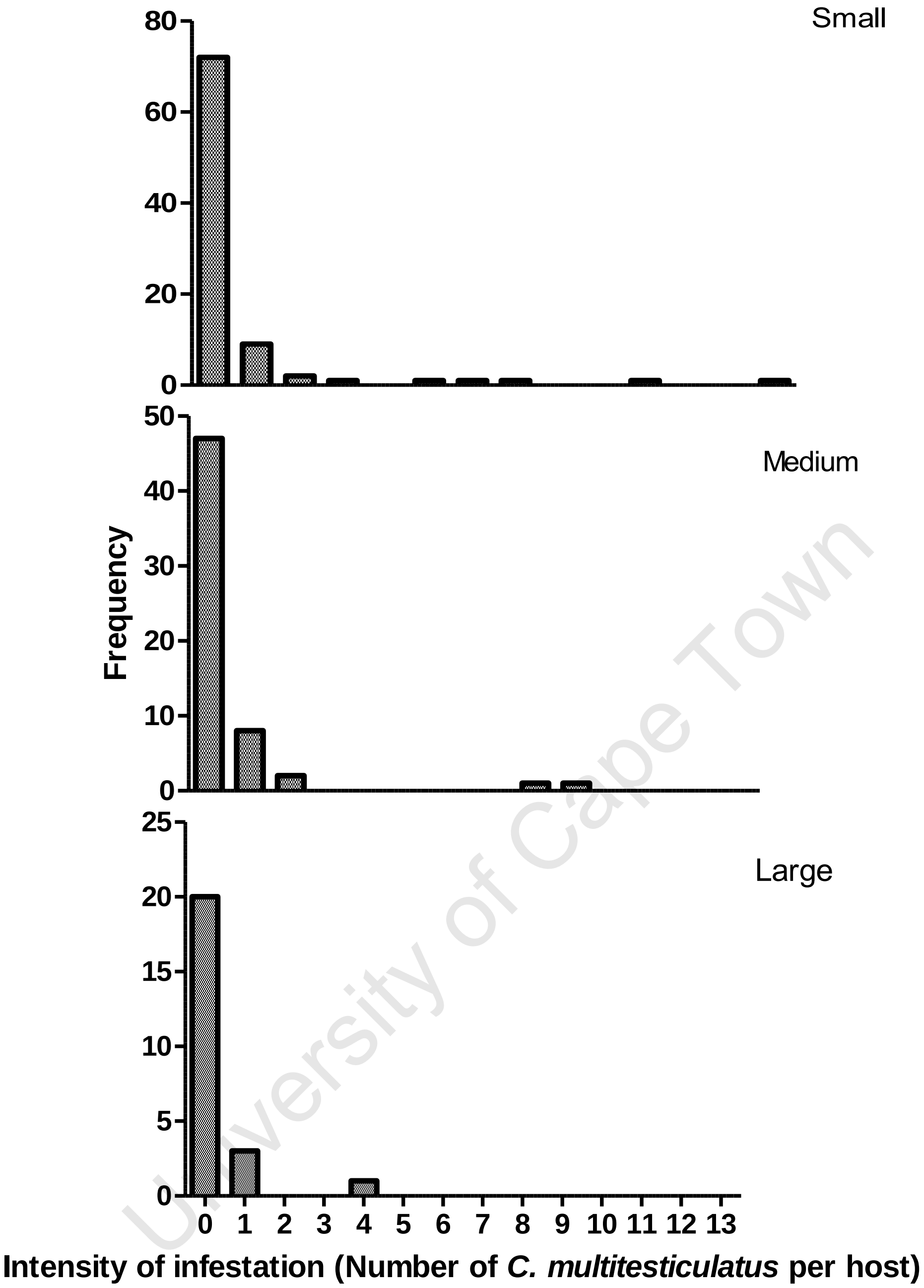

Figure 2.7 The number of *Callorhynchichola multitesticulatus* per individual found infesting the three size classes of *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

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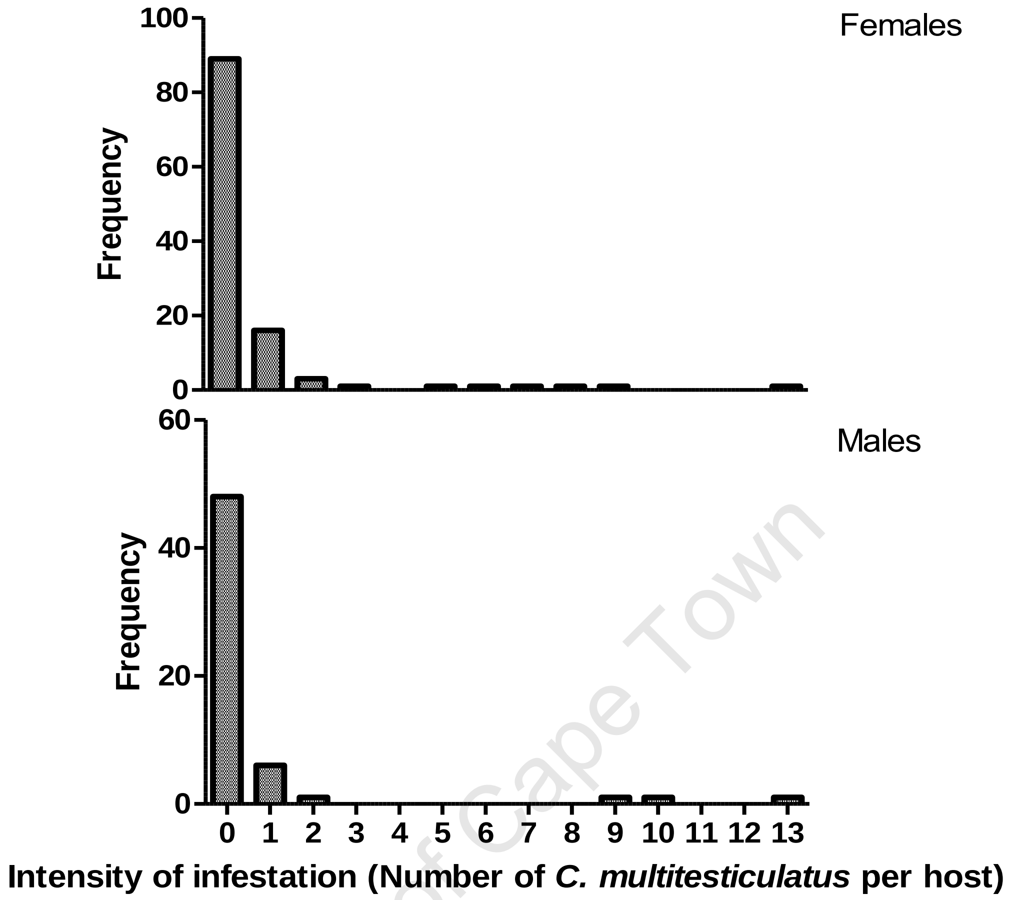

Figure 2.8 Frequency distribution of *C. multitesticulatus* per host in female and male *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

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The coefficient of condition of *C. capensis*, represented by K, indicates the degree of wellbeing of the fish. Variations in a fish's coefficient of condition primarily reflect state of sexual maturity and degree of nourishment (William 2000). Condition values may also vary with fish age, and in some species, with sex (Williams 2000). The K values are interpreted as in Table 2.3 (Barnham and Baxter 1998). There is no interpretation for values of K less than 0.80 and greater than 1.60.

Table 2.3 K value of fish and their corresponding description of condition (Barnham and Baxter 1998).

K value	**Condition**
1.60 +	Excellent
1.40 to 159	Good
1.20 to 1. 39	Fair
1.00 to 1.19	Poor
0.80 to 0.99	Extremely poor

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The single condition factor equation used in these calculations indicated that larger fish were lighter per unit length than smaller fish, hence poorer condition than smaller ones. Length-weight regressions for fish or other animals seldom ever have an exponent as high as 3. This means that larger animals are inherently lighter per unit length than smaller ones. The mean (± standard deviation) K of the small size class of fish was 1.43 ± 0.19 and their frequency distribution showed that most of the small fish ranged between 0.80 to 2.20, peaking at 1.20 and 1.40 (Figure 2.9). The medium size class of fish had a mean K (± standard deviation) of 1.35 ± 0.33 and frequency distribution showed that the highest number of medium fish were in the range 1.20 to 1.60 and a few in the range 0.80 t0 1.00 (Figure 2.9). The large size class of fish recorded a mean K (± standard deviation) of 1.30 ± 0.28, and the frequency distribution indicated that the majority of the large fish ranged between 1.20 and 1.40, peaking at 1.20. (Figure 2.9).

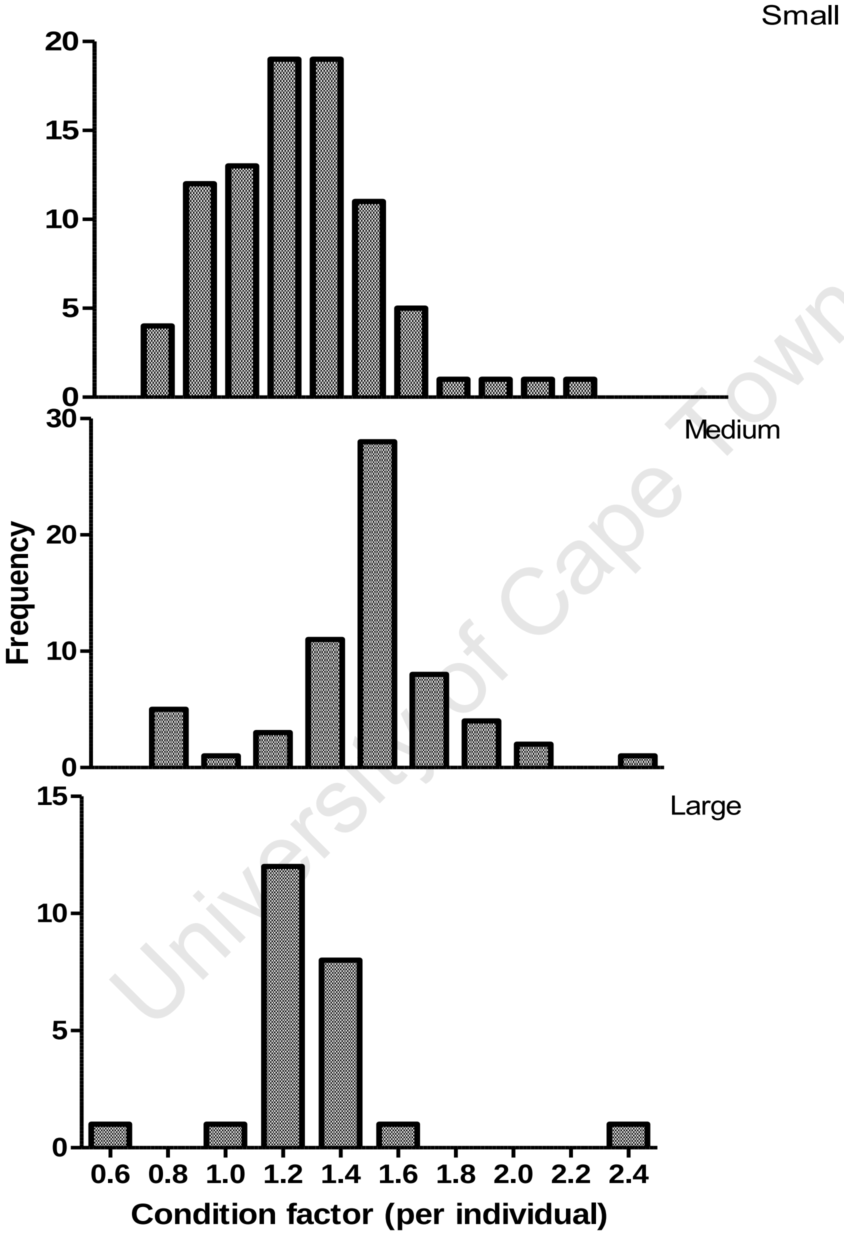

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Figure 2.9 Frequency distribution of the number of *Callorhinchus capensis* with different K values for small, medium and large size classes of *Callorhinchus capensis* collected in November and December 2010, from St. Helena Bay, South Africa.

OTHER PARASITES

The isopod *Anilocra capensis* (Figure 2.10) was recorded from the skin and fins and the leech *Branchellion* sp. from the skin of *C. capensis.* Both parasites had prevalence values of 2% and were not considered in intensity calculations, due to their very low prevalence values.

Figure 2.10 *Anilocra capensis* attached to the dorsal fin of *Callorhinchus capensis* collected from the south west coast of South Africa in November and December 2010, from St Helena Bay, South Africa.

DISCUSSION

The present study increases the knowledge of the parasite fauna of South African cartilaginous species. Except for *G. plana* (Linton 1924) and *C. multitesticulatus* (Manter 1955), the rest are new parasite records for *C. capensis*. The prevalence of *G. plana* depended neither on the size nor sex of *C. capensis*, with a large overall prevalence of 73%. *Gyrocotyle plana* is typical to *C. capensis* (Linton 1924) and this is the first study that examined the prevalence and intensity of this parasite. *Gyrocotyle* species have been recorded on other holocephalan fishes around the world (Table 1.1). Williams *et al.* (1987) had similar results with a prevalence of 90-100% when they studied *G. rugosa* in *Chimaera monstrosa* from Norway. It is interesting to see high prevalence values in both species of fish and it is worth noting that these parasites do not seem to cause any harm to the fish (Williams *et al*. 1987). The other studies that examined *Gyrocotyle* from other holocephalan fishes were based on the description and taxonomy of the parasite and merely recorded the incidence.

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Holocephalan fishes mostly feed on small invertebrates (Halvorsen and Williams 1967/8, Williams *et al*. 1987, Freer and Griffiths 1993a, Xylander 2005). An analysis of food items in the gut of *C. capensis* revealed that they feed mainly on crustaceans (Freer and Griffiths 1993a, Xylander 2005), and these same prey items were found in the stomach contents of *C. capensis* in this study (Table 2.2). Nothing is known about the relationship between the diet of *C. capensis* and the rate of infection with *G. plana*. Williams *et al*. (1987) suggested that the diet of *C. monstrosa* could be the reason for high prevalence values of *Gyrocotyle*, as it does not change with age, as is the case with other holocephalan species, when they studied the biology of gyrocotylideans. Similarly, *C. capensis* could become infected by *G. plana* when they consume the parasite in their prey because they also similar infection rates among size classes (Figure 2.3) and sex (Figure 2.4), thus infections are cumulative. The smallest holocephalan fish examined by Halvorsen and Williams (1967/8) and Dienske (1968) included fish with yolk sacs. Halvorsen and Williams (1967/8) found individuals of *Gyrocotyle* only in fish that had started feeding on small invertebrates. Based on the findings of Halvorsen and Williams (1967/8) it is possible that *C. capensis* does not acquire *G. plana* very early in their life time, as very young fish obtain their food requirements from yolk sacs, but only feed on invertebrates when they are a little older.

Gyrocotyle plana mostly occured in pairs, as is the case with other *Gyrocotyle* species, though three individuals were found infesting three fish each and just one found infesting each of 29 fish in this study. Manter (1951) discussed *G. rugosa* from *Callorhynchus milii* in New Zealand and suggested that the larvae of this species may penetrate the host through the gills, or some other open surfaces. They are carried in the blood stream to the intestine, where they emerge and make use of their powerful hooks for anchorage. Halvorsen and Williams (1967/8) also suggested that young *Chimaera monstrosa* initially take up many larval *Gyrocotyle* and of these, only two succeed in establishing themselves until the parasite reaches maturity, supporting the views of Wardle (1932) and Lynch (1945) that the establishment of two *Gyrocotyle* in one host follows a mass infestation with larvae. The occasional occurrence of one or three adult specimens of *Gyrocotyle* may be as a result of irregularities in the uptake of infestation and/or the mechanism involved in the establishment of two *Gyrocotyle*.

The species of *Gyrocotyle* (*G. plana*) found in this study were all confined to the stomach of *C. capensis*, as is the case for all other individuals of *Gyrocotyle* found in other holocephalan fish examined thus far. No information currently exists on the subject of organ specificity of *G. plana*. The subject of organ specificity among fish parasites has been studied by various

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researchers. William and Jones (1994) reported that host and organ specificity is determined by physiological requirements of the hosts and the parasites. Halvorsen and Williams (1967/8) indicated that the stomach of *Chimaera monstrosa* is mainly composed of villi which are easily adapted for attachment by the rosette and lateral body of *Gyrocotyle*. It therefore appears that the stomach is most suitable for optimum growth of *Gyrocotyle*, especially if the amount of food and space available are important factors in the process (Halvorsen and Williams 1967/8).

Gyrocotyle seems to stay permanently inside the stomach of their hosts for many years and possibly for as long as the fish lives (Williams *et al.* 1987). The life cycle of gyrocotylidians is still unknown. The only known stages of these helminths are the intestinal stages from the stomachs of holocephalans and the ciliated larvae, which hatch from eggs from the uterus of mature specimens in the spiral valve (Williams *et al.* 1987, Xylander 2005). No intermediate host has yet been detected and several authors therefore consider this group to have a direct life cycle. At this point, we are unable to distinguish between the direct or indirect transmission of *Gyrocotyle*.

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The two monogenean parasites (*Callorhynchichola multitesticulatus* and *Callorynchocotyle callorhynchi)* were the second and third most common species infesting *C. capensis. Callorhynchicola multitesticulatus* was previously found attached to the gills and facial musculature of *C. capensis* from South Africa and *C. milii* from New Zealand (Manter 1955). The parasite has not been found on any other host. This study therefore provides a second record of *C. multitesticulatus* on *C. capensis* in South Africa. In this study the prevalence and intensity of infestation by *C. multitesticulatus* was similar on all sizes of *C. capensis* (Figure 2.7) with an overall prevalence of 18%. Also there was no difference in infestation between males and females (Figure 2.8). This differs from the findings of Beverly-Burton *et al*. (1993) who found that young *C. capensis* and *C. milii* were most infested by *C. multitesticulatus,* with overall prevalences of 25% and 30% respectively, and the degree of infestation decreased with increasing age. There was no record of *C. multitesticulatus* on the largest size class of *C. capensis* (776-1851 mm standard length). Also, male and female *C. capensis* had the same infestation rates, but this was not examined by Beverly-Burton *et al*. (1993).

Population studies on monogenean ectoparasites have shown that prevalence and intensity of infestation are generally related to abiotic (temperature, pH, oxygen concentration) and biotic (reproductive behaviour, growth rate, migratory pattern, age, and immunity of the host) factors, and these can produce seasonal patterns of occurrence (Chubb 1977, Barker and Cone 2000). Beverley-Burton *et al*. (1993) also found that young *C. capensis* and *C. milii* stay in shallow waters (< 20 m) during their early developmental period for about three years, feeding on crustaceans, molluscs, echinoderms and polychaetes. During this period, male and female fish grow at approximately the same rate and then move into deeper water for approximately one and a half years, before returning to breed during summer (November to January), which is the same period during which *C. capensis* was captured. It is assumed that *C. multitesticulatus* infects *C. capensis* during their early stages of growth during the shallow water period and they grow with the parasite in them (Beverley-Burton *et al.* 1993). This assumption is supported by the findings of this study, with equal levels of infestation across all three size classes of *C. capensis.*

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Callorynchocotyle callorhynchi is newly recorded here from *C. capensis* with a low prevalence of 20%, though previously recorded by Kitamura *et al.* 2006 on a holocephalan off the coast of Japan. Unfortunately, no prevalence values exist for that study. There were size differences in infestation by *C. callorhynchi* with higher prevalence of the parasite in adult *C. capensis*. Also, the intensity of infestation by *C. callorhynchi* was greater in larger *C. capensis* than small ones (Figure 2.5). Male and female *C. capensis* had similar infestation intensities (Figure 2.6). This is not surprising, as a cumulative effect has been commonly reported for fish parasites in the literature. Larger fishes tend to harbour more parasites due to higher feeding rates, larger surfaces for parasite contact and attachment, a broader range of prey items and higher levels of activity (Guegan *et al*. 1992, Poulin 2000, Timi *et al*. 2005). This parasite has not been found on any other holocephalan. Five species of *Callorhynchocotyle* currently exist (Kitamura *et al.* 2006), but no prevalence and intensity values have been estimated for the species, only the incidences. *Callorynchocotyle callorhynchi* and *C. multitesticulatus* have a direct life cycle (Trouve *et al.* 1998), infesting only one host.

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OTHER PARASITES

Cymothoid (*Anilocra capensis*)

These parasitic isopods, mostly ectoparasites, attach to the exterior body surface, mouth and gills and can even burrow into the flesh of fish (Bunkley-Williams and Williams 1998, Ramdane *et al*. 2007, Ketmaier *et al*. 2008). Three individuals of these isopods were found attached to the skin and fin of *C. capensis* in this study. They are predominantly marine parasites and occur mostly in warmer seas (Lester and Roubal 2005), which is contrary to this study as fish were collected from the west coast of South Africa with cold water temperatures and coastal upwelling. This is the first record of this parasite on the holocepahalan *C.*

capensis. *Anilocra capensis* infests several species of sparid such as the hottentot *Pachymetopon blochii*, which are endemic to southern Africa (Kensley 1978, Wright *et al.* 2001). It has been found attached above the operculum of *P. blochii* from False Bay in South Africa with 5.2 % prevalence, which can be compared with 2% prevalence on *C. capensis*. It is interesting to see that *A. capensis* did not show any significant selection for a specific sex of *P. blochii*. No conclusion for *C. capensis* in this study as only three individuals were found.

***Branchellion* sp. (Leeches)**

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Two *Branchellion* sp. were found attached to the skin and fins of two *C. capensis* in this study with an overall prevalence of 2%. This is the first record of *Branchellion* sp. on *C. capensis* and the first record of the parasite in South Africa. Yeld (2009) carried out research on the parasite assemblage of three endemic catshark species from the south and west coasts of South Africa. She recorded 18 individuals of a species of leech that was identified to be juvenile *Stibarobdella macrothela*. Leeches of the genus *Branchellion* are common parasites of sharks, rays and skates (Williams and Burreson 2005). Approximately 20 known species of leeches have been reported from the skin of the sharks and rays (Caira and Healy 2004). Representatives of *Branchellion* have been reported on three holocephalan fishes: *B. parkeri* reported on *Callorhynchus milii* (Richardson 1953), *B. callorhynchus* from *Callorhynchus callorhynchus* (Szidat 1972), and *B. manteri* on the dark ghost shark, *Hydrolagus novaezealandiae* (Williams and Burreson 2005). Representatives of *Branchellion* have a simple, direct life cycle infecting only a single host (Hayward 2005). No records currently exist of prevalence and intensity values of the genus *Branchellion* on the fish studied thus far.

The most recent research on shark parasites in South Africa is the PhD thesis of Yeld (2009). The three species of catsharks studied were found to host representatives of a large variety of different parasitic taxa, that is Crustacea, Trematoda, Nematoda, Hirudinea, Cestoda and Protozoa. Some of these species had previously been recorded parasitising South African elasmobranchs, but little data are available other than the original taxonomic description. *Callorhinchus capensis* is an elasmobranch like the catsharks and was caught in the same location as the catsharks, that is St Helena Bay but interestingly, these different species of sharks have no common macroparasite species.

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CHAPTER 3

CONCLUSIONS AND FUTURE WORK

The criteria for the use of parasites as biological markers of fish populations have been reviewed by Williams *et al*. (1992) and MacKenzie and Abaunza (1998). These criteria include: parasite prevalence or intensity of infestation, longevity of infestation, life cycle of parasite and ease of detection of the parasite. Following the above criteria, parasites that are ‘permanent’, that is, they are resident in the fish for many years and possibly for the entire life of the fish, are likely to give more reliable results than ‘temporary’ parasites that remain in the fish for only a brief period of time. *Gyrocotyle* persists in holocephalans for a long period of time (Halvorsen and Williams 1967/8), has a single life cycle, infesting only one host (Halvorsen and Williams 1967/8) and the parasite is easily detectable. According to the above mentioned characteristics *G. plana* will be a suitable potential biological marker for *C. capensis*.

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The monogeneans also meet the following criteria for a good biological tag: they are easily detectable and they have a single life cycle. However, the length of time they spend in their host is still unknown. For this reason, *C. callorhynchi* and *C. multitesticulatus* should not be considered as potential biological tags for *C. capensis* until the length of time they spend in the fish host is known.

In summary, parasites of holocephalan fishes have not been studied in great detail. Most parasite studies on holocephalan fishes have centred on identification and description of the parasites, with most attention focused on the *Gyrocotyle* species, which seem to be the most common parasites of most holocephalans studied thus far. These parasites have not been used in population studies. This study has identified the macroparasite species that infest *C. capensis*. It has shown that the parasite fauna of the St. Joseph shark (*C. capensis*) might provide useful information on stock discrimination of this population of fish, as has been demonstrated for other fish species (Williams *et al*. 1992, Arthur 1997). *Callorhinchus capensis* occur on the south, west and east coasts of South Africa and these populations could be separated on the basis of abundance of at least one species of parasite. This will only be achieved if the parasites infecting *C. capensis* on the south and east coast are identified.

Out of the five macroparasite species identified on *C. capensis, G. plana* best meets the criteria for biological tagging. However, more research needs to be done on the mode of transmission of this parasite, as varying opinions occur. The monogeneans lacked one important aspect of biological tagging, which is knowledge of the duration of the parasites in their host. If this is addressed, then *C. callorhynchi* and *C. multitesticulatus* could be good tags for *C. capensis*. This study has added to knowledge of the macroparasite diversity of *C. capensis*, but additional work is still required on both macroparasites and microparasites.

Some aspects of the study led to potential biases in the results. For example: fish were collected from a single location, the west coast of South Africa, though this species (*Callorhinchus capensis*) also occurs off the south and east coasts. All fish dissected were frozen and, in the course of thawing them, some ectoparasites were washed off and endoparasites extruded from the stomach of the host, thereby influencing the entire parasite assemblage. Sampling was only done in summer so there are no winter records. More research on different populations of *C. capensis* from the south and east coast need to be carried out in both summer and winter seasons, which will provide more information and enhance understanding of the stock structure.

REFERENCES

Alarcon, C., Cubillos, A. L. and Acuna, E. 2011. Length-based growth, maturity and natural mortality of the cockfish *Callorhinchus callorhynchus* (Linnaeus, 1758) off Coquimbo, Chile. *Environmental Biology of Fish.* DOI 10.1007/s10641-011-9816-0.

Anon, 1993. Report of the Study Group on Stock Identification Protocols for Finfish and Shellfish Stocks. ICES C.M. 3: 23.

Anon, 1994. Report of the ICES Advisory Committee on Fishery Management. ICES Cooperative Research Report No. 210. International Council for the Exploration of the Sea.

Anon, 1995. Northwest Atlantic Fisheries Organization, Scientific Council Reports 1995.

Arthur, J. R. 1997. Recent advances in the use of parasites as biological tags for marine fish. In: Diseases in Asian Aquaculture III. T. W. Flegel and I. H. MacRae (eds.) Manila: Fish Health Section, Asian Fisheries Society 141-154.

Baker, T. G., Morand, S., Wenner, C. A., Roumillat, W. A. and Isaure D. B. 2007. Stock identification of the sciaenid fish *Micropogonias undulatus* in the western North Atlantic Ocean using parasites as biological tags. *Journal of Helminthology* **81**: 155-167.

Balbuena, J. A., Aznar, F. J., Fernandez, M. and Raga, J. A. 1995. Parasites as indicators of segregation and social structure and stock identity of marine mammals. In Whales, Seals, Fish and Man, eds. A. S. Blix, L. Walloe, and O. Ulltang. pp. 133–140. Amsterdam: Elsevier.

Barker, D. E. and Cone, D. K. 2000. Occurrence of *Ergasilus celestis* (Copepoda) and *Pseudodactylogyrus anguillae* (Monogenea) among wild eels (*Anguilla rostrata*) in

University of Cape Town

relation to stream flow, pH and immunity on the gills of *Pimelodus maculatus* in Rio de la Plata (Argentina). *Parasitology* **119**: 177-182.

Barnham, C. and Baxter, A. 1998. Condition factor, K, for Salmonid fish. *Fisheries Notes* 1-3.

Benton, M. J., Kumer, S. and Davis, Y. L. 2009. Calibrating and constraining molecular clocks.In: S. B. Hedges and S. Kumar (eds). The time scale of life. City Oxford University Press. pp. 35-86.

Beverly-Burton, M., Chisholm, L. A. and Allison, F. R. 1993. The species of *Callorhynchicola* Brinkmann (Monogenea: Chimaericolidae) from *Callorhinchus* spp. (Chimaeriformes: Callohrinchidae): adult morphology and the larval haptor. *Systematic Parasitology* **24**: 201-215.

Boje, J., Riget, F. and Koie, M. 1997. Helminth parasites as biological tags in population studies of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)), in the north-west Atlantic. *Journal of Marine Science* **54**: 886–895.

Braicovich, P. E. and Timi, J. T. 2008. Parasites as biological tags for stock discrimination of the Brazilian flathead *Percophis brasiliensis* in the south-west Atlantic. *Journal of Fish Biology* **73**: 557–571.

Brennan, M. H. and Gormley, T. R. 1999. The quality of under-utilised deep-water fish species. Teagasc Research Report No. 22 (Project Armis No. 4560).

Brinkmann, A. 1952. Some Chilean monogenetic trematodes. *Reports of the Lund University Chile expedition* 1948-49 **47**: 1-26.

Bunkley-Williams, L. and Williams, E. H. 1998. Isopods associated with fishes: a synopsis and corrections. *Journal of Parasitology* **84**: 893-896.

Caira, J. N. and Healy, C. J. 2004. Elasmobranchs as hosts of metazoan parasites. In: J. C. Carrier, J. A. Musick and M. R. Heithaus (eds). Biology of Sharks and Their Relatives. New York: CRC Press. pp. 523-551.

University of Cape

Carozza, C., Fernandez, N., Ruarte, C., Massa, A., Hozbor, N. and Jaureguizar, A. 2004. Definicio´ n de una zona de reproduccio´ n y crı´ a de especies demersales costeras en la costa sur de la provincia de Buenos Aires. Informe Tecnico Interno INIDEP 84.

Chubb, J. C. 1977. Seasonal occurrence of helminths in freshwater fishes. Part I. Monogenea. *Advances in Parasitology* **15**: 133-199.

Coakley, A. 1973. A study in the conservation of elephant fish *(Callorhynchus milii* Bory), in New Zealand. *Fish Technical Report, New Zealand Marine Department* **126**: pp. 18.

Colin, A., Judith, K., Williams, H. H. and Halvorsen, O. 1986. One or three Gyrocotlideans (Platyhelminthes) in *Chimaera monstrosa* (Holocephali). *Journal of Parasitology* **72**: 10-21.

Compagno, L. J. V. 1988. Sharks of the Order Carcharhiniformes. *Princeton University Press.* Princeton, New Jersey, USA.

Dienske, H. 1968. A survey of the metazoan parasites of the rabbit fish, *Chimaera monstrosa* L. holocephali. *Netherlands Journal of Sea Research* **4**: 32-58.

Francis, M. P. 1997. Spatial and temporal variation in the growth rate of elephant fish (*Callorhynchus milii*). *New Zealand Journal of Marine and Freshwater Research* **31**: 9-23.

Freer, D. W. L. and Griffiths, C. L. 1993a. The fishery and biology of the St Joseph shark *Callorhinchus capensis* (Dumeril) off the South-Western Cape, South Africa. *South African Journal of Marine Science* **13**: 63-74.

Freer, D. W. L. and Griffiths, C. L. 1993b. Estimation of age and growth in the St. Joseph *Callorhinchus capensis* (Dumeril). *South African Journal of Marine Science* **13**: 75-81.

University of Cape Town

Fuhrmann, O. 1930. Dritte Klasse des Cladus Platyhelminthes: Cestoidea. In Handbuch der Zoologie (Kukenthal und Krumbach) **2**: 141-256.

Gorman, T. B. S. 1963. Biological and economic aspects of the elephant fish *Calloryhnchus milii* Bory, in Pagasus Bay and Canterbury Bight. *Fisheries Technical Report* **8**: 54.

Grimes, C. B., Johnson, A. G. and Fable, W. A. 1987. Delineation of king mackerel (*Scomberomorus cavalla*) stocks along the US east coast and in the Gulf of Mexico. In: H. E. Kumpf, R. N. Vaught, C. B. Grimes, A. G. Johnson and E. L. Nakamura (eds). *Proceedings of the Stock Identification Workshop*, November 1985, Panama City Beach, F L. NOAA Technical Memorandum NMFS±SEFC-199. US Government Printing Office 186-187.

Guegan, J. F., Lambert, A., Leveque, C., Combes, C. and Euzet, L. 1992. Can host body size explain the parasite species richness in tropical freshwater fishes? *Oecologia* **90**: 197–204.

Halvorsen, O. and Williams, H. H. 1967/8. Studies on the helminth fauna of Norway, IX. *Gyrocotyle* (Platyhelminthes) in *Chimaera monstrosa* from Olso Fjord, with emphasis on its mode of attachment and a regulation in the degree of infection. *Nytt Magasine for Zoologi* **15**: 130-142.

Hardy, R. and Mackie, P. R. 1971. Observations on the chemical composition and toxicity of Ratfish (*Chimaera monstrosa*). *Journal of the Science of Food Agriculture* **22**: 382–388.

Hayward, C. 2005. Monogenea Polyopisthocotylea (Ectoparasitic Flukes). In: K. Rohde (ed). Marine Parasitology. CSIRO Publishing Melburne and CABI Wallingford Oxon. pp. 55 - 63.

Hilborn, R., Walters, C. J. 1992. Quantitative Fisheries Stock Assessment. Choice, Dynamics and Uncertainty. Chapman and Hall, New York. pp. 570.

University of Cape Town

Hungerbuhler, K. 1910. A study of *Gyrocotyle* in the San Juan Archipelago, Puget Sound, U.S.A., with observations on the host, *Hydrolagus colliei* (Lay and Bennett). *International Journal of Parasitolgy* **2**: 59-64.

Kensly, B. 1978. Guide to the Marine Isopods in Southern Africa. Trustees of South African Meseum, Cape Town. 1-8.

Ketmaier, V., Joyce, D. A., Horton, T. and Mariani, S. 2008. A molecular phylogenetic framework for the evolution of parasites and strategies in cymothoid isopods (Crustacea). *Journal of Zoological Systematics and Evolutionary Research* **20**: 403-414.

Kitamura, A., Ogawa, K., Taniuchi, T. and Hirose, H. 2006. Two new species of hexabothriid monogeneans from the ginzame *Chimaera phantasma* and shortspine spurdog *Squalus mitsukurii. Systematic Parasitology* **65**: 151-159.

Lambert, T. C. 1993. The timing of the winter migration of 4T cod into 4Vn. *Fisheries Research* **93**: 25.

Lankford, T. E., Targett, T. E. and Gaffney, P. M. 1999. Mitochondrial DNA analysis of the population structure of Croaker using parasite tags 165 in the Atlantic Croaker, *Micropogonias undulates* (Perciformes: Sciaenidae). *Fishery Bulletin* **97**: 884-890.

Lester, R. J. G. 1990. Reappraisal of the use of parasites for fish stock identification. *Australian Journal of Marine and Freshwater Research* **41**: 855-864.

Lester, R. J. G. and Roubal, F. R. 2005. Isopoda. In Rohde, K. (ed.) Marine Parasitology Collingwood: CSIRO Publishing 138-144.

Lester, R. J. G. and MacKenzie, K. 2009. The use and abuse of parasites as stock markers for fish. *Fisheries Research* **97**: 1-2.

University of Cape Town

Linton, E. 1924. *Gyrocotyle plana sp*. nov. with notes on South African cestodes of fishes. *Union of South African Fisheries and Marine Biology survey*. Report No.3 **8**: 1-27.

Luque, J. L., Cordeiro, A. S. and Oliva, M. E. 2010. Metazoan parasites as biological tags for stock discrimination of whitemouth croaker *Micropogonias furnieri. Journal of Fish Biology* **76**: 591–600.

Lynch, J. E. 1945. Redescription of the species of *Gyrocotyle* from the ratfish, *Hydrolagus colliei* (Lay and Bennet), with notes on the morphology and taxonomy of the genus. *Journal of Parasitology* **31**: 418-446.

MacKenzie, K. 1987. Parasites as indicators of host populations. Proceedings of 6th International Congress on Parasitology, Brisbane Australia. *International Journal of Parasitology* **17**: 345-352.

MacKenzie, K. 2002. Parasites as biological tags in population studies of marine organisms: an update. *Parasitology* **124**: 153-163.

MacKenzie, K. 2005. Parasites as biological tags. *Marine Parasitology* 351-355.

MacKenzie, K. and Abaunza, P. 1998. Parasites as biological tags for stock discrimination of marine fish: a guide to procedures and methods. *Fisheries Research* **38**: 45-56.

MacKenzie, K. and Abaunza, P. 2005. Parasites as biological tags. In: S.X. Cadrin, K.D. Friedland and J.R. Waldman (eds). Stock identification methods: Applications in Fisheries Science. pp. 211-226. Elsevier Academic Press, MA, USA.

MacKenzie, K., Campbell, N., Mattiucci, S., Ramos, P., Pinto, A. L. and Abaunza, P. 2008. Parasites as biological tags for stock identification of Atlantic horse mackerel *Trachurus trachurus*. *Fisheries Research* **89:** 136-145.

Manter, H. W. 1951. Studies on *Gyrocotyle rugosa* Diesing, 1850, a cestode parasite of the elephant fish, *Callorhinchus milii. Zoology Publication from the Victoria University College* **17**: 1-11.

University of Cape Town

Manter, H. W. 1955. Two new monogenetic trematodes from elephant fishes (*Callorhynchus*) from South Africa and New Zealand. In. *Essays in the natural sciences in honour of Captain Allan Hancock on the occasion of his birthday, July 26, 1955*, Los Angeles: University of South California Press 211-220.

McClatchie, S. and Lester, P. 1994. Stock assessment of the elephant fish *(Callorhinchus milii). New Zealand fisheries assessment research document 94/6.* Unpublished report held in library, NIWA Greta Point, Wellington.

McClelland, G. and Melendy, J. 2011. Use of parasites as tags in delineating stocks of Atlantic cod *Gadus morhua* from the southern Gulf of St. Lawrence and the Cape Breton Shelf. *Fisheries Research* **107**: 233–238.

McClelland, G., Melendy, J., Osborne, J., Reid, D. and Douglas, S. 2005. Use of parasite and genetic markers in delineating populations of winter flounder from the central and south-west Scotian Shelf and north-east Gulf of Maine. *Journal of Fish Biology* **66**: 1082–1100.

Melendy, J., McClelland, G. and Hurlbut, T. 2005. Use of parasite tags in delineating stocks of white hake (*Urophycis tenuis*) from the southern Gulf of St. Lawrence and Cape Breton Shelf. *Fisheries Research* **76**: 392-400.

Moser, M. and Hsieh, J. 1992. Biological tags for stock separation in Pacific herring *clupea harengus pallasi* in California. *Journal of Parasitology* **78**: 54-60.

Mosquera, J., De Castro, M. and Go´mez-Gesteira, M. 2003. Parasites as biological tags of fish populations: advantages and limitations. *Comments on Theoretical Biology* **8**: 69-91.

Oliva, M. E. and Ballon, I. 2002. Metazoan parasites of the Chilean hake *Merluccius gayi gayi* as a tool for stock discrimination. *Fisheries Research* **56**: 313-320.

University of Cape Town

Pascual, S. and Hochberg, F. G. 1996. Marine parasites as biological tags of cephalopod hosts. *Parasitology Today* **12**: 324–327.

Poulin, R. 2000. Variation in the intraspecific relationship between fish length and intensity of parasitic infection: biological and statistical causes. *Journal of Fish Biology* **56**: 123–137.

Poulin, R. 2004. Parasite species richness in New Zealand fishes: a grossly underestimated component of biodiversity? *Diversity and Distribution* **10**: 31-37.

Power, A. M., Balbuena, J. A. and Raga, J. A. 2005. Parasite infracommunities as predictors of harvest location of bogue (*Boops boops*): a pilot study using statistical classifiers. *Fisheries Research* **72**: 229–239.

Ramdane, Z., Bensouilah, M. and Trilles, J. P. 2007. The Cymothoidae (Crustacea, Isopoda) parasites on marine fishes from Argelian fauna. *Belgian Journal of Zoology* **137**: 67-74.

Richardson, L. R. 1953. Studies on New Zealand Hirudinea Part III. *Bdellamaris eptatreti* and notes on other Piscicolidae. *Transactions of the Royal Society of New Zealand* **81**(2): 283-294.

Salinas, X., Gonzalez, M. T. and Acuna, E. 2008. Metazoan parasites of the thumb grenadier *Nezumia pulchella* from the south-eastern Pacific, off Chile, and their use for discrimination of host populations. *Journal of Fish Biology* **73**: 683-691.

Sardella, N. H. and Timi, J. T. 2004. Parasites of Argentine hake in the Argentine Sea: population and infracommunity structure as evidence for host stock discrimination. *Journal of Fish Biology* **65**: 1472–1488.

Sequeira, V., Gordo, L. S., Neves, A., Paiva, R. B., Cabral, H. N. and Marques, J. F. 2010. Macroparasites as biological tags for stock identification of the bluemouth *Helicolenus dactylopterus* (Delaroche, 1809) in Portuguese waters. *Fisheries Research* **106**: 321–328.

University of Cape Town

Simmons, J. E. and Laurie, J. S. 1972. A study of *Gyrocotyle* in the San Juan Archipelago, Puget Sound USA, with observations on the host *Hydrolagus colliei* (Lay and Bennet). *International Journal of Parasitology* **2**: 59-77.

Smith, M. M. and Heemstra, P. C. 1986. Smith's Sea Fishes. The Sea Fishes of Southern Africa. First published in 1949. In: M. Smith (ed). Revision of J.L.B. Smiths. Macmillan South Africa, Johannesburg. pp.1047.

Speare, P. 1995. Parasites as biological tags for sailfish *Istiophorus platypterus* from east coast Australian waters. *Marine Ecology Progress Series* **118**: 43-50.

Swain, D. P., Savoie, L., Hurlbut, T., Surette, T. and Daigle, D. 2009. Assessment of the southern Gulf of St. Lawrence cod stock. *Canadian Journal of Fisheries and Aquatic Science* **65:** 2315–2319.

Szidat, L. 1972. Über zwei Arten der Hirudineen-Gattung *Branchellion Savigny*, 1820, von der Haut des Elephanten-Fisches *Callorhinchus callorhynchus* L. der chilenischen Pazifik-Kuste. *Studies on the Neotropical Fauna* **7**: 187-193.

Timi, J. T., Lanfranchi, A. L. and Etchegoin, J. A. 2009. Seasonal stability and spatial variability of parasites in Brazilian sandperch *Pinguipes brasilianus* from the Northern Argentine Sea: evidence for stock discrimination. *Journal of Fish Biology* **74**: 1206–1225.

Timi, J. T., Luque, J. L. and Sardella, N. H. 2005. Parasites of *Cynoscion guatucupa* along South American Atlantic coasts: evidence for stock discrimination. *Journal of Fish Biology* **67**: 1603–1618.

Trouve, S., Sasal, P., Jourdane, J., Renaud, F. and Morand, S. 1998. The evolution of life-history traits in parasitic and free-living platyhelminthes: a new perspective. *Oecologia* **115**: 370-378.

University of Cape Town

Valdivia, I. M., Chavez, R. A. and Oliva, M. E. 2007. Metazoan parasites of *Engraulis ringens* as tools for stock discrimination along the Chilean coast. *Journal of Fish Biology* **70**: 1504–1511.

van der Land and Templeman, W. 1968. Two new species of *Gyrocotyle* (Monogenea) from *Hydrolagus affinis* (Brito Capello) (Holocephali). *Journal of the Fisheries Research Board of Canada* **25**: 2365-2385.

Van Der Elst, 1988. A Guide to the Common Sea Fishes of Southern Africa, *2nd ed*. Cape Town; Struik: pp. 398.

Van de Lingen, C. D., Shannon, L. J., Cury, P., Kreiner, A., Moloney, C. L., Roux, J-P. and Vaz-Velho, F. 2006. Resources and ecosystem variability, including regime shifts in the Benguela current system. In: V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney and J. Woods (eds). Large Marine Ecosystems. pp. 147-150.

Vasconcellos, M. and Haimovici, M. 2006. Status of white croaker *Micropogonias furnier* exploited in southern Brazil according to alternative hypotheses of stock discreetness. *Fisheries Research* **80**: 196–202.

Wagener, G. R. 1852. Uber einen neunen in der *Chimaera monstrosa* gefunden eingeweide Wurm, *Amphiptyches urna* Grube and Wagener. *Archiv fur Anatomie und Physiologie* 543-554.

Wardle, R. A. 1932. The Cestoda of Canadian fishes, The Pacific Coast region. *Contributions to the Canadian Biology and Fisheries*. **7**: 717-734.

Watson, E. 1911. The genus *Gyrocotyle* and its significance for problems of cestode structure and phylogeny. *University of California Publications in Zoology* **6**: 353-468.

William, H. and Jones, A. 1994. Parasitic worms of fish. *Folia Parasitologica* **41**: 38.

Williams, J. E. 2000. The coefficient of condition of fish. In: C. James (eds). Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor. pp 1-3.

University of Cape Town

Williams, J. and Burreson, E. 2005. Revision of the genus *Bdellamaris* (Hirudinea: Piscicolidae) including a new combination, *Bdellamaris manteri. New Zealand Journal of Marine and Freshwater Research* **39**: 1331-1337.

Williams, H. H., Colin J. A. and Halvorsen, O. 1987. Biology of gyrocotylideans with emphasis on reproduction, population ecology and phylogeny. *Parasitology* **95**: 173-207.

Williams, H. H., MacKenzie, K. and McCarthy, A. M. 1992. Parasites as biological indicators of the population biology, migrations, diet and phylogenetics of fish. *Review of Fish Biology and Fish*eries **2**: 144-176.

Wright, R. V., Lechanteur, Y. A. R. G., Prochazka, K. and Griffiths C. L. 2001. Infection of Hottentot *Pachymetopon blochii* by the fish louse *Anilocra capensis* (Crustacea: Isopoda) in False Bay, South Africa. *South African Journal of Marine Science.* **17**: 56-61.

Xylander, W. E. 2005. Gyrocotylidea (unsegmented tapeworms). In: K. Rohde (ed). Marine Parasitology. CSIRO Publishing: Collingwood, Vic (Australia). pp. 565.

Xylander, W. E. and Poddubnaya, L. G. 2009. Ultrastructure of the neodermal sclerites of *Gyrocotyle urna* Grube and Wagener, 1852 (Gyrocotylidea, Cestoda). *Parasitological Research* **105**: 1593–1601.

Yamaguchi A, Huang, S. Z., Chen, C. T. and Taniuchi, T. 1999. Age and growth of the starspotted smooth-hound, *Mustelus manazo* (Chondrichthyes: Triakidae) in the waters of north-eastern Taiwan. In: B. Séret and J. Y. Sire (eds). *Proceedings of the 5th Indo-Pacific Fish Conference*, 3–8 November 1997, Noumea. Societe of Francaise d'Ichtyologie, Paris 505-513.

Yamaguchi, A., Taniuchi. T. and Shimizu, M. 1998. Geographic variations in growth of the starspotted dogfish *Mustelus manazo* from five localities in Japan and Taiwan. *Fisheries Science* **64**: 732–739.

University of Cape Town

Yamaguchi, A., Yokoyama, H., Ogawa, K. and Taniuchi, T. 2003. Use of parasites as biological tags for separating stocks of the starspotted dogfish *Mustelus manazo* in Japan and Taiwan. *Fisheries Science* **69:** 337–342.

Yeld, E., M. 2009. Parasite assemblages of three endemic catshark species from the West and South Coasts of South Africa. PhD thesis.

University of Cape Town