# Aspects of the early life history and a per-recruit assessment of white stumpnose *Rhabdosargus globiceps* (Pisces: Sparidae) in Saldanha Bay with recommendations for future research and monitoring

**CLEMENT J. ARENDSE**

SUPERVISOR: A/PROF. COLIN G. ATTWOOD

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## DECLARATION

I know the meaning of plagiarism and declare that all of the work in this dissertation, save for that which is properly acknowledged, is my own.

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Clement J. Arendse

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Date

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# SUMMARY

*Rhabdosargus globiceps* is an economically important seabream species (Family: Sparidae) found along the coast of southern Africa. It is the most important angling species in Saldanha Bay, where it is targeted by recreational and commercial fishers. Concerns have been raised about the status of the stock as well as the effects of increased fishing pressure by a growing local population. The stock is separated from sympatric stocks along the south-western coast of South Africa, increasing the need for controlled exploitation of the resource.

This study focuses on several aspects of the life history of *R. globiceps*, and includes a study of juvenile habitat, a hatch date analysis, methods to increase precision of age estimates obtained from reading otoliths and a per-recruit assessment.

Juvenile habitats were compared using dendrograms, multi-dimensional scaling (MDS) ordination plots and principle component analysis. There was a correlation between environmental variables (temperature and surf zone width) and the species composition at each site. Juvenile *R. globiceps* were most common at sites with moderate wave height and temperature. These sites are found in the northern embayment in Saldanha Bay. High densities of juvenile *R. globiceps* were attributed to favourable conditions associated with sites of intermediate temperature and moderate wave height, increased food and shelter opportunities associated with detached macrophytes found at these sites. The prevalent wind direction during the spawning period is believed to concentrate eggs and larvae along the northern shores of Saldanha Bay.

Hatch dates were estimated using catch-at-age analysis (by reading sliced otoliths) and catch-at-length analysis (by fitting a regression to the mean age of a cohort over a given period). Hatch dates were compared to the periods when adult female *R. globiceps* ovaries were in the ripe-and-running stage, the assumed spawning period, to determine if estimated peaks in hatch dates corresponded to periods where most ovaries of adults were in the ripe-and-running stage of development. Hatch date peaks estimated using catch-at-age data occurred after the assumed spawning peaks, suggesting that age of fish were underestimated using the model. Hatch date peaks estimated using catch-at-length data occurred soon after the assumed spawning peaks, suggesting that the model more closely followed trends in the spawning patterns. The catch-at-age model was considered the better of the two, as errors can be quantified and corrected whereas the effects of cohort mixing are common in the catch-at-length model and cannot be corrected for in the model. The hatch period for *R. globiceps* was found to occur throughout the year using estimates based on the two models. This differed from the estimated spawning peaks, which showed no spawning in the winter months. Several assumptions regarding the period of first ring formation on the otolith as well as the difference between the date of hatching and the date the first increment was formed were made. These assumptions must be validated before this study can be considered a true reflection of the hatch date distribution of *R. globiceps* in Saldanha Bay.

A test was conducted using four otolith preparation techniques (OPTs) to determine whether slicing and baking could enhance rings on the otoliths of adult *R. globiceps* and increase precision of age estimates obtained by reading otoliths. OPTs compared were whole unbaked, sliced unbaked, whole baked and baked-and-sliced. Within and between variation of OPTs were tested. Slicing generally increased precision of age counts when compared to whole otoliths and baked otoliths increased precision when compared to unbaked otoliths. Baking otoliths before slicing produced the best results.

Yield-per-recruit (Y/R), spawner biomass-per-recruit (SB/R) and ovary mass-per-recruit (OM/R) were estimated for *R. globiceps* in Saldanha Bay using catch data for the period 2006-2008. Per-recruit analysis were done at length at first capture ($L_c$) = 210, 250 and 290 mm TL and Natural Mortality ($M$) = 0.059, 0.179 and 0.54 $y^{-1}$. Per-recruit analysis showed that *SB/R* is below 25% of the unfished level, suggesting overexploitation of the stock. Reduction in fishing effort was simulated using daily bag limits. An increase in $L_c$ to 290 mm TL or a decrease in the daily bag limit of *R. globiceps* from 10 fish/angler/day to 5 fish/angler/day is recommended.

Major outstanding questions about *R. globiceps* in Saldanha Bay relate mainly to the egg and larval phases of the species as well as the population size of spawning adults within Saldanha Bay.

A study of egg and larval survival and distribution is suggested. A mark-recapture experiment to determine adult population size is recommended and an appropriate methodology which can be adopted outlined.

# CHAPTER 1

# INTRODUCTION

## 1.1 *RHABDOSARGUS GLOBICEPS*: A BRIEF DESCRIPTION

The family Sparidae (seabreams or sparids) consists of a diverse group of fish found in all oceans of the world (Garratt 1993). The family includes approximately 140 species in 29 genera (http://fishbase.org), of which 41 species can be found in South African waters, 25 of which are endemic (van der Elst 1993, Branch *et al*. 2002, Heemstra & Heemstra 2004).

Some characteristics of the family Sparidae include large heads, steep foreheads, jaws that do not extend beyond a point in line with the centre of the eyes, mouths that are small in relation to body size, and well formed scales on the body and pre-operculum. The lateral line is always visible (van der Elst 1993, Smith & Heemstra 2003, Heemstra & Heemstra 2004). Also, sparids have one continuous dorsal fin with 10-13 spines and 8-16 rays and an anal fin with three spines and 8-15 rays with the last ray of both the dorsal and anal fins usually double (Smith & Heemstra 2003, Heemstra & Heemstra 2004).

Within the family Sparidae, four species belonging to the genus *Rhabdosargus* are found in South African waters, of which three are endemic (Smith & Heemstra 2003). The genus *Rhabdosargus* was described by Smith (1979) and Smith & Heemstra (2003) as sparids with 4-6 enlarged subequal incisiform teeth (rounded in adults) situated anteriorly in the upper jaw. Large adults have three or more series of large molariform teeth in each jaw with interior molars considerably enlarged and situated posterior to the incisors. Species in the genus have 11-13 dorsal fin rays and 10-13 anal fin rays with the second spine not greatly thickened. The interorbital area and soft dorsal and anal fins are naked. The pectoral fins are longer than the head of the fish and the preopercule flange is naked or with few scales.

*R. globiceps* can be distinguished from the rest of the *Rhabdosargus* genus by the presence of dark vertical bars along the body of the fish and the absence of any yellow colouration (Smith 1979). *R. globiceps* is a silver fish with 5-7 dark vertical bars - the first over the nape and the last on the penduncle - and a blunt head (Branch *et al*. 2002, Smith & Heemstra 2003, Heemstra & Heemstra 2004). *R. globiceps* is also sexually dichromatic, suggesting mate selection by females (Anderson 1994). The head of the male is darker than that of the female, with a dark patch ventrally and anterior to the pelvic fins and another posterior to the head (Griffiths *et al*. 2002). These colors are more intense in the spawning season and the intensity has been found to be related to the stage of testes; i.e. resting, ripe or spent (Attwood *et al*. 2010). The fin formula used to identify *R. globiceps* is three anal spines, 11 dorsal spines, 10-11 anal rays and 11-13 dorsal rays (Smith & Heemstra 2003).

## 1.2 DISTRIBUTION

Along the coast of South Africa, four populations of *R. globiceps* have been recorded, one off Algoa Bay, one on the central Agulhas Bank, one off False Bay and one in Saldanha Bay (Whitfield *et al.* 1989, Griffiths *et al*. 2002, Hutchings & Lamberth 2002, Pradervand & Baird 2002). These four populations are believed to form separate stocks because of differences in growth rates, size at maturity and lack of movement between stocks, as shown by tagged fish recoveries, and telemetry studies (Attwood *et al*. 2010). Range contractions related to population declines associated with exploitation may have stopped movement of fish between the False Bay and Saldanha Bay stocks (Griffiths *et al*. 2002). Catches of *R. globiceps* by netfishers in the area between False Bay and Saldanha Bay have collapsed and are now very rare (Hutchings & Lamberth 2002).

## 1.3 EXPLOITATION

*R. globiceps* have been exploited in South African waters for over a century by seine-net, trawl and hook and line fishermen (Scott 1951, Talbot 1955, Japp *et al*. 1994, Hutchings &

Lamberth 2002, Pradervand & Baird 2002). The range of the species extends from southern Angola on the west coast of Africa to the Kei River on the east coast of South Africa (Whitfield 1998). It is presently a valuable resource in both the recreational- and commercial linefish sectors.

*R. globiceps* are generally targeted by hook and line fishermen on the west and southwest coast with high catches recorded in summer and catch reaching its lowest point in winter. The inverse is true for the southern and south-eastern Cape with highest catches recorded in the winter. This pattern is attributed to the onshore/offshore spawning migration of the species; with commercial trawlers targeting the species at greater depth on the south and south east coasts (Griffiths *et al*. 2002).

## 1.4 ECOLOGY

*R. globiceps* have pelagic eggs and larvae (Gilchrist 1916 in Griffiths *et al*. 2002). Juvenile fish move into the surf-zone or estuarine habitats (Bennett 1986, Griffiths *et al*. 2002) when they are 2-5 cm TL (c. three months; Talbot 1955) and can stay there until they reach > 20 cm TL. Griffiths *et al*. (2002) suggests that the maximum size of fish in surf-zone or estuarine habitats could be related to water temperature, as fish leave the surf-zone for deeper waters sooner in areas with higher average water temperature, thus accounting for the smaller size of juveniles in estuaries along the east coast.

Talbot (1955) found that juvenile *R. globiceps* in the Klein River estuary, ranging from 27-158 mm SL are omnivorous, feeding on small crustaceans, polychaetes and molluscs and cropping plants such as *Zostera capensis*, *Ruppia maritime* and filamentous algae (mainly *Enteromorpha* spp.). Adult *R. globiceps* feed mainly on benthic invertebrates such as crabs, polychaetes, amphipods, barnacles and molluscs (van der Elst 1993, Griffiths 2000, Heemstra & Heemstra 2004).

*R. globiceps* is a slow-growing, long-lived sparid (> 20 years), which reaches sexual maturity at 17-23 cm (2-4 years) and can attain a maximum size ($L_{max}$) of 50 cm (van der Elst 1993, Attwood *et al*. 2010).

The study by Talbot (1955) suggested that *R. globiceps* deposits one hyaline and one opaque band per year, as fish of one year displayed one translucent zone. Several studies on *R. globiceps* have used age estimates based on counts of annual bands from transverse sections of saggital otoliths (Griffiths *et al.* 2002, Laquar Consultants 2006, Attwood *et al.* 2010).

Evidence suggests that *R. globiceps* move offshore to spawn as there are seasonal differences in catch rates of the species (Talbot 1955, Griffiths *et al*. 2002). Griffiths *et al*. (2002) postulated that the migration would be limited on the cold temperate west coast because of the limited inshore-offshore temperature gradient during the winter months. *R. globiceps* spawn between August and February in the south-western Cape (Talbot 1955, Griffiths *et al*. (2002). Attwood *et al*. (2010) found a relationship between fat stage of fish and stage of ovaries and testes, where individuals with high fat scores were associated with spent or resting gonad stages and zero or low fat scores were associated with ripe and ripe-and-running gonad stages, suggesting that it may be possible to use fat content as an indicator of fecundity.

Based on a telemetry study, Kerwath *et al*. (2009) found that individual fish from the Saldanha Bay population moved up to 30 km per day, yet frequented Saldanha Bay for most or all of this time. They also found that certain individuals had preference for certain sites, with some individuals staying inside the boundary of the Marine Protected Area (MPA) in the southernmost part of Langebaan Lagoon for 96% of the time of study.

## 1.5 MANAGEMENT AND RESEARCH OF *R. GLOBICEPS* IN SALDANHA BAY

Concerns about fishing pressure placed on the Saldanha stock have resulted in several studies on *R. globiceps* in Saldanha Bay (e.g. Attwood *et al*. 2007, Kerwath *et al*. 2009, Attwood *et al*. 2010). These concerns are mainly based on stock collapse of sympatric stocks (Griffiths *et al.* 2002) and the long-lived nature of many sparids (Griffiths 2000). Catch rates have declined substantially for the False Bay and Agulhas Bank populations (up to 99.8% - Griffiths *et al*. 2002).

Recreational angling for *R. globiceps* is limited by a bag limit of 10 fish/person/day and a minimum size limit of 250 mm TL. Commercial fishers are fewer in number than recreational fishers. The commercial fishery is effort controlled and only a few boats are permitted to harvest this area. Catch restrictions include a minimum size limit of 250 mm TL. No quotas are imposed on the commercial fishermen. Although net fishers are active within Saldanha Bay, their target species is mullet, *Liza richardsonii*, with *R. globiceps* rarely caught as bycatch (pers. obs.). There are currently no closed season imposed for the fishery (Regulations promulgated in terms of the Marine Living Resources Act, 1998 (Act No. 18 of 1998)) yet the MPA (Figure 1 – Zone C) provides a buffer zone for the population.

The population of *R. globiceps* is mobile, possibly migratory and shows characteristics of three behavioural categories: station-keeping, commuting and migration (Kerwath *et al*. 2009). Kerwath *et al*. (2009) concluded that the MPA provides partial protection of the stock, as the frequency of habitat use (averaging 50% in the MPA) is disproportional to the area of the MPA (4% of total suitable habitat). The MPA could provide protection of the spawning stock (even if only for a few individuals), preventing recruitment overfishing, even though fish migrate out of the MPA in winter. Fishing is most popular in summer when a large proportion of fish frequent the MPA, whereas almost no fishing occurs in the winter months when all fish leave the MPA and are theoretically vulnerable to capture.

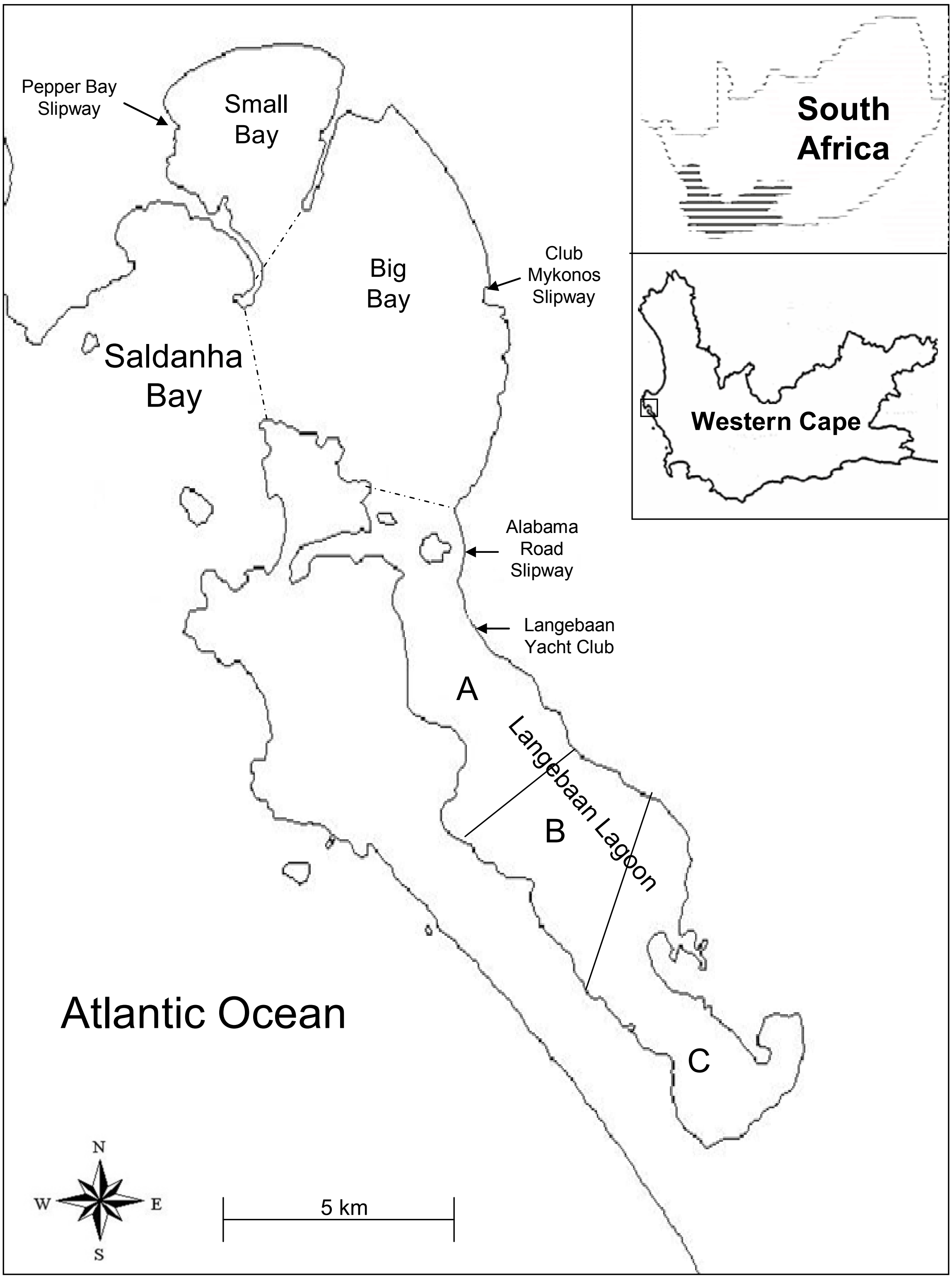


**Figure 1.1: Map of the Langebaan Lagoon showing Ski-boat access points and the three zones into which the Lagoon is divided: Zone A (recreational area); Zone B (restricted recreational area); and Zone C (sanctuary area)**

## 1.6 SALDANHA BAY: AREA DESCRIPTION

Saldanha Bay can be divided into two main components; the Bay across the mouth of Saldanha and Langebaan Lagoon. The Bay is further divided into two components, the exposed Big Bay directly across the mouth of Saldanha and the more sheltered Small Bay to its north (Figure 1). Big Bay and Small Bay are divided by an iron ore jetty, a man-made structure used as an interface between rail and ship transport of iron ore (Anchor Environmental Consultants 2009). Big bay is situated directly across the mouth of the Saldanha bay and is characterized by rough waters and exposed beaches; whereas Small Bay is relatively sheltered with intermediate exposure to ocean currents (Clark 1997). Both areas are host to mussel raft farms and are also frequented by recreational and commercial fishers who target *R. globiceps*. Langebaan Lagoon is relatively warm, with temperatures ranging from 14-19°C in the Lagoon as opposed to 10-14°C outside the Bay (Shannon & Stander 1977). The Lagoon is also sheltered compared to the rest of Saldanha Bay and is host to abundant fish life (Attwood *et al*. 2007). The warm waters and the influence of the nutrient rich Benguella upwelling system make the Lagoon a very productive system. It is one of the few sheltered areas along the exposed west coast of South Africa and provides important refuge and nursery areas for many marine species. The Lagoon is an entirely marine system with limited inflow of freshwater from groundwater or seepage of rainwater in winter (Christie 1981, Whitfield 2005). Salinity in the Lagoon is not substantially different from the surrounding ocean, averaging about 35‰, though elevated salinities of up to 37‰ were recorded in the southern regions of the Lagoon in the summer months; the elevation attributed to evaporation (Shannon & Stander 1977). Tidal exchange with the open sea is limited because of the interaction of the three bodies of water found in the Langebaan Lagoon and Saldanha. These bodies of water, the Benguella body, the Big Bay body (essentially the 'plug' that limits the influence of the Benguella current on, amongst others, the water temperature of the Lagoon) and the Lagoon body, exchange approximately 12% of its volume at the mouth of the Lagoon at a spring tide, with currents ranging from 10-20 cm per second at the surface (Shannon & Stander 1977, Weeks *et al*. 1991).

The Lagoon is 14 km long and about 3.5 km at its greatest width (Christie 1981) and the substrate varies from sand and gravel at the mouth of the Lagoon to rich organic mud at the top end of the Lagoon (Attwood *et al*. 2007). The Lagoon consists of shallow mudflats rich in invertebrate species, including *Callianassa krausii* and *Upogebia africana* (Christie & Moldan 1977) the primary prey species of *R. globiceps*, and deep channels that are 4-9 m deep (Attwood *et al*. 2007). *R. globiceps* move mostly in the channels swimming in the direction of the current (Attwood *et al.* 2007).

Langebaan Lagoon was declared a RAMSAR site in 1976 (de Graaff & Hanekom 1995) and is divided into three zones (Figure 1). Zone A is located in the northern section of the Lagoon extending into the Bay area and is the only zone in which fishing is allowed; Zone B is considered a “restricted recreational zone” where no power boats or fishing are allowed except for commercial netfishing; and Zone C, situated at the southernmost end of the Lagoon is a sanctuary zone where no access is allowed for the protection of local shorebirds and marshlands (Attwood *et al*. 2007).

## 1.7 MOTIVATION FOR A STUDY OF *R. GLOBICEPS* IN SALDANHA BAY

The most economically important fish species in Saldanha Bay is *R. globiceps*, with approximately 90 tons being harvested annually by recreational boat and shore anglers (Næsje *et al*. 2008). The knowledge that the population is isolated has lead to growing concerns over the sustainability of current exploitation levels of the stock as there has been a steady increase in fishing pressure on the stock (Attwood *et al*. 2007). The stock has not yet been assessed.

There are several major gaps in our knowledge of the *R. globiceps* population Saldanha Bay that prevent the effective management of the stock. Habitat preference of juvenile *R. globiceps* is unknown, although data collected by Clark (1997) suggests that they frequent most of the sandy shores along Saldanha Bay. This is a cause of concern as the proposed expansions of the iron ore jetty (PDNA & SRK Consulting 2007) and other human encroachment in the Saldanha Bay region could remove or degrade essential juvenile habitat (Anchor Environmental Consultants 2006, 2009). The effects of the current harvesting rate on spawner biomass and yield are unknown. The optimal harvest rate for the population has not been modelled.

Some of the key issues still facing management of the population are the effectiveness of bag limits, whether anglers are complying with bag and size limits and whether user group conflicts may arise between commercial and recreational anglers. Reduction in fishing mortality by implementing various bag limits will be explored if results indicate that the resource is under pressure.

## 1.8 STRUCTURE OF THE DISSERTATION

To address the issues raised above, the dissertation will be divided into several chapters dealing with the juvenile growth and habitat selection, optimal preparation of otoliths for regular ageing, per-recruit analysis and recommendations for future monitoring and studies.

### Chapter 2: Juvenile habitat selection

This is an investigation into the habitat use of *R. globiceps* recruits in Saldanha Bay. Correlates of abundance and environmental factors affecting site selection are investigated.

### Chapter 3: Juvenile growth and hatch date analysis

This is an investigation into the spawning season of *R. globiceps*. Daily rings in the otolith microstructure are examined and spawning date distribution is determined. Results are compared to the periods when female *R. globiceps* have ripe-and-running ovaries and hatch date is estimated from cohort analysis of beach-seine catches. Species composition of the surf-zone of Saldanha Bay is discussed, with emphasis placed on the relative contribution of *R. globiceps* to the species composition of the sites sampled.

## Chapter 4: Improved ageing

This chapter deals mainly with reproducibility and precision of age estimates obtained from reading otoliths of adult *R. globiceps*. Four otolith preparation techniques, reading otoliths whole; whole-and-baked; sliced; and baked-and-sliced are compared to determine which method produces better results when compared to the conventional technique used for this species (slicing of unbaked otoliths).

## Chapters 5 and 6: Per-recruit assessment

Chapter 5 provides a brief description of stock assessment methods available. In Chapter 6, catch and effort estimates are used in simulation models to predict the yield, spawner biomass and spawning potential of the stock and to assess the current exploitation pressure. By using catch data collected over the period January 2006 to December 2008, total mortality is estimated. Reductions in catch by implementing various daily bag limits are simulated.

## Chapter 7: Recommendations for future research and monitoring of *Rhabdosargus globiceps* in Saldanha Bay

This chapter aims to provide a reference on which future experiments or data collection can be based. A fin-clip experiment is outlined to provide a more reliable estimate of population size, some useful statistical tools are discussed and future monitoring plans for the stock are outlined.

# CHAPTER 2

# RECRUITMENT AND NURSERY HABITAT USE OF *RHABDOSARGUS GLOBICEPS* AND THEIR CONTRIBUTION TO SPECIES DIVERSITY WITHIN THE SURF-ZONE OF SALDANHA BAY

## 2.1. INTRODUCTION

Historically, fishery management actions have been focused primarily on the conservation of spawning fish while less attention was paid to juveniles and their habitat (Fuiman & Werner 2002). This focus may have been misplaced given the generally poor relationship between spawner biomass and subsequent recruitment in most of the world's fisheries, the latter often being more closely related to environmental variation (Caley *et al*. 1996). The identification, study and conservation of juvenile habitats as well as the change in relative abundance of juveniles between habitats has, however, become a major focus in many studies conducted in the last few decades as the importance of this life stage has become clearer (Bennett 1989b, Heck *et al.* 1995, Caley *et al*. 1996, Beck *et al*. 2001, Bell *et al.* 2001, Watt-Pringle & Strydom 2003, DeMartini *et al*. 2009). High mortality rates are experienced by the pre-adult stages (egg, larval and juvenile stages). On average, adult mortality of medium sized, long-lived fish (such as *Rhabdosargus globiceps*) range from 5-10% per year whereas the average larval mortality is 2-10% per day (Pitcher & Hart 1982, Houde 2002). Pre-adult mortality and survivorship are likely to have a strong influence on the population trajectories and estimates of sustainable yield (Bergenuis *et al*. 2002, Fuiman & Werner 2002), especially in closed populations (Caley *et al*. 1996).

Pre-adult life stages usually utilise specific habitats distinct from those of later stages (Sheridan & Hays 2003), as is generally true for sparids (e.g. see Gordoa & Moli 1997, Macpherson 1998, Planes *et al*. 1998, James *et al*. 2007). Beck *et al*. (2001) noted that although juveniles may frequent many environments, not all juvenile habitats are suitable nursery habitats. The study noted that although juveniles may frequent a diverse range of habitats, the chances of survival and/or increased growth rate were higher at certain sites. These sites were termed nursery areas as they contribute more to recruitment into the adult population per square meter than would an adjacent site of the same size but less suitable habitat. Nursery habitats tend to have high species diversity and abundance and are often rich in primary and secondary production (Beck *et al.* 2001). The amount of time juveniles spend in these nursery areas depends on the specific requirements of the species in question but generally lasts until the fish reaches a size where predation is significantly decreased or when a specific life history cue (e.g. sexual maturation) is reached (Gordoa & Moli 1997, James *et al*. 2007).

Saldanha Bay, along the west coast of South Africa, is an area where fish species diversity is higher than the surrounding coastal waters (Whitfield 2005). The cold, upwelled water found along the west coast is nutrient rich. When this nutrient rich water is introduced into the shelter of Saldanha Bay, it is warmed by the sun and supports the growth of phytoplankton (Shannon & Stander 1977) which in turn supports the high species diversity and abundance. The juveniles of several fish species utilise the shallow waters of Saldanha Bay, including those of *R. globiceps*, the dominant species in the fishery of the bay (Clark 1997, Watt-Pringle & Strydom 2003, Anchor Environmental Consultants 2009).

Talbot (1955), Bennett (1989a, b) and Griffiths *et al*. (2002) noted that juvenile *R. globiceps* frequent estuarine and surf-zone environments. Saldanha Bay provides a range of potential refugia to juveniles, as the habitats range from the sheltered marshlands at the southernmost end of the Langebaan Lagoon to the wave exposed beaches across the mouth of Saldanha Bay (Clark 1997, Attwood *et al.* 2007), and juveniles of several species are found all around the bay (Clark 1997).

Griffiths *et al*. (2002) noted that adult *R. globiceps* on the south coast move offshore to spawn. This might not, however, be the case for the Saldanha Bay population. The telemetry data of Kerwath *et al*. (2009) suggests that adults do not leave the confines of Saldanha Bay. A study by Attwood *et al*. (2010) found that adult female *R. globiceps* collected over a one year period within the confines of Saldanha Bay displayed all gonad maturity stages, from active to spent, suggesting spawning may occur within Saldanha Bay. Based on these studies, it was assumed that *R. globiceps* spawn in Saldanha Bay. *R. globiceps* produce pelagic larvae, which presumably use the prevailing currents to aid in dispersal to preferred juvenile habitats.

Other populations of the species have been heavily impacted by fishing (Griffiths *et al*. 2002), and there is concern that this small isolated population might also succumb to heavy fishing pressure. It is therefore important that nursery habitats of this species are identified and conserved as these areas ultimately feed the fishery, as noted for other species (see Beck *et al.* 2001). Degradation of nursery habitat could result in higher juvenile mortality and hence lower recruitment into the spawning stock (Le Pape *et al*. 2003).

There is also evidence to suggest that juveniles stay in nursery environments longer (i.e. for extended periods) along the colder west coast than the warm east coast, as noted by the higher average size of juveniles in nursery habitats along the west coast (Beckley 1983, 1984, Lasiak 1983, Lamberth *et al*. 1994, Griffiths *et al*. 2002). In the case of Saldanha Bay, the high productivity and warmer waters (compared to conditions elsewhere on the west coast) may favour faster growth by juveniles, a trait which is considered important in reducing juvenile mortality (Anderson 1988, Cowan *et al*. 2000) and thus sustaining higher adult population sizes (Beck *et al*. 2001, Bergenius *et al*. 2002). Growth rates of juveniles could be used as an indicator of habitat quality, as faster growth occurs in favourable habitats (Phelan *et al*. 2000). A study of the relative growth rate of *R. globiceps* in Saldanha Bay relative to other areas may explain their habitat preference.

Management measures directed towards the *R. globiceps* population will depend on having a good knowledge of the nursery habitat. The relative importance of various habitats need to be quantified (Beck *et al*. 2001) to assess the effects of development and pollution. Development in Saldanha Bay may cause changes in the Bay ranging from changes in water circulation by breakwaters to degradation of water quality by pollution and eutrophication (Shannon & Stander 1977, Anchor Environmental Consultants 2006, 2009). Such environmental changes could have significant effects on juvenile survival as alteration of water currents could prevent juveniles from reaching favourable environments, as many eggs and larvae of fish use currents as a means of transport (Watt-Pringle & Strydom 2003).

From analysis of gut content of juvenile fish (2 to 15 cm SL) in the Klein River estuary, Talbot (1955) found that young *R. globiceps* are omnivorous, grazing on *Zostera capensis, Ruppia maritime* and some filamentous algae (mainly *Enteromorpha* spp.) and they consume invertebrates such as small crustaceans, polychaetes and molluscs. Representative species of the abovementioned food sources are found in abundance along the shores of Saldanha Bay (Anchor Environmental Consultants 2006, 2009).

This chapter presents the results of systematic sampling of the shallow beaches of Saldanha Bay and describes the community structure and the density of *R. globiceps*. The aim of this was to locate and describe areas of high abundance and identifying physical factors that could influence the choice of habitat by juveniles.

## 2.2 METHODS

### 2.2.1 SAMPLING METHODS

Beach seine hauls were conducted (at 15 sites in March-April of 2008) using a seine net 30 m long, 2 m deep and with a stretched mesh size of 12 mm within Saldanha Bay. Beach seine hauls were done in 2007 at seven sites and again in 2008 at 15 sites. The sites ranged from the sheltered waters within the Marine Protected Area at the southern end of the Langebaan

Lagoon to the wave exposed surf across the mouth of Saldanha Bay (Figure 2.1). All sampling was conducted over sandy substrata. This type of net is not suitable for use over reefs, and juvenile *R. globiceps* are not known to be reef associated (van der Elst 1993, Heemstra & Heemstra 2004). Several of the sites were characterised by the presence of macrophytes (present in > 20% of the sample area) such as *Gracilaria ciliaris* (site 10, 11 and 12), *Zostera capensis* (sites 3, and 4) and *Gigartina* spp. (sites 10 and 15). Sites across all wave exposure gradients in Saldanha Bay (as described by Clark 1997) were sampled to allow for comparisons with respect to wave height (cm), temperature (°C) and surf-zone width (m) as well as proximity to probable spawning areas.

The maximum wave height was calculated by measuring the height difference between the crest and the trough of the largest waves observed at the back of the surf line using a tape measure along a vertically held survey pole, water temperature was measured using a thermometer and surf-zone width was measured as the distance between the shore and the last wave at the back of the surf (Clark 1997).

Sites were divided into *sheltered* (wave height <10 cm), *intermediate* (wave height 10-49.9 cm) and *exposed* (≥ 50 cm) and *cold* (< 17°C), *moderate* (17 -18.9°C) and *warm* (≥ 19°C) categories.

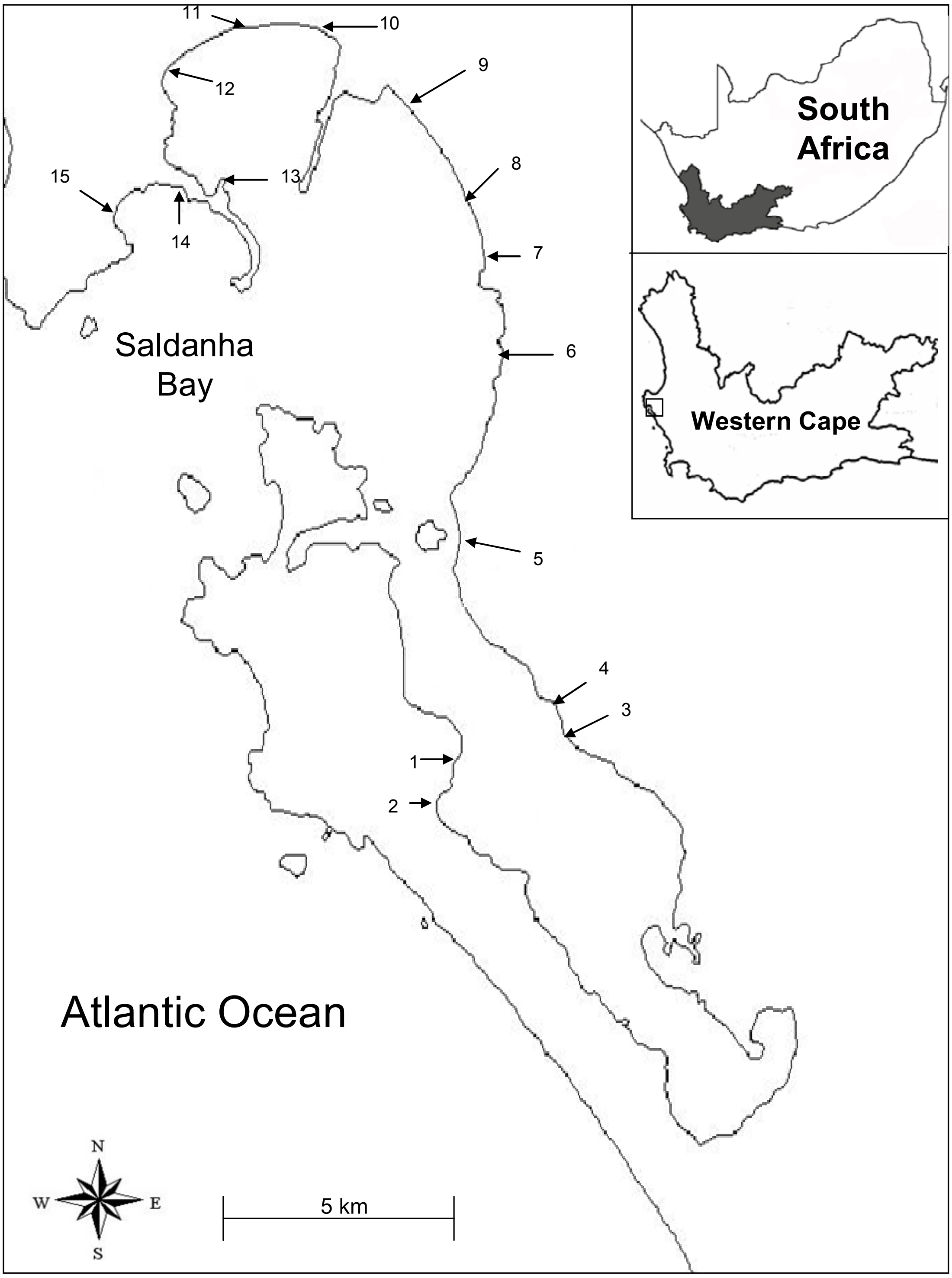


**Figure 2.1: Map of Saldanha Bay showing trek sites: (1) Kraalbaai; (2) Churchhaven; (3) Bottlery; (4) Klein Oesterwal; (5) Langebaan Beach; (6) Leentjiesklip; (7) Mykonos; (8) Spreeuwalle; (9) Dam; (10) Blue Water Bay East; (11) Blue Water Bay West; (12) Hoedjiesbaai; (13) Port Control; (14) North Bay North; and (15) Military Beach.**

### 2.2.2 DENSITY CALCULATIONS

The density of *R. globiceps* was calculated by dividing the abundance (measured as the number of individuals in the haul) by the swept area. Swept area was calculated as the distance the net was hauled multiplied by half the length of the net (Clark 1997).

To test for differences in the mean density of *R. globiceps* between sites and years, an analysis of variance test with equal replication (two-way ANOVA) (Zar 2010) was used. Sites 5, 9, 10 and 12 were the only sites with sufficient data for both years for testing with a two-way ANOVA.

Correlations between *R. globiceps* abundance and water temperature, wave height and surf-zone width were tested to determine if *R. globiceps* abundance could be related to a physical characteristic of the site sampled.

### 2.2.3 MULTIVARIATE ANALYSES

Multivariate analysis was performed using the statistical package PRIMER (Clarke & Warwick 1994, Clarke & Gorley 2006). Principle Component Analysis (PCA) was used to display patterns in the environmental data across samples using multivariate ordination. The physical variable(s) that contributed to most of the variation (≥ 90%) in the PCA analysis were used as the factor(s) in the analysis of similarity of species composition.

The relative species composition per haul was calculated by dividing the abundance of each species by the total abundance. The relative species composition per site was calculated by averaging across all hauls per site. A dendrogram of species composition at all sites for both years was constructed. The data were normalised and root-root transformed. The group average procedure was used to link sites.

A non-parametric multidimensional scaling (MDS) technique was used to “map” sites on a two-dimensional scale (Clarke & Warwick 1994). The MDS technique used a similarity/dissimilarity matrix of sites based on ranks and places sites with similar species composition closer to each other than sites with different species composition.

ANOSIM was used to test for differences in fish community structure between sites grouped according to the variables wave height and temperature using abundance data of sites sampled. ANOSIM assigns a significance value based on the number of randomised (re-labelling) trials for which an *R*-value exceeds that calculated from the data. A test statistic, *R*, is calculated and is approximately zero if no differences exist between the average similarity of samples within sites and between sites. As the discrepancy becomes larger, *R* approaches 1. The *R*-value usually falls between 0 and 1, indicating some discrimination between sites sampled (Clarke & Warwick 1994).

The SIMPER test was used to determine the species that contributed most to within group similarity and between group dissimilarity of the wave height and temperature groups. The latter was achieved by identifying species that are relatively high in one group and low in another, thereby accounting for the differences observed between the two groups being compared (Clarke & Warwick 1994).

The BIO-ENV procedure was used to match the biotic data to environmental patterns by determining which combination of environmental variables best group sites in a manner consistent with the faunal patterns observed (Clarke & Warwick 1994).

## 2.3 RESULTS

### 2.3.1 SITE DENSITIES

Mean measured *R. globiceps* density was higher in 2007 (1.56 individuals per $m^{-2}$) than 2008 (0.17 individuals per $m^{-2}$) when sites sampled in both years were compared, but similar spatial trends were apparent between years. *R. globiceps* density was comparatively low at sites 1-4 and 13-15 and higher for sites 5-12 across both years (Figure 2.2). *R. globiceps* densities were not significantly different between the two years or sites 5, 9, 10 and 12, nor were any significant interaction effects detected.

Scatter plots of mean densities of *R. globiceps* per site against water temperature (Figure 2.3), wave height (Figure 2.4) and surf-zone width (Figure 2.5) were prepared to determine if one of the physical variables could be used to explain *R. globiceps* site abundance. No distinct patterns were evident.

### 2.3.2 SPECIES COMPOSITION AND DIVERSITY

Species caught during the sampling period are listed in Table 2.1. PC1 and PC2 described over 90% of the variation in the environmental data (66.6% and 29.1% respectively) between sites, calculated by linking the variation to the physical characteristics of each site (Table 2.2). Water temperature and wave height were the two physical variables which explained most of the variation in environmental variables across sites. Surf-zone width was excluded from subsequent analyses.

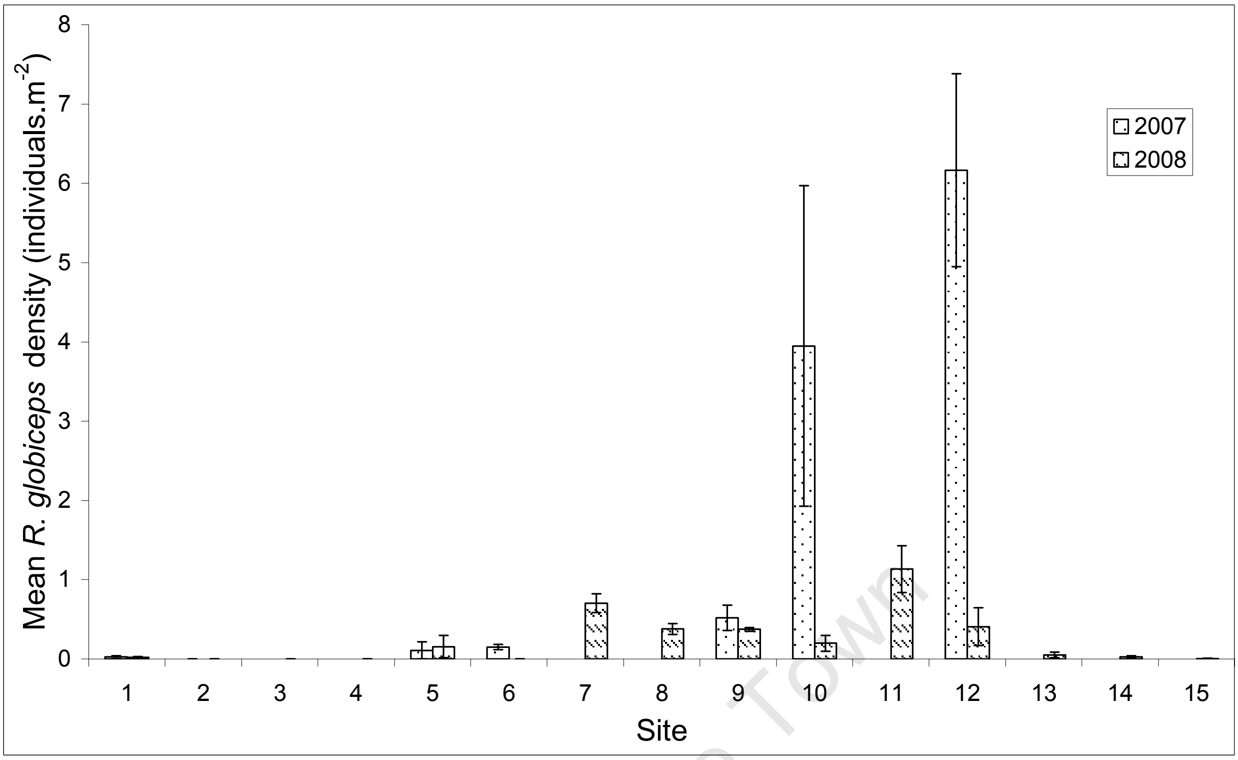


**Figure 2.2: Mean density of *R. globiceps* at sites sampled in Saldanha Bay during March-April of 2007 and 2008. Refer to Figure 2.1 for corresponding site names. Bars represent +/- 1 standard error.**

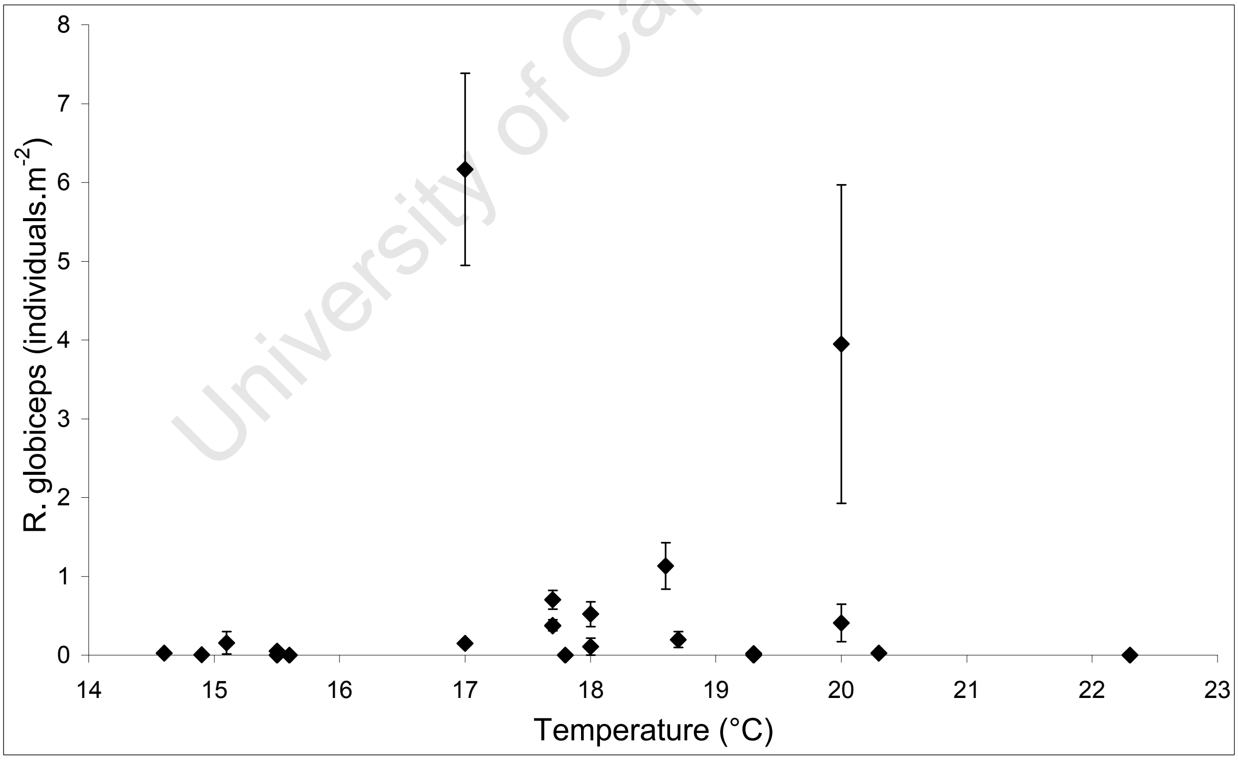


**Figure 2.3: *R. globiceps* density for different temperatures in Saldanha Bay**

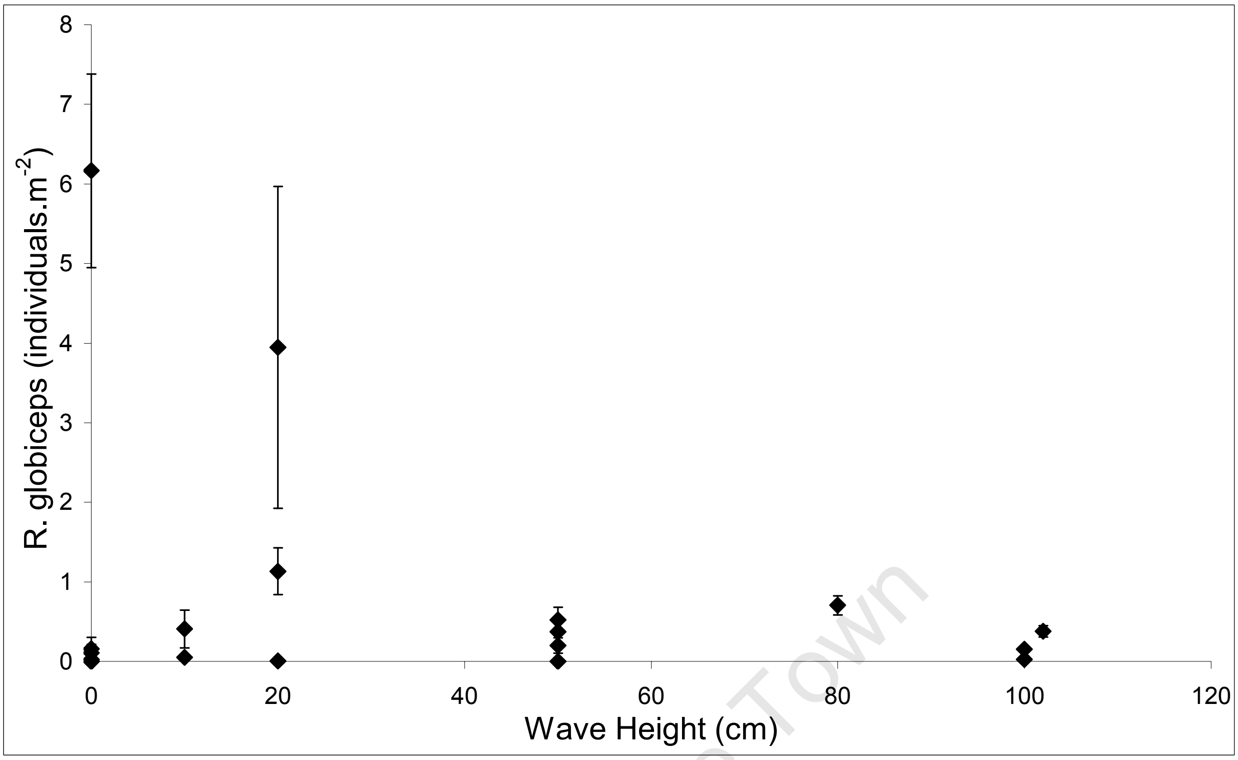


**Figure 2.4:** ***R. globiceps*** **density for different wave heights in Saldanha Bay**

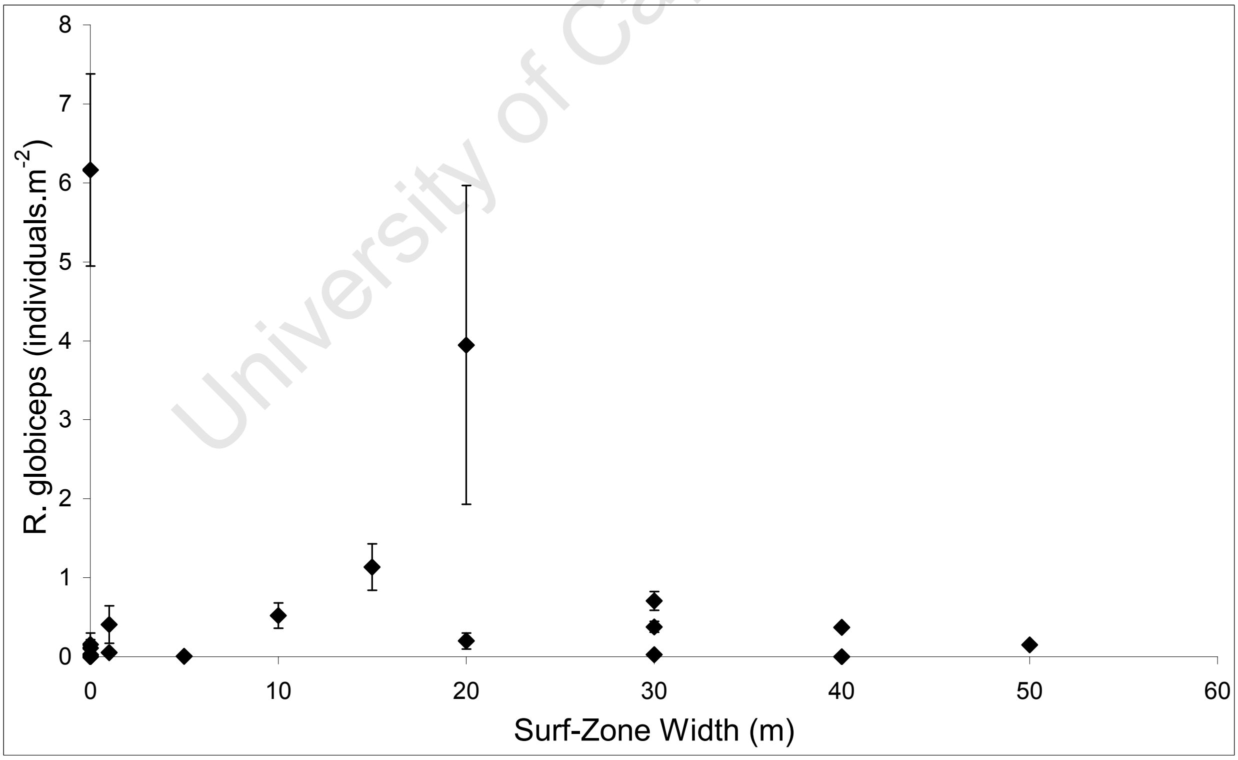


**Figure 2.5:** ***R. globiceps*** **density for different surf-zone widths in Saldanha Bay**

**Table 2.1: Average catch per site sampled in Saldanha Bay in March and April of 2007 and 2008. Catches are averaged for 3 hauls per site. *a* represents catch in 2007 and *b* catch in 2008**

| **Location** | | **1-a** | **1-b** | **2-a** | **2-b** | **3** | **4** | **5-a** | **5-b** | **6-a** | **6-b** | **7** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Netting Area ($m^2$)** | | **375** | **600** | **625** | **600** | **600** | **600** | | **600** | **1083.33** | **750** | **450** |
| **Species Name** | **Common Name** | | | | | | | | | | | |
| *Diplodus sargus capensis* | Blacktail | | | | | | | | | | 1 | 0.67 |
| *Chelidonichthys capensis* | Cape Gurnard | | | | | | | | 0.33 | 1 | | 5.67 |
| *Atherina breviceps* | Cape Silverside | 12.25 | 34.67 | 102 | 117.67 | 196 | 75.67 | | 0.67 | | | 230.33 |
| *Heteromycteris capensis* | Cape Sole | | 0.33 | 0.67 | 4 | 4.67 | 10.67 | 1 | 80.67 | 155 | 16.33 | 1.33 |
| *Myliobatis aquila* | Eagle Ray | | | | | | | | | 0.67 | | |
| *Pomatomus saltatrix* | Elf | | | | | | | | | 39.67 | | 15.33 |
| *Caffrogobius spp / Psammogobius knysnaensis* | Goby spp | 225.5 | 152 | 1028 | 353 | 190 | 93.67 | 2 | 70 | | | |
| *Clinus agilis / Clinus latipennis / Clinus superciliosus* | Klipvis spp | | | | | | 0.33 | | | 0.67 | 1 | 1.33 |
| *Rhinobatos annulatus* | Lesser Sand Shark | | | 0.33 | 0.67 | 1 | | | 0.67 | 0.33 | | 1.33 |
| *Syngnathus temminckii* | Longsnout Pipefish | | | | | | | | | | | |
| *Trachurus trachurus* | Maasbanker | | | | | | | | | | | |
| *Mustelus mustelus* | Smoothhound | | | | | | | | | | | |
| *Liza richardsonii* | Southern Mullet | 25.25 | 6.67 | 790.33 | 28.33 | 16.33 | 87 | 380.67 | 326 | 41.67 | 280.67 | 132.33 |
| *Spondyliosoma emarginatum* | Steentjie | | | | 2.67 | | | | | | | |
| *Chorisochismus sp / Apletodon pellegrini* | Sucker spp | | | | | | | | | | | |
| *Rata clavata* | Thornback Skate | | | | | | | | | | | |
| *Rhabdosargus globiceps* | White stumpnose | 8.25 | 11.33 | | 0.33 | 0.67 | | 68.33 | 94 | 158.67 | | 317 |
| | **Total** | **271.25** | **205** | **1921.33** | **506.67** | **408.67** | **267.33** | **452** | **572.33** | **397.67** | **299** | **705.33** |

**Table 2.1…continued**

| **Location** | | **8** | **9-a** | **9-b** | **10-a** | **10-b** | **11** | **12-a** | **12-b** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Netting Area (m$^2$)** | | **450** | **1000** | **600** | **625** | **466.67** | **200** | **625** | **450** | **450** | **350** | **300** |
| **Species Name** | **Common Name** | | | | | | | | | | | |
| *Diplodus sargus capensis* | Blacktail | 0.67 | 1 | | 29.67 | 4 | 279 | 40 | 222 | 2.33 | 1 | |
| *Chelidonichthys capensis* | Cape Gurnard | 10 | | 1 | 0.33 | 0.33 | | | | | 2 | |
| *Atherina breviceps* | Cape Silverside | 187.67 | | 55.33 | 550.33 | 241.67 | 857.33 | 657 | 1131.33 | | 0.33 | |
| *Heteromycteris capensis* | Cape Sole | 13 | 26 | 128.33 | 19.67 | 1 | | | | 2.33 | | |
| *Myliobatis aquila* | Eagle Ray | | | | 10 | | | | | | | |
| *Pomatomus saltatrix* | Elf | 139.67 | | | 1.33 | 0.67 | | | | | | |
| *Caffrogobius spp / Psammogobius knysnaensis* | Goby spp | | 1 | 0.67 | 17.33 | 3.67 | 10 | 1291 | 2.67 | 0.33 | | |
| *Clinus agilis / Clinus latipennis / Clinus superciliosus* | Klipvis spp | 0.67 | | 0.67 | 0.33 | 1.67 | 5.33 | 11.67 | 12.67 | 3.33 | 6.67 | 6.33 |
| *Rhinobatos annulatus* | Lesser Sand Shark | 0.33 | 5.67 | 5.33 | 20.33 | 0.67 | | 0.33 | 0.67 | 0.33 | | |
| *Syngnathus temminckii* | Longsnout Pipefish | 1 | | 0.33 | | 1 | 7 | 4.33 | 37.33 | | | |
| *Trachurus trachurus* | Maasbanker | 0.33 | | | | | | | 22.67 | | | |
| *Mustelus mustelus* | Smoothhound | | | | | | | 1 | | | | |
| *Liza richardsonii* | Southern Mullet | 61.33 | 2775.33 | 210.67 | 335.33 | 384.33 | 211.67 | 2443.67 | 269.33 | 134.33 | 16.67 | |
| *Spondyliosoma emarginatum* | Steentjie | 0.67 | | | | | | | 0.67 | | 1 | 0.33 |
| *Chorisochismus sp / Apletodon pellegrini* | Sucker spp | | | | | | | | | | | 0.33 |
| *Rata clavata* | Thornback Skate | | | | | | | 1.33 | | | | |
| *Rhabdosargus globiceps* | White stumpnose | 170.33 | 520 | 223.67 | 2221.67 | 107.33 | 226.67 | 3868 | 183.67 | 23.33 | 8.33 | 1.67 |
| | **Total** | **585.67** | **3329** | **626** | **3206.33** | **746.33** | **1597** | **8318.33** | **1883** | **166.33** | **36** | **8.67** |

**Table 2.2: Eigenvalues for PCA of the environmental variables temperature (°C), wave height (cm) and surf-zone width (m)**

| PC | Eigenvalues | % Variation | Cumulative % Variation |
|---|---|---|---|
| 1 | 2 | 66.6 | 66.9 |
| 2 | 0.87 | 29.1 | 95.7 |
| 3 | 0.13 | 4.3 | 100 |

A dendrogram of species composition showed three groups and three outliers at 60% Bray-Curtis similarity (Figure 2.6). Sites 1*a,* 1*b,* 2*a,* 2*b,* 3 and 4 formed a group (Group A), sites 5*a, 5b, 6b, 9a* and *13* formed a group (Group B), sites *7, 8, 9b, 10a, 10b, 11, 12a* and *12b* formed a group (Group C) and sites 6*a,* 14 and 15 were outliers. The MDS ordination plot showed grouping at the 45% and 60% Bray-Curtis similarity (Figure 2.7). Wave height and temperature data were superimposed onto the dendrogram and MDS ordination plots. Group A consisted mostly of sheltered and warm sites, with site 2*b* having sheltered and moderate characteristics and site 4 having sheltered and cold characteristics. Group B consisted of sites with a range of characteristics; with sheltered and moderate, intermediate and cold, exposed and moderate, sheltered and cold as well as exposed and cold sites present. Group C consisted mostly of the intermediate and exposed sites, with site 12*a* the only site with sheltered characteristics. Outlier sites were cold sites with intermediate or exposed characteristics (site 6*a*, 14 and 15). Sites in close proximity to each other had similar species composition. Sites 6*a* and 14 were the most exposed sites and site 15 is outside the inner bay area of Saldanha, factors which influenced the species composition at these sites. Group B could be classified as sites which show characteristics that fall between Group A and Group C.

There were significant differences between species composition among the three temperature groups (*R = 0.408; p = 0.018)* and among the three wave height groups (*R = 0.504; p = 0.005*).

Percentage contribution of species to the total catch was calculated for Groups A-C (Figure 2.8). Sites from Group A had relatively few *R. globiceps* present in the catch (1%), sites from Group B had a higher number of *R. globiceps* present (12%) and Group C had the highest percentage of *R. globiceps* in the catch (32%).

For each group, the average percentage similarity of sites based on species composition was calculated and the three species which contributed most to within-group similarity were listed (Table 2.3). Percentage similarity was high in the warm group (>70%), moderately high in the sheltered, exposed, moderate and cold groups (50%-70%) and lower in the intermediate group (<50%). *R. globiceps* was one of the three species that contributed most to within-group similarity at all sites except sheltered and warm sites. Average similarities were similar for temperature and wave height groupings.

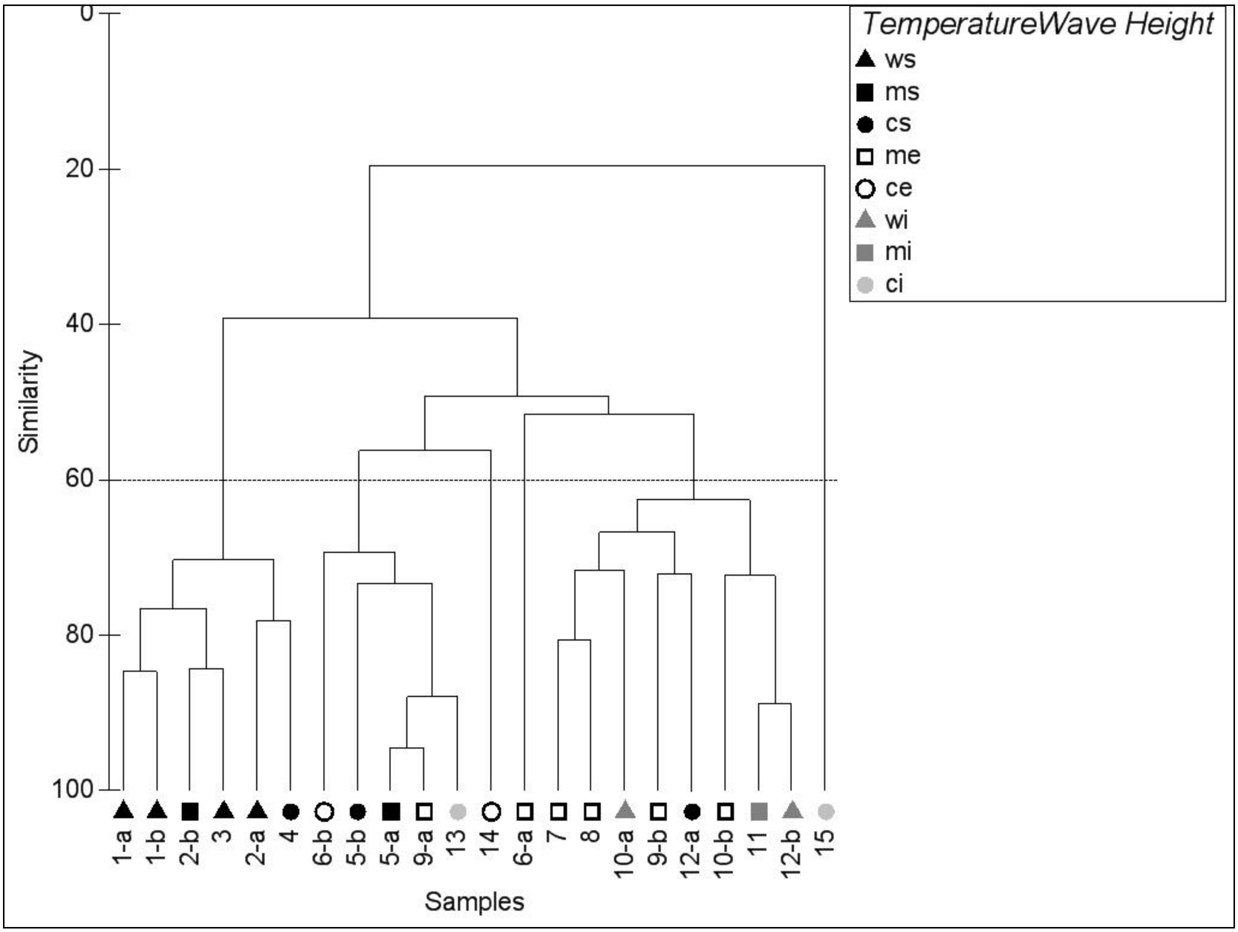


**Figure 2.6: Dendrogram of species similarity of sites sampled in Saldanha Bay between March-April in 2007 and 2008. The dotted line represents 60% Bray-Curtis similarity between sites. Temperature is symbolised by: W (Warm (▲) ≥19°C), M (Moderate (□) 17 -18.9°C) and C (Cold (○) ≤ 17°C). The shading representing wave height are: S (Sheltered (▲) ≤ 10 cm), I (Intermediate (▲) 10-49.9 cm) and E (Exposed (▲) ≥ 50 cm)**

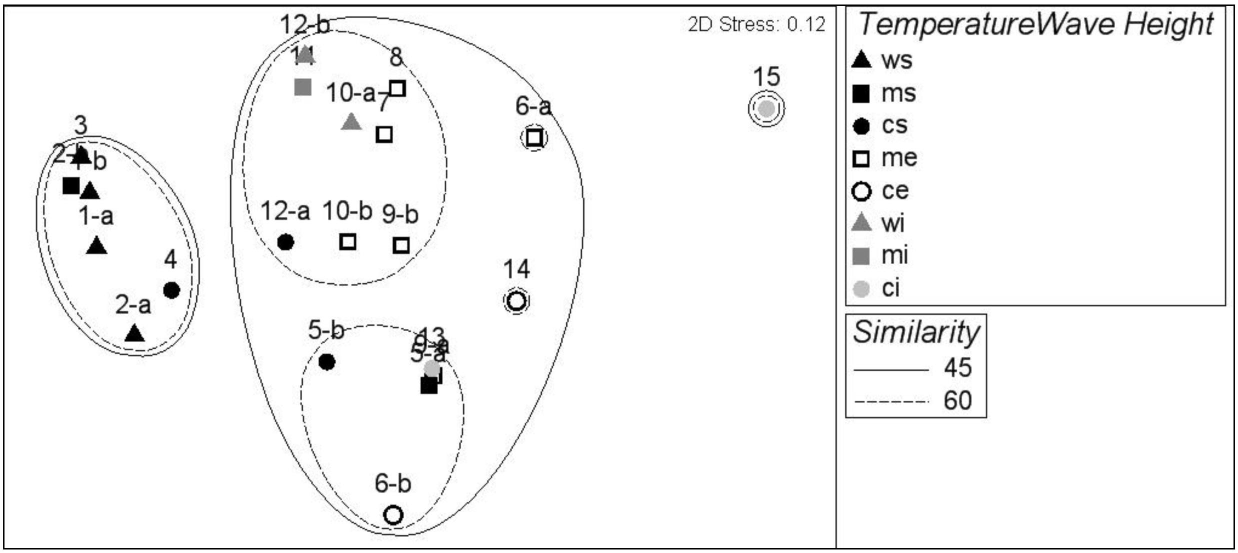


**Figure 2.7: MDS ordination plot of species similarity based on abundance data between sites sampled in Saldanha Bay in 2007 and 2008. 45% and 60%Bray-Curtis similarity is shown. Temperature is symbolised by: W (Warm (▲) ≥19°C), M (Moderate (□) 17 -18.9°C) and C (Cold (○) ≤ 17°C). The shading representing wave height are: S (Sheltered (▲) ≤ 10 cm), I (Intermediate (▲) 10-49.9 cm) and E (Exposed (▲) ≥ 50 cm)**

**Table 2.3: Average within group similarity based on temperature and wave height measurements in Saldanha Bay showing the three species which contributed most to similarity**

| Group | Similarity (%) | Top three contributing species to within-group similarity | | |
|---|---|---|---|---|
| | | **1** | **2** | **3** |
| **Sheltered** | 65.22 | *Goby spp* | *Liza richardsonii* | *Atherina breviceps* |
| **Intermediate** | 43.86 | *Rhabdosargus globiceps* | *Atherina breviceps* | *Liza richardsonii* |
| **Exposed** | 61.57 | *Liza richardsonii* | *Rhabdosargus globiceps* | *Atherina breviceps* |
| **Warm** | 71.17 | *Goby spp* | *Atherina breviceps* | *Liza richardsonii* |
| **Moderate** | 60.24 | *Rhabdosargus globiceps* | *Liza richardsonii* | *Atherina breviceps* |
| **Cold** | 52.56 | *Liza richardsonii* | *Goby spp* | *Rhabdosargus globiceps* |

Average dissimilarities between groups were calculated using the SIMPER procedure. Average dissimilarity was 59.54% between sheltered and intermediate groups, 52.32% between sheltered and exposed groups, 46.87% between intermediate and exposed groups, 39.51% between warm and moderate groups, 47.07% between warm and cold groups and 50.04% between moderate and cold groups. Species which contributed most to the dissimilarity are listed in Table 2.4. *R. globiceps* contributed significantly to the dissimilarity of species composition of sheltered vs. intermediate and sheltered vs. exposed sites, where the species was relatively common at intermediate and exposed sites and rare at sheltered sites. *R. globiceps* also contributed significantly to the dissimilarity of species composition of warm vs. moderate and warm vs. cold sites, where the species was common at moderate and cold sites and rare at warm sites. Dissimilarity results for both temperature and wave height support the similarity data presented above.

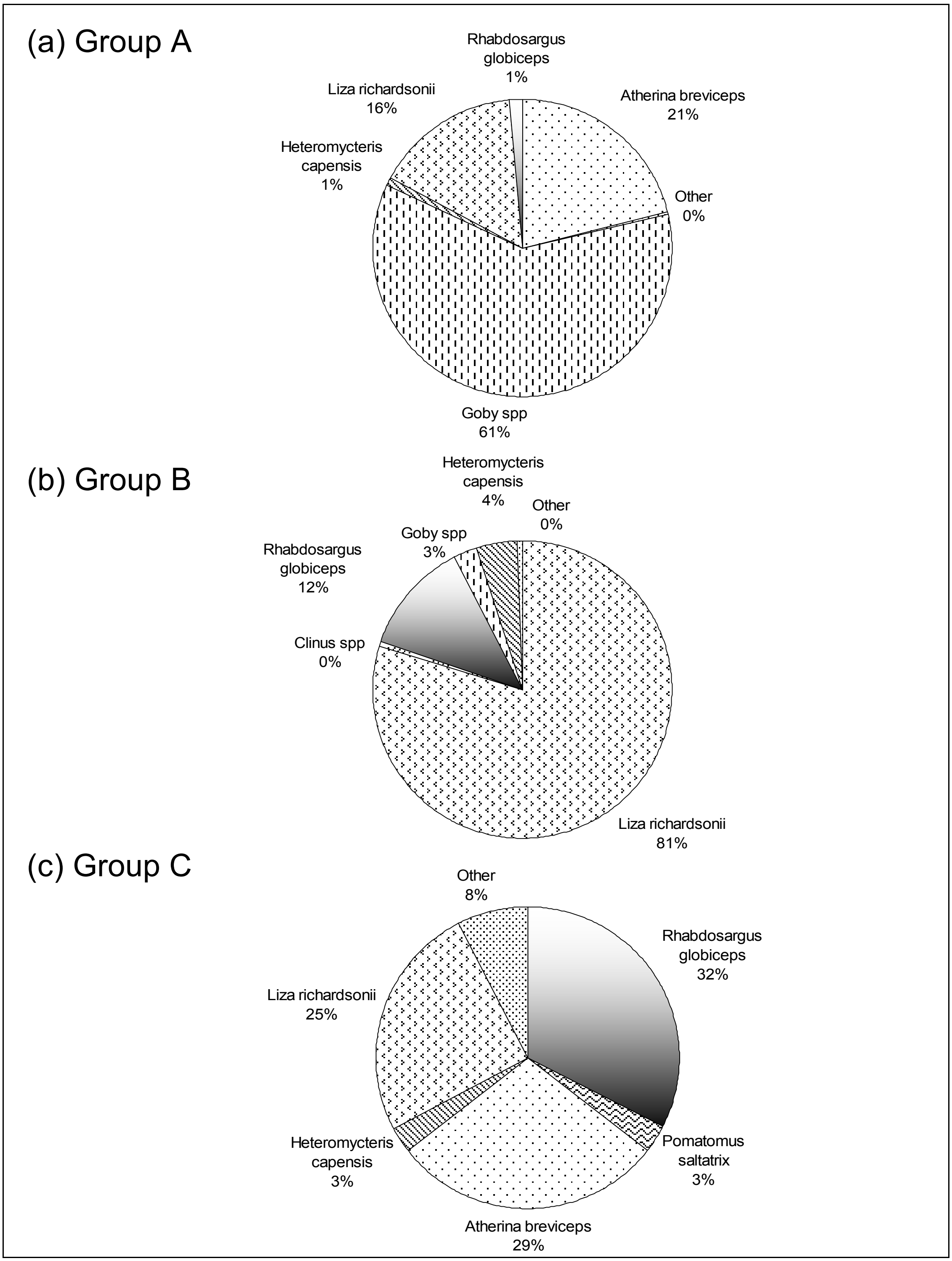


**Figure 2.8 Species composition of Groups A-C in Saldanha Bay as based on groupings at 60% Bray-Curtis similarity of sites**

**Table 2.4: List of species which contributed to between group dissimilarity based on (a) wave height and (b) temperature measurements in Saldanha Bay. Each entry indicates relative abundance in the group listed for each column, but relative scarcity in the group listed for each row**

| **(a)**<br>**Group** | **Sheltered** | **Intermediate** | **Exposed** |
|---|---|---|---|
| **Sheltered** | | *Rhabdosargus globiceps*<br>*Diplodus sargus capensis*<br>*Clinid spp* | *Rhabdosargus globiceps*<br>*Clinid spp*<br>*Pomatomus saltatrix* |
| **Intermediate** | *Goby spp* | | *Heteromycteris capensis*<br>*Pomatomus saltatrix*<br>*Liza richardsonii*<br>*Cheilidonichthys capensis*<br>*Pomatomus saltatrix* |
| **Exposed** | *Goby spp* | *Diplodus sargus capensis*<br>*Clinid spp* | |

| **(b)**<br>**Group** | **Warm** | **Moderate** | **Cold** |
|---|---|---|---|
| **Warm** | | *Heteromycteris capensis*<br>*Liza richardsonii*<br>*Rhabdosargus globiceps* | *Liza richardsonii*<br>*Heteromycteris capensis*<br>*Rhabdosargus globiceps*<br>*Clinid spp* |
| **Moderate** | *Goby spp* | | *Clinid spp* |
| **Cold** | *Atherina breviceps*<br>*Goby spp* | *Atherina breviceps*<br>*Pomatomus saltatrix* | |

BIO-ENV analysis showed that a combination of the physical variables temperature and surf-zone width best grouped sites in a manner consistent with the biotic data (sample statistic = 0.294).

## 2.4 DISCUSSION

Studies of the effects of physical variables on fish abundance and habitat preference typically produce some measure of species composition and regress this against physical metrics (e.g. temperature, salinity, wave height, etc.) (Watt-Pringle & Strydom 2003, Crawley *et al*. 2006). The approach generally adopted is to look at a community and identify which species are characteristic of specific environments or which abiotic factors influence species composition.

In the current study, species composition of sites and the effects of the physical environment on the distribution of species were used to identify sites with high juvenile *R. globiceps* abundance and to identify site preference. Habitat use between years was also compared.

In the analysis of habitat use, no statistically significant differences could be detected between years or between sites sampled. It was, however, evident that juvenile *R. globiceps* abundance in the shallow fringes of Saldanha Bay varied from site to site and from year to year. The failure to detect differences that were statistically significant between sites and years was most likely a result of low statistical power as there were insufficient samples to detect a trend. Year to year variation is likely to be related to recruitment success (Potter *et al*. 1997, 2001, Maes *et al*. 2005), whereas variation from site to site is related to habitat preference (Guidetti 2000, Young & Potter 2002, Crawley *et al*. 2006, James *et al*. 2008). Although *R. globiceps* were present at all sites sampled, their density and dominance varied between sites, with a preference for sites around the iron ore jetty in the northern section of the bay (sites 7-12).

This preference is related to the intermediate/high wave action and moderate temperatures (around 18°C) experienced at these sites. Similar trends were noted by Clark (1997) who found that sites could be grouped based on the physical characteristics of a site (e.g. the wave exposure gradient calculated from the McLachlan index). Based on Clarke's (1997) analysis, sites were divided into exposed and sheltered groups. This study grouped sites into three groups and found that species abundance and diversity were highest at sites with intermediate exposure and lowest at the most exposed and most sheltered sites. Higher species abundance and diversity at sites with intermediate exposure (which included all sites in the exposed group except the most exposed sites) can be attributed to the greater availability of suitable food resources and the physical disturbance caused by breaking waves (Clark 1997). The results suggest that juvenile *R. globiceps* prefer exposed sites. Watt-Pringle & Strydom (2003) found that sites with intermediate exposure increased successful predator avoidance of larvae and increased the chance that individuals would come across prey items, whereas too much wave exposure could remove individuals from suitable habitat.

Sites with intermediate wave height would have intermediate disturbance; with enough turbulence to promote growth and increase the availability of food resources but not enough disturbance to decrease the chances of interaction of juveniles with prey items (Watt-Pringle & Strydom 2003). It was assumed that *R. globiceps* would prefer warmer waters, but due to the sheltered nature of the warmer sites in the southern end of Langebaan Lagoon, densities were low. The one sheltered site with high *R. globiceps* abundance (site *12a*) was in close proximity to the intermediate sites. Crawley *et al*. (2006) found that increased presence of detached macrophytes was correlated to increased presence of juvenile *Cnidoglanis macrocephalus* and *Pelsartia humeralis* along the south-western coast of Australia, likely as a result of the greater shelter from predators and increased food abundance associated with the detached macrophytes. Detached macrophytes were found at sites 10, 11 and 12 in this study, which were the sites with the highest abundance of *R. globiceps*. *R. globiceps* therefore appears to avoid sheltered and warm sites and prefer sites where detached macrophytes were present.

Distribution patterns provided evidence supporting site selection by individuals. *R. globiceps* juveniles should be equally well represented at all sites unless active selection of preferred sites occurred. Active site selection was therefore considered likely as not all sites in the northern end of the lagoon had the same densities of *R. globiceps*.

Another theory explored was that initial settlement of larvae into juvenile habitat was reliant on water circulation and the prevalent wind direction, as noted for other surf-zone environments (Watt-Pringle & Strydom 2003, Jaureguizar *et al*. 2006). In summer, the prevalent wind direction is from south-east to north-west (Shannon & Stander 1977), resulting in a net northward movement of particles in the upper water column. This, along with the interaction of water bodies in Saldanha Bay (Shannon and Stander 1977, Anchor Environmental Consultants 2009) would result in the majority of eggs/larvae accumulating in Big Bay (sites 6 to 10) and Small Bay (sites 11 to 14). Sites in these areas would therefore receive the most eggs. Several studies have shown that certain fish species, including several sparids, correlate their time of spawning to certain environmental cues to increase chances of eggs and larvae reaching suitable habitats or to coincide with periods of high food abundance (Cowley *et al*. 2001, Young & Potter 2002, Jaureguizar *et al*. 2006, James *et al*. 2007).

Sites within Small Bay, Big Bay and Langebaan Lagoon (sites 1 to 13) had higher *R. globiceps* abundance than the more exposed sites directly impacted by the Atlantic Ocean (sites 14 and 15). This was likely a result of the low levels of interaction between the water bodies within Saldanha Bay (Shannon & Stander 1977, Weeks *et al*. 1991) as the temperatures and environmental characteristics at sites 14 and 15 were similar to temperatures at sites 6 and 7.

A combination of temperature and surf-zone width was found to have the greatest effect on the species composition of sites. The low percentage variation explained by the two variables could mean that not enough physical variables were measured in the study. Letourneur *et al*. (2003) found that bottom slope of a site was more important than depth when determining habitat preference of sites. Bottom slope is correlated to surf-zone width in Saldanha Bay, as the surf zone usually starts at the channel-shallow fringe interface, except where no swell is present. The influence of surf-zone width on species composition could therefore be a result of the influence of bottom slope on site preference by individuals. The effects of wave height on species composition was less pronounced, possibly due to the presence of detached macrophytes at certain sites which may have offered advantages not normally common at sites with those specific environmental characteristics.

It is likely that adult *R. globiceps* time their spawning events to coincide with periods when temperature is favourable for juvenile growth and water circulation patterns would promote movement of eggs and larvae to suitable juvenile habitat. From the results of this study, it was evident that the northern shores of Saldanha Bay were favoured, possibly due to enhanced food and shelter availability due to the presence of detached macrophytes.

# 2.5 CONCLUSIONS

Juvenile *R. globiceps* frequent all sites sampled in Saldanha Bay, though a preference for sites in Small Bay (sites 10, 11 and 12) and south of the iron ore jetty (sites 7, 8 and 9) was evident. The high abundance of individuals at sites 7 to 12 were attributed to prevalent water currents, favourable environmental conditions, presence of shelter in the form of detached macrophytes as well as abundant food sources. *R. globiceps* showed a preference for sites with intermediate wave action and moderate-warm temperatures, though they were found at all sites in Saldanha Bay. A study on egg and larval movement, including a comparison of the timing of recruits and water currents, as well as the effects of differing amounts of detached macrophytes on juvenile *R. globiceps* abundance is required.

# CHAPTER 3

# JUVENILE GROWTH AND HATCH DATE ANALYSIS OF *RHABDOSARGUS GLOBICEPS* IN SALDANHA BAY

## 3.1. INTRODUCTION

Fish otoliths grow via the accretion of layers of fibro-protein and calcium carbonate crystals (Lang & Buxton 1993, Mann-Lang & Buxton 1996, Panfili *et al*. 2002). These layers are visible as rings in the sliced otoliths and can be used to age fish. Deposition of fibro-protein and calcium carbonate crystal layers on fish otoliths takes place on a daily basis in most species, leading to a one-to-one relationship between rings and age in days (Helfman *et al.* 2009). The study of these rings for the determination of fish age and growth is known as daily increment analysis (Jones 1992). The use of daily increment analysis to accurately age fish was first described in Panella (1971) and has become routine in analysis of age of juvenile fish (Jones 1992).

The age of fish can be determined by counting the daily rings on the otolith and by knowing the age of first increment formation. The latter can be determined by rearing fish in a laboratory. Where this is not possible, it is common to assume that the first increment is formed at hatching, at yolk-sac absorption or at the age at which a similar species that was laboratory reared deposited its first increment (Jones 1992).

Disadvantages of the daily increment technique using otoliths include the possibility of cessation of daily increment formation of some fishes during shortened day length and low temperatures, not all otoliths are readable and sagittae, lapillae and asterisci may form at different stages of development (Neilson 1992). In the latter, reading of different otoliths can produce different age estimates and are thus not comparable.

In this chapter I apply the daily increment analysis using sagittal otoliths to estimate the growth rate and age of juvenile *Rhabdosargus globiceps*. The relationship between age and length of juvenile fish is used to estimate the range of hatch dates for young-of-the-year sampled on the nursery grounds in Saldanha Bay over the period October 2007 - November 2008.

Hatch date distribution is compared to the estimated dates of spawning based on the periods when adult female *R. globiceps* have ripe-and-running ovaries (Attwood *et al.* 2010) (the assumed spawning period). In Attwood *et al*.'s (2010) study on the life-history parameters of *R. globiceps* in Saldanha Bay, ovary stages were recorded each month for three years. The spawning period extended from September to February, with spawning peaks in October and February.

The Saldanha Bay population of *R. globiceps* is assumed to be a closed population as many adults can be found in Saldanha Bay throughout the year (Kerwath *et al*. 2009). Several movement studies found no evidence of movement to locations outside of Saldanha Bay (Griffiths *et al.* 2002, Attwood *et al.* 2007). Spawning most likely occurs in the lagoon and the water circulation patterns within the bay suggest that the eggs, larvae and juvenile *R. globiceps* most likely remain in the confines of Saldanha Bay (Shannon and Stander 1977, Weeks *et al.* 1991). Sampling to obtain estimates of recruitment can therefore be limited to the confines of Saldanha Bay.

Adults are found throughout Saldanha Bay but most occur in the southernmost part of the lagoon (Kerwath *et al*. 2009). The prevalent wind during the period when females have stage six ovaries (September to February) (Attwood *et al*. 2010) blows in a northerly direction. This could account for the movement of eggs from the southern end of the lagoon to the juvenile habitats with the highest juvenile density at the northern end of the bay (e.g. Nakata *et al*. 2000) (see Chapter 2). This is also used as the criteria for site selection.

# 3.2 METHODS

## 3.2.1 SAMPLING OF FISH

Fish were sampled with a seine-net on sandy beaches in Saldanha Bay. Sampling sites were divided into groups according to environmental characteristics and the abundance of juvenile *R. globiceps* in each group was calculated (Chapter 2). For the cohort analysis (described below), fish were sampled from sites 10, 11 and 12 (Figure 2.1) to provide a size-at-sample day distribution. Catch-at-size data were collected at sites in close proximity to each other, with similar environmental characteristics and with similar *R. globiceps* abundance to reduce errors associated with different growth rates and settlement dates experienced at different microhabitats due to, e.g. water currents and water temperature (see Francis 1994, Rooker & Holt 1997, Aburto-Oropeza *et al*. 2009). These sites belong to the group with intermediate wave exposure and moderate temperature – Figure 2.6. Sites were sampled between 9 am and 2 pm from November 2007-November 2008.

Fish were sampled with a 30 m long beach seine net with a stretched mesh size of 12 mm. The number of *R. globiceps* in each catch was recorded. If less than 100 *R. globiceps* were caught, the total length (TL) of all fish were measured to the nearest mm. If more than 100 were caught, 100 were randomly selected for measurement and 5-15 individuals were randomly selected for weighing and ageing. Fish sampled for morphometric analyses were frozen immediately after collection.

## 3.2.2 MORPHOMETRICS

TL and fork length (FL) measurements were taken to the nearest mm for 212 fish randomly selected from all sites sampled between November 2007 and May 2008. These data were used to model the relationship between TL and FL. Each fish was weighed using an electronic balance (to the nearest dg). A length-weight regression was calculated after logtransforming each variable. Fish were randomly selected from the above sample and kept for otolith extraction.

### 3.2.3 OTOLITH PREPARATION

Sagittal otoliths were used in this study. Otoliths were extracted and stored dry in pill vials. After extraction, otoliths were set in casting resin with the post-rostrum to the left of the mould and the rostrum to the right.

After the otolith was cast in resin it was glued to a microscope slide (post-rostrum to the left and rostrum to the right of the cast) and the top side of the resin block was ground level using 1200 grit waterpaper before being polished using micropolish and a kemet pad until the surface was smooth with a glass-like appearance. The otolith in the resin casting was then removed from the slide and the first side (along the rostrum - post-rostrum plane) was ground down using 800 grit waterpaper until the outer edge of the nucleus was reached. The nucleus was identified by its murky appearance compared to the rest of the otolith.

The otolith was then ground using 1200 grit waterpaper until one third of the nucleus of the otolith was ground away, and then 1500 grit waterpaper until the centre of the nucleus was reached. When the otolith was as smooth and straight as possible it was polished using micropolish and a kemet pad.

All excess resin was removed before the otolith was glued to the slide with the ground surface attached to the slide; after which the otolith was again polished with 800, 1200 and 1500 grit waterpaper as described above (after Secor *et al*. 1992). The result was a thin section through the nucleus of the otolith approximately 0.1 mm thick.

After the otoliths were ground down, the otolith slides were placed under a high powered microscope and viewed under transmitted light. Photographs of the otoliths were taken at 100x and 300x magnification to be used in age determination of the fish. If the nucleus was too dark, the otolith was ground further until a suitably thin slice was achieved and a photograph was taken.

### 3.2.4 AGE AND GROWTH ESTIMATION

The number of daily increments were counted on each prepared otolith. It was assumed that first increment formation occurred at hatching (Tsuji & Aoyama 1982, Vilizzi 1998, Baumann *et al*. 2006). Validation of periodicity of band deposition was not determined due to time constraints; therefore it was assumed that one ring was deposited per day, as is the case for similar species (e.g. Mann-Lang & Buxton 2006). Each otolith was read three times without reference to fish length with at least one week between readings. The average of the estimates was used as the age estimate for that individual, provided that the average percentage error (APE) (Campana 2001) was less than 10%. Those otoliths for which readings exceeded this variability were discarded (Geffen 1992).

APE was calculated using the equation:

$$APE = 100 \times \left( \frac{1}{n} \right) \times \sum_{i=1}^{n} \frac{\left| x_i - \bar{x} \right|}{\bar{x}} \qquad (3.1)$$

where *i* is the otolith count; $x_i$ is the age estimate of otolith *x* for otolith count *i*; $\bar{x}$ is the mean age estimate and *n* is the number of times each otolith was read.

The coefficient of variation (CV) was calculated using the equation:

$$CV = 100 \times \frac{\sqrt{\left( \frac{\sum_{i=1}^{n} \left( x_i - \bar{x} \right)^2}{n-1} \right)}}{\bar{x}} \qquad (3.2)$$

Both APE and CV provide an estimate of precision of ageing; but the APE incorporates the absolute deviation from the mean age (which is proportional to the mean age) whereas the

CV incorporates the standard deviation. Both estimates produce similar values of precision but the CV is the more statistically rigorous procedure as there is no assumed proportionality between the standard deviation and the mean (Campana & Jones 1992).

The precision index, *D*, was calculated as:

$$D = \frac{CV}{\sqrt{n}} \tag{3.3}$$

The TL of each fish was plotted against average estimated age and a linear regression (Zar 2010) was fitted to these data to estimate the growth rate. To test whether the model accurately described the data, a runs test was done (Butterworth *et al*. 1989, Zar 2010).

The growth rate was estimated independently using size-at-sample day distribution. The progression of mean size from one month to the next was assumed to correspond to the growth of fish in the cohort. The length of fish caught per sampling day was plotted against the number of days that had elapsed since the first day of November 2007 (arbitrarily chosen as a starting point) and linear regressions with replication (Zar 2010) were fitted to estimate the daily increase in mean length. Separate regression equations were used for each cohort.

Differences in growth rate between the two catch-at-size models and between the catch-at-age and catch-at-size models were compared by testing for differences in the slopes of the regression equations using a student's T-test (Zar 2010).

### 3.2.5 NATURAL MORTALITY

Natural mortality (*M*) was assumed to be size-dependent, decreasing with increasing size of an individual (Yoklavich & Bailey 1990, Sogard 1997). *M* was estimated using the equation proposed by McGurk (1986), which describes the relationship between *M* and the dry weight (*W*) of individual fish:

$$M = 0.0053W^{-0.25} \tag{\textit{3.4}}$$

where the dry weight of an individual was calculated by dividing the wet-weight of each individual by 5, the wet:dry conversion ratio for most fish species (Anon 2006).

## 3.2.6 HATCH DATE DISTRIBUTION

The expected birth date of each fish was calculated by subtracting the age estimate of each fish from the sample day. This procedure was repeated for each length class and sampling day.

$$B_{SL} = D_S - A_L \tag{3.5}$$

$$A_L = \frac{L-a}{b} \tag{3.6}$$

where $B_{SL}$ is the birth date of a fish of length $L$ sampled on day $D_S$, $D_S$ is the date of sample $S$, $A_L$ is the age of a fish of length $L$ and $a$ and $b$ are parameters of the growth function.

The relative recruitment strength was calculated for each length on each sampling day.

$$R_{B_{SL}} = \frac{C_{SL}}{(1-M)^{-A_L}} \tag{3.7}$$

where $R_{B_{SL}}$ is the relative recruitment indicated by $C_{SL,}$ $C_{SL}$ is the size of the catch of fish of length $L$ on day $D_S$ and $M$ is the size-dependent daily mortality rate, calculated using (3.4).

The relative recruitment was used to calculate the proportion of fish recruited per month.

$$R_m = \sum_s \sum_{B_{SL}=m_{start}}^{m_{end}} \frac{R_{B_{SL}}}{n} \tag{3.8}$$

where $R_m$ is the number of fish recruited in month $m$, averaged across all $S$ sample days, $m_{start}$ is the start of month $m$, $m_{end}$ is the end of month $m$ and $n$ is the number of samples.

Birth date distributions were obtained using growth estimates derived from otolith and cohort analysis.

Hatch dates obtained from each model were compared to the assumed spawning date to determine which model best correlated to the trends in the ovary stage data for *R. globiceps* in Saldanha Bay.

## 3.3 RESULTS

### 3.3.1 SAMPLE SIZE

Samples were obtained from every month except August. In total 6522 juvenile *R. globiceps* were sampled from 101 hauls (Table 3.1).

### 3.3.2 MORPHOMETRIC RELATIONSHIPS

The following morphometric relationships were obtained for juvenile *R. globiceps*:

$$FL = 0.950 \times TL - 0.561 \qquad R^2 = 0.997;\ p = 2.389e^{-266} \qquad n = 212 \qquad (3.9)$$

$$Mass = 6e^{-6} \times TL^{3.1889} \qquad R^2 = 0.957;\ p = 1.911e^{-146} \qquad n = 212 \qquad (3.10)$$

The size and mass relationship is shown in Figure 3.1.

### 3.3.3 DAILY INCREMENT ANALYSIS

Of the 100 otoliths prepared for the ageing study, only 77 yielded readable sections. Otoliths were discarded because the nucleus was missed or because otoliths were ground too deeply. Three examples of sliced otoliths are shown in Plates 3.1-3.4. Readings were generally taken along the longest axis unless rings were unclear, in which instance readings were taken along the axis with the clearest rings when observed in a straight line. Where only small sections of the otolith were unclear, these sections were read along clearer axes (see Plate 3.4 for an example). Only 56 of the otoliths had an APE < 10% and an age estimate of each of these individuals were obtained. Residuals of each age count are presented in Figure 3.2. Residuals were similar for counts 1 and 2 indicating consistency of age estimates between readings, whereas the mean age of count 3 underestimated the age of fish when compared to the other counts.

Average APE was 7.49%, CV was 10.18% and D was 6.43. High error in the age readings was attributed to difficulties in obtaining a single axis along which an age estimate could be obtained and defining the first ring (assumed hatch date), here chosen as the outer edge of the nucleus visible as the edge of the dark centre of the otolith in Plates 3.1-3.4.

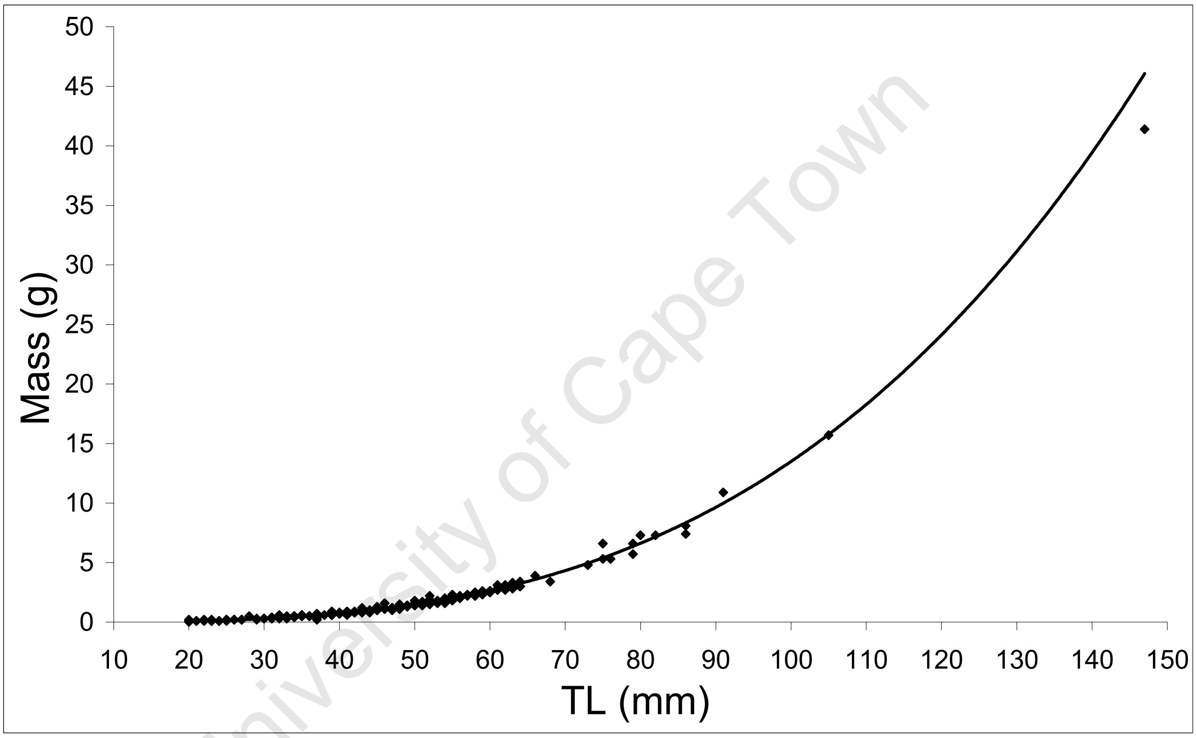


**Figure 3.1: Length-mass regression for juvenile *R. globiceps***

**Table 3.1: Number of *R. globiceps* caught in Saldanha Bay from November 2007- November 2008. Values between brackets represent the number of hauls per site per sampling month**

| Year | Date | Blue Water Bay East | Blue Water Bay West | Bottlery | Churchhaven | Dam | Hoedjiesbaai | Klein Oesterwal | Kraalbaai | Langebaan beach | Leentjiesklip | Mykonos | North Bay North | Military Beach | Port Control | Spreeuwalle | Visklip | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | Nov | 27 (1) | 0 (1) | | 0 (1) | | | 0 (1) | 0 (1) | 0 (1) | 1 (1) | | | | | | | 28 (7) |
| | Dec | | | | | | | 0 (1) | | | 0 (1) | | | | | | 0 (1) | 0 (3) |
| 2008 | Jan | 1336 (1) | | | 2 (1) | | | 9 (1) | 0 (1) | 18 (1) | 24 (1) | | | | | | | 1389 (6) |
| | Feb | 223 (1) | | | | | 108 (1) | 12 (1) | 18 (1) | | | | | | | | 24 (1) | 385 (5) |
| | Mar | 322 (3) | 680 (3) | 2 (3) | 1 (3) | | | 0 (3) | 34 (3) | 282 (3) | 0 (3) | | | | | | | 1321 (24) |
| | Apr | | | | | 671 (3) | 551 (3) | | | | | 951 (3) | 5 (3) | 25 (3) | 70 (3) | 511 (3) | | 2784 (21) |
| | May | 12 (1) | | | 14 (1) | | 0 (1) | 0 (1) | 0 (1) | 14 (1) | | | | | | | | 40 (6) |
| | Jun | 0 (1) | 2 (1) | | | | 14 (1) | | | 388 (1) | | | | | | | | 404 (4) |
| | Jul | 2 (1) | | | | | 0 (1) | | | | | | | | | | | 2 (2) |
| | Aug | | | | | | | | | | | | | | | | | NO DATA |
| | Sep | 6 (3) | | | 25 (3) | | 15 (3) | | 0 (1) | | 0 (3) | | | | | 0 (3) | | 46 (18) |
| | Oct | 98 (1) | | | | | | | | | | | | | | | | 98 (1) |
| | Nov | 8 (1) | | | 0 (1) | | 17 (1) | | 0 (1) | | | | | | | | | 25 (4) |
| Grand Total | | 2034 (14) | 682 (5) | 2 (3) | 42 (10) | 671 (3) | 705 (11) | 21 (8) | 52 (11) | 702 (7) | 25 (9) | 951 (3) | 5 (3) | 25 (3) | 70 (3) | 511 (6) | 24 (2) | 6522 (101) |

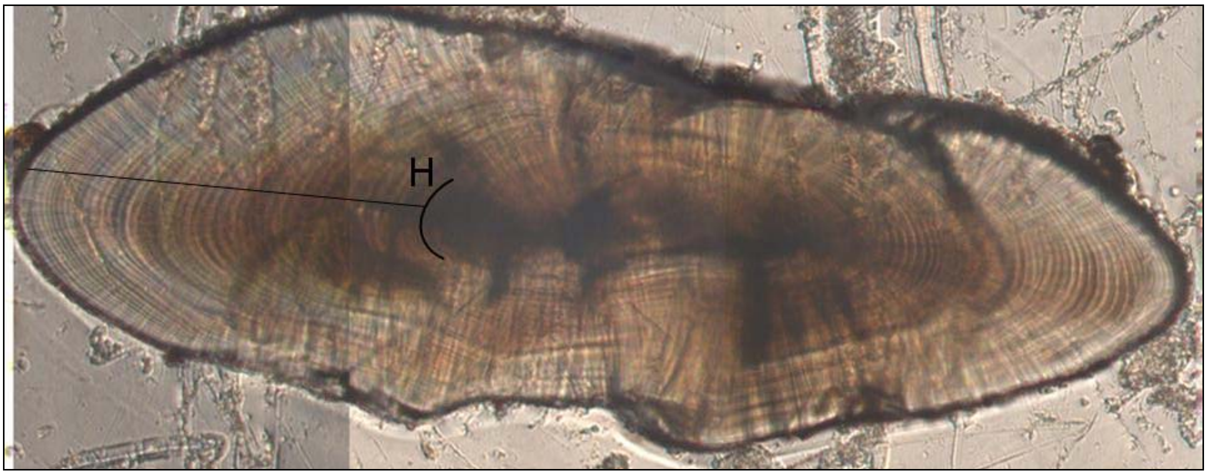


**Plate 3.1: Photograph of an otolith of a 42 day old *R. globiceps* caught in Saldanha Bay (APE = 7%) taken at 100x magnification. Indicated is the ring assumed to correspond with the hatch date (H)**

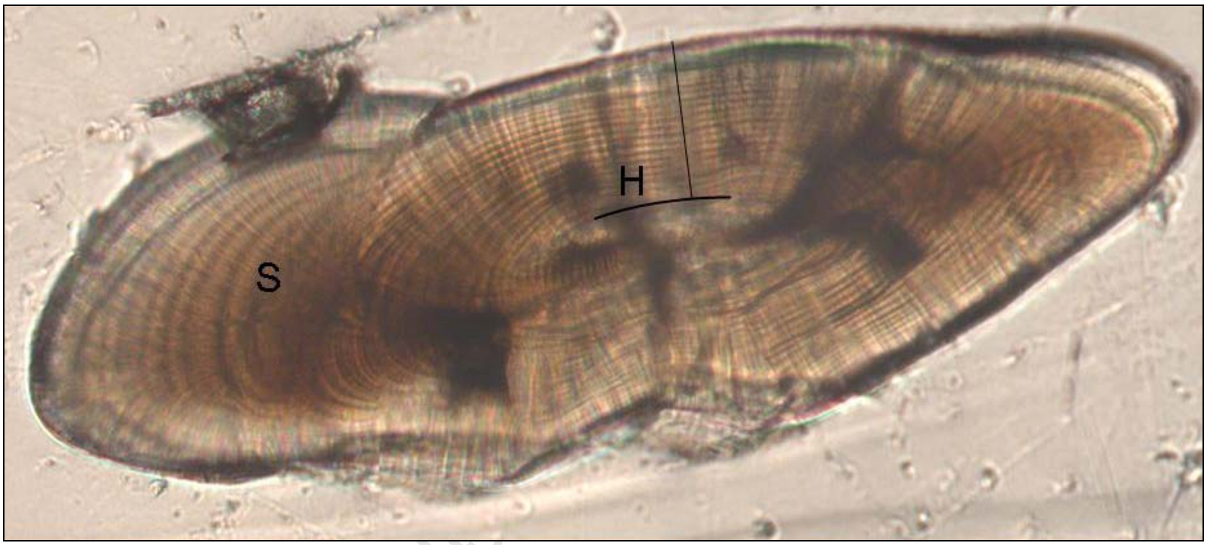


**Plate 3.2: Photograph of an otolith of a 24 day old *R. globiceps* caught in Saldanha Bay (APE 22%) taken at 100x magnification. This otolith was excluded from the analyses as the APE > 10%. Indicated is the secondary axis (S) beyond which the age of the fish cannot be calculated by counting rings in a straight line from the centre of the otolith. Assumed hatch date (H) is also indicated**

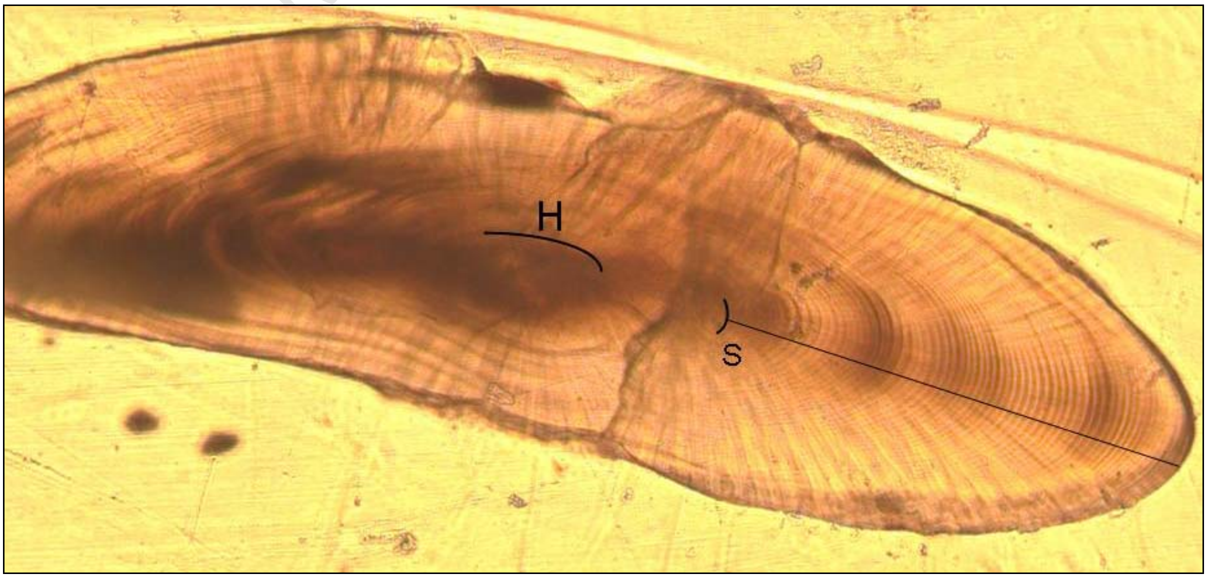


**Plate 3.3: Photograph of an otolith of a 62 day old *R. globiceps* caught in Saldanha Bay (APE = 2%) shown at 100x magnification**

**Plate 3.4: The same otolith shown in Plate 3.3 presented at a higher magnification (300x). Where a section of the otolith was unreadable along the line, the otolith was read along a clearer axis (follow dotted lines)**

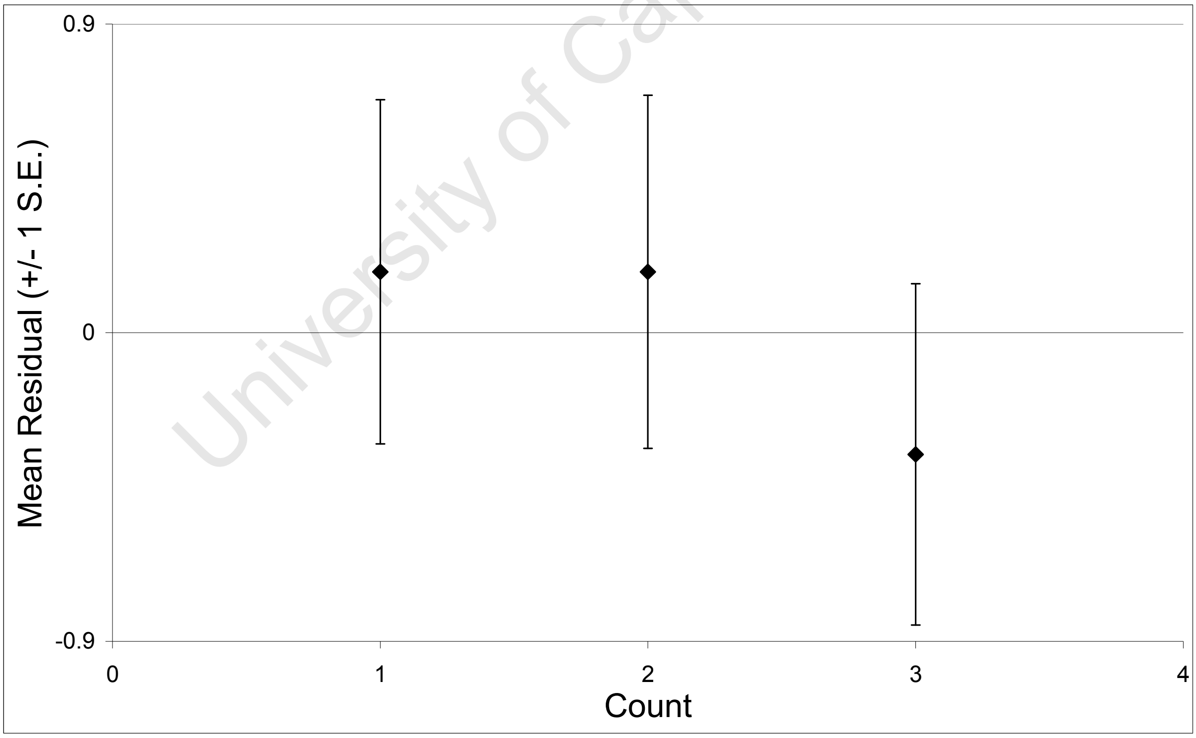


**Figure 3.2: Mean residuals for age estimates of juvenile *R. globiceps***

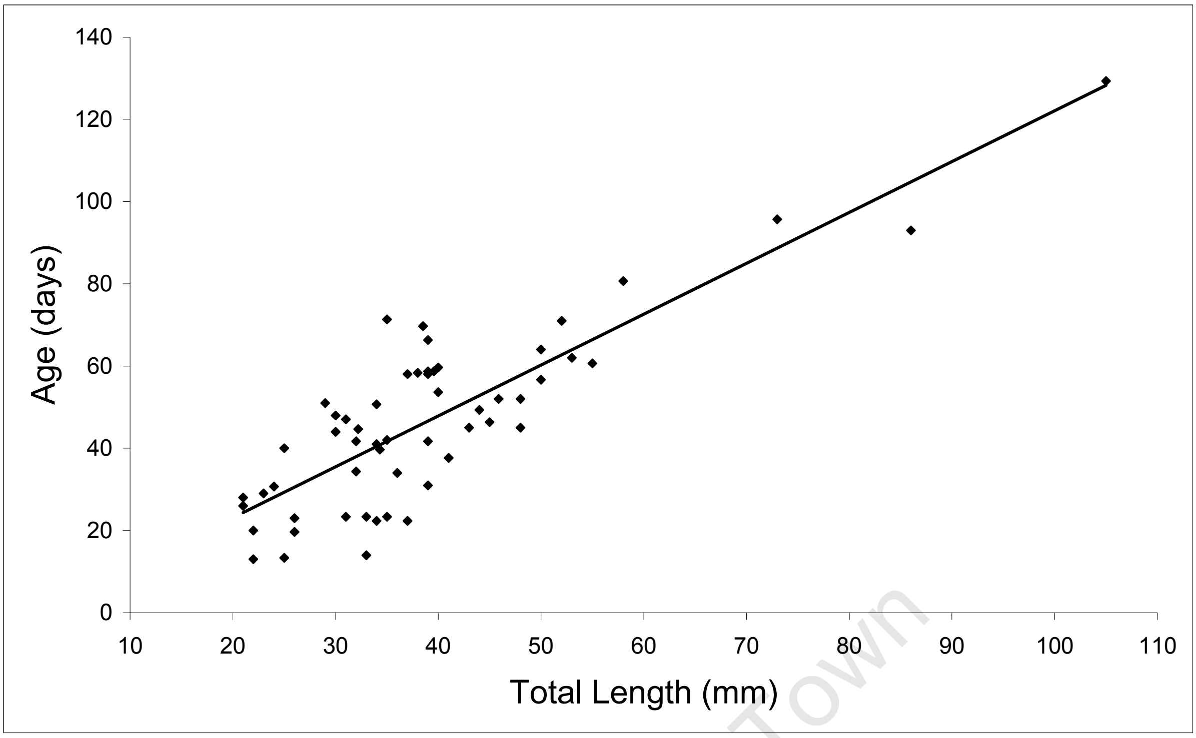


**Figure 3.3: Daily age-length regression for juvenile *R. globiceps*. All data points with > 10% APE were removed**

The age estimates were plotted against TL (Figure 3.3). The resultant equation was

$$TL = 0.574 \times Age + 12.244 \qquad R^2 = 0.711;\ p < 0.001 \qquad n = 58 \qquad (3.11)$$

The regression described the data adequately, passing the runs test (*p* < 0.001). The 95% confidence intervals for the slope and intercept were 0.47-0.67 and 7.09-17.40 respectively.

Analysis of the length frequency distribution of *R. globiceps* for sites 10, 11 and 12 showed a clear modal progression of size from November 2007-April 2008 (Figure 3.4) and again between May 2008 and November 2008 (not shown).

Two distinct cohorts were evident from the catch-at-size data (Figure 3.5). Regressions fitted to these lengths yield the following two relationships:

$$TL = 0.219 \times SampleDay + 17.573 \qquad R^2 = 0.96,\ p = 3.89e^{-3} \qquad n = 875 \qquad (3.12)$$

$$TL = 0.207 \times SampleDay - 17.902 \qquad R^2 = 0.93,\ p = 7.39e^{-3} \qquad n = 114 \qquad (3.13)$$

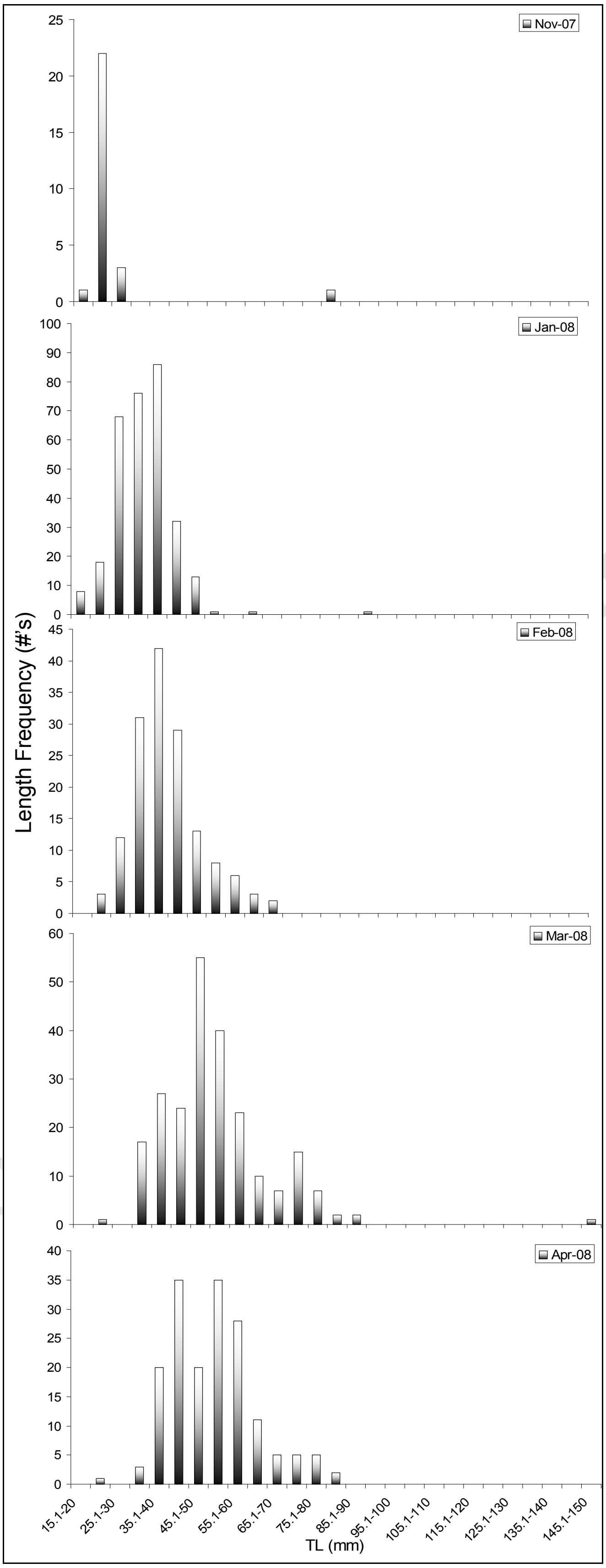


**Figure 3.4: Length frequency distribution of *R. globiceps* sampled at sites 10, 11 and 12 in Saldanha Bay for the period November 2007-March 2008. Counts are not comparable between months because of different sampling sizes**

The slopes were not significantly different (t-test). The similar slopes of the regressions suggest that both cohorts grew at the same rate. Equation 3.12 was used for length frequency distribution analysis because sample size for this cohort was larger than the cohort described by equation 3.13.

A comparison of the slopes of the catch-at-age and catch-at-size regressions showed significant differences between the two models ($t = 14.18 \gg t_{\alpha(2),930}$, $p = 0.05$). Regression equations described the data adequately.

*M*-estimates obtained using McGurk's (1986) equation ranged from $0.018\ d^{-1}$ for the smallest individuals to $0.0045\ d^{-1}$ for the largest individuals.

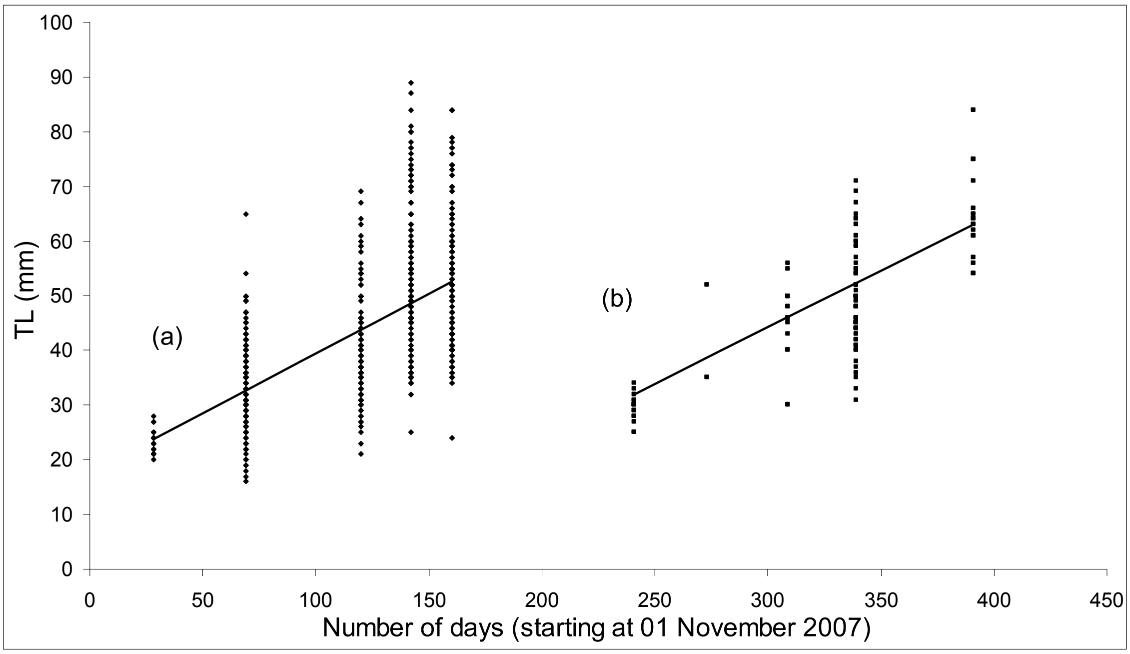


**Figure 3.5: Changes in *R. globiceps* size between November 2007 and November 2008 at Blue Water Bay East, Blue Water Bay West and Hoedjiesbaai. Day 1 is 1 November 2007. Regressions were calculated from the mean length per sampling day**

Hatch date analysis using catch-at-age data showed two hatch peaks, a large peak from November-December 2007 and a smaller one in July 2008, with relatively low levels of recruitment in the months between the peaks (Figure 3.6).

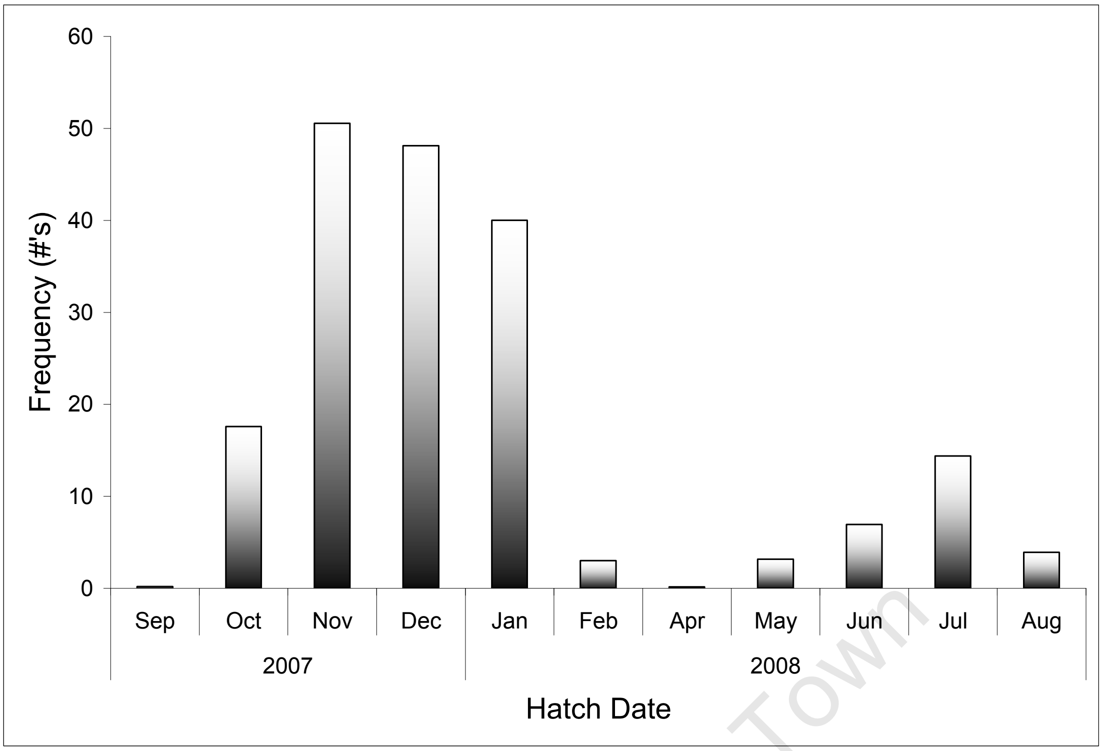


**Figure 3.6: Estimated hatch dates of juveniles sampled at the sites Blue Water Bay East, Blue Water Bay West and Hoedjiesbaai based on catch-at-age analysis. No fish were hatched in March 2008**

The extrapolations from catch-at-size data also showed spawning throughout the year with two hatch peaks. Spawning peaks were in July-August 2007 and February 2008, with the August hatch peak being the greater of the two (Figure 3.7).

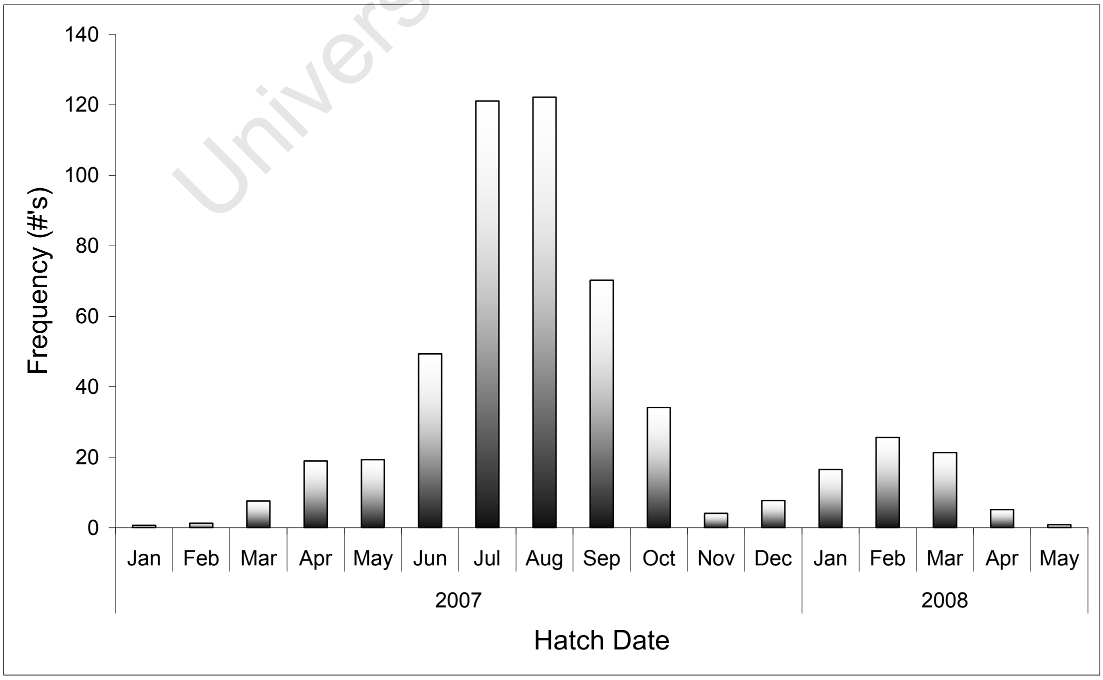


**Figure 3.7: Estimated hatch dates of juveniles sampled Saldanha Bay for the period November 2007 to November 2008 based on catch-at-size analysis**

# 3.4 DISCUSSION

## 3.4.1 JUVENILE GROWTH

Trends in the catch-at-age and catch-at-size data were described using linear models. Even though a linear growth model cannot be used to describe growth for juveniles of all species (e.g. Matić-Skoko *et al*. 2004), the model passed the runs test and therefore accurately described trends for both catch-at-age and catch-at-size data.

Planes *et al*. (1999) found that a linear growth model best explained the variation in early growth of three seabreams (*Diplodus puntazzo*, *D. sargus* and *D. vulgaris*) in the Mediterranean Sea. Individuals sampled in their study ranged from 5-71 mm TL. The growth rates varied from 0.08 mm.day$^{-1}$ for *D. puntazzo* to 1.01 mm.day$^{-1}$ for *D. sargus*. In this study, a linear model appropriately described the growth on *R. globiceps*. The growth rate for *R. globiceps* was slightly higher at 1.238 mm.day$^{-1}$ (95% confidence intervals ranged from 1.022-1.453 mm.day$^{-1}$), possibly due to the favourable environment in Saldanha Bay, as opposed to the nutrient-poor conditions of the Mediterranean.

James *et al*. (2007) studied the recruitment patterns of two seabream species (*R. holubi* and *Lithognathus lithognathus)* into an intermittently open estuary. Their study found that recruit sizes ranged from 20-100 mm standard length (SL) and 30-350 mm SL, respectively. *R. globiceps* sampled ranged from 20-5 mm TL. The size ranges of *R. globiceps* and *R. holubi* are similar (Heemstra & Heemstra 2004), suggesting that both species occupy juvenile habitat for similar time periods. The growth rate of the two species might be similar as the habitats provide similar advantages for the species. The size range of *Lithognathus lithognathus* was much broader and individuals stayed in the juvenile habitat much longer than the other two species. Inter species comparisons between the growth rates and mortality of *R. globiceps* and *R. holubi* should therefore be possible.

Based on the seine-net data collected at sites 10,11 and 12, a catch-at-size model was constructed and compared to the more widely used catch-at-age model (see Yoklavich & Bailey 1990, Quiñonez-Velázquez *et al*. 2000, Vigliola *et al*. 2000 for the latter). The models were compared because data were available for juveniles from a well defined area with similar environmental constraints (see Chapter 2), suggesting that similar growth curves would be obtained.

Each model was based on several assumptions, many of which are still to be validated. Assumptions for the catch-at-age model relate mainly to otolith microstructural analysis. If age was underestimated by the model, it was likely due to (1) failure to validate the periodicity of ring formation (Secor *et al*. 1992); (2) the period of first ring formation did not coincide with hatch date (Campana & Jones 1992); and/or (3) the assumed hatch check did not coincide with the hatch date. In the latter, the rate of deposition of bands may have differed between life-history stages (e.g. peaks increment width for two *Diplodus* species occurred 26 and 30 days after hatching (Vigliola *et al*. 2000) therefore hatch date would be underestimated by almost one month if the peak in increment width was mistakenly assumed to represent with the check formed at hatch) (Campana 1996, Suthers *et al*. 1999, Bergenius *et al*. 2002). The period between the hatch date and the transition into the juvenile phase may therefore have been excluded from this analysis.

Ideally, eggs should be hatched in a controlled environment (thereby knowing the hatch date) and by periodically sacrificing individuals, the date when the check is formed (as various environmental factors could initiate the formation of the first band) and the periodicity of band depositions can be determined (Campana & Jones 1992). This approach is often adopted to validate the time of first ring formation (Arrhenius & Hansson 1996, Alanondo *et al*. 2008). The age estimate is then corrected for the difference between the hatch check and the date of first ring formation (Francis 1994). Where no studies have been done to validate the assumptions used, it is often assumed that closely related species for which the assumptions have been validated would have similar trends to the species in question (Geffen 1992).

Problems with laboratory rearing relate mainly to the controlled conditions of a laboratory. Natural conditions for the juveniles can be highly variable and the physical environment can have significant effects on the rate of otolith deposition (Geffen 1992).

There are other alternatives for determining the periodicity of ring formation that can be explored, but these are generally considered unfeasible due to time and/or monetary constraints. Possibilities include mark-and-recapture experiments (by e.g. a fluorescent elastomer tattoo (McCormick & Hoey 2004) for individual tagging or immersion in a Alizarin solution (Wilson *et al.* 2009) for mass tagging) and rearing young in their natural environment (Geffen 1992). Problems with mark-and-recapture experiments include the number of individuals that need to be marked (as millions of juveniles can be present at any nursery habitat) and preventing mixing of the cohort used in the study could be problematic in the latter (as individuals move around to find more suitable habitat (Limburg 2002)). A mass tagging experiment would probably be the most feasible of these for the Saldanha Bay population. The tagging experiment should focus on individuals found on the northern shores of Saldanha Bay where juveniles are most abundant (Chapter 2).

Length-based methods are less accurate than otolith-based methods and are strongly influenced by environmental conditions and spawning discreteness (Butler & Folkvord 2000), but were compared to otolith-based analysis in this study because they are less labour intensive (Vigliola *et al*. 2000), making them more attractive when time and/or monetary constraints are important.

### 3.4.2 HATCH DATE DISTRIBUTION

This study also aimed to use juvenile growth information to determine hatch dates from catch data and otolith analysis and to compare these to the assumed spawning dates obtained from Attwood *et al*.'s (2010) study. Results from both catch-at-age and catch-at-size analysis showed two spawning peaks, though the timing of peaks for both models differed from the assumed spawning peaks.

In extrapolating back to birth dates, mortality of juveniles was assumed to be size specific, with mortality decreasing relative to increasing individual size (e.g. Methot 1983, Quiñonez-Velázquez *et al*. 2000). This was based on the “bigger is better” hypothesis where larger individuals are less susceptible to predators than smaller individuals (Bailey & Houde 1989, Sogard 1997, Bergenius *et al*. 2002).

The slopes of the catch-at-age and catch-at-size models differed significantly, suggesting that the estimation of growth differed between the two models. Spawning peaked in October and February, suggesting that the hatch date would occur soon afterward as eggs of seabreams usually hatch approximately 2 days after spawning (Houde 1975, Hussain *et al*. 1981, Huang & Chiu 1997). Hatch dates for both models should therefore coincide with spawning peaks.

Hatching peaks estimated from catch-at-age analysis occurred in November and July. Overestimation of growth rate by this model was likely as a result of violations of the assumptions of the model used (Vigliola *et al*. 2000), most likely those assumptions related to the period of first increment formation.

Differences between the estimated hatch date from the catch-at-age analysis and the assumed spawning date could be attributed to differences in area specific growth rates between sites sampled. Jones (1987) found that growth was slower for *Pomacentrus amboinensis* in the winter months than the summer months. It can therefore be assumed that different growth curves would be required for cohorts spawned at different times (if environmental factors differed) or cohorts spawned at different areas (thereby experiencing different environmental constraints). To increase accuracy of comparisons of this nature, data should be collected from a discrete, pre-defined habitat type over a set period of time (e.g. see Dahlgren & Eggleston 2000 for a comparison of growth rates between habitats).

Differences between the timing of each peak in the catch-at-age analysis and the assumed spawning peaks suggested that the two cohorts in the samples possibly grew at different rates. If differences in growth between cohorts exist, a growth rate must be calculated for each cohort and incorporated into the catch-at-age model to improve correlation between the two data sets. Peaks based on catch-at-age analysis were mismatched to assumed spawning peaks (occurring later than the spawning peaks) (Attwood *et al*. 2010), suggesting that the age of fish were underestimated by the model.

Spawning peaks from the catch-at-size model occurred in August and February. The peaks were earlier than the periods when ovaries in stage six peaked, suggesting underestimation of growth and overestimation of age by the model. Hatch dates were approximately one month before the first spawning peak and in the same month as the second peak, suggesting that growth was underestimated by the cohort analysis.

Discrepancies between the spawning peaks and the catch-at-size model relate mainly to cohort overlap, gear avoidance by larger fish and the emigration of larger fish from the sample area (Planes *et al*. 1999, Aburto-Oropeza *et al*. 2009, Miller *et al*. 2010). Although peaks in the hatch dates derived from catch-at-size data were close to the spawning peaks, spawning appeared to continue throughout the year, a trend which is not evident in the Attwood *et al*'s (2010) study. This could be as a result of differences in the growth rate of individuals, where faster growing fish were larger than slower growing fish of the same age (Bailey & Houde 1989) coupled with emigration of larger individuals (Christensen 1978, Morato *et al*. 2003, Aburto-Oropeza *et al*. 2009). Cohort overlap, though less likely for this population, could also influence the growth curve of cohorts (James *et al*. 2007). Movement of larger individuals to more suitable habitat was evident for the population, as could be seen by the lack of individuals from the first cohort at the time of recruitment of the second cohort into the area (Figure 3.6). Error associated with emigration of larger individuals from the study site was difficult to quantify as the proportion of fish emigrating from the study area was not known, making violation of assumptions difficult to correct for in the model.

The onset of spawning may differ from year to year, following trends in environmental variables (Hesp & Potter 2003) (e.g. juvenile *Rhabdosargus holubi* make use of overwashing events following heavy rains to enter estuarine habitats when the mouth of an estuary is closed, which varies from year to year, therefore adults time spawning events to coincide with periods of heavy rain – James *et al*. 2007). The sample data and spawning data were collected in different years. As annual differences in spawning periods exist (Hesp & Potter 2003), the assumed bias in the model could be as a result of a change in the onset of spawning (e.g. Wieland *et al*. 2000) and not actual bias in the models applied.

The catch-at-age model is preferred over the catch-at-size model even thought it showed poor correlation to the spawning periods, as the assumptions of the model can readily be validated and error associated with breaches of the assumptions can be quantified.

To correct for potential bias in the models, validation of egg and larval movement, hatch date, position of first ring formation, periodicity of ring deposition and timing of emigration of larger fish from the nursery area is required.

## 3.5 CONCLUSIONS

Growth estimates differed between the catch-at-age and catch-at-size models. The growth rate obtained from this study was comparable to the growth rates calculated for closely related species. Two spawning peaks for *R. globiceps* were evident from analysis of the data. This finding supports the findings of Attwood *et al*. (2010), who showed that gonads of the majority of breeding aged female *R. globiceps* were ripe twice in a one year period. Timing of spawning peaks differed between the hatch date analysis and the assumed spawning dates. Discrepancies between age estimates based on length frequency distribution analysis, reading of otoliths and estimated spawning dates are possible due to cohort mixing (by catch-at-size analysis) or underestimation of age (by catch-at-age analysis). Reading of otoliths is the better of the two procedures (as assumptions can be verified) but a larger sample size, a constant sampling effort over the study period and validation of the frequency of band deposition, especially in the larval stage, is needed before estimates can be regarded as a true reflection of age.

# CHAPTER 4

# COMPARISON OF OTOLITH PREPARATION TECHNIQUES FOR AGE ESTIMATION OF ADULT *RHABDOSARGUS GLOBICEPS*

## 4.1 INTRODUCTION

Since the first researchers noted varying translucent and opaque zones on hard structures in fish and found many of these deposits were annual in nature, the use of hard structures in fish, especially otoliths, have become routine in the estimation of fish age (Campana 2001, Kolding & Giordano 2002, Panfili *et al*. 2002). Since then, many studies have published age estimates based on the count of annual deposits on otoliths for various species (e.g. Griffiths & Hecht 1995, Griffiths 1996, Graynoth 1999, Kirchner & Voges 1999, Holtzhausen & Kirchner 2001, Radebe *et al*. 2002, Pajuelo *et al*. 2006). Age estimates are used to produce age-length keys which are ultimately used in growth studies and stock assessment studies (Kolding & Giordano 2002).

Age estimates based on otolith readings are not always accurate and as a result some marine resources have been over-utilized due to, for example, underestimation of age and consequently overestimation of growth (Dwyer *et al*. 2003, Brouwer & Griffiths 2004). More emphasis has therefore been placed on accuracy and precision of age estimates and quantification of error (Campana & Jones 1992, Campana 2001, Potts & Cowley 2005).

A common source of error is one associated with the precision of age estimates. Precision is defined as the reproducibility of measurements (such as age counts) on a given structure. Measures of precision are the Average Percentage Error (APE) and the Coefficient of Variation (CV). Age estimates with high precision indicate that the results obtained are highly reproducible but do not necessarily indicate that they are accurate; and vice versa (Campana & Jones 1992, Campana 2001).

A second source of error that may be encountered is if age counts from different age readers are biased. Bias is defined as the consistent under- or overestimation of fish age (Campana *et al*. 1995).

Another area of debate has been choice of structures to use for age determination. As several hard structures in fish show regular deposits of calcium, a number of techniques can be applied to determine the age of fish (Campana 2001). Structures used include otoliths, scales and vertebrae (Galtsoff 1952, Campana 2001, Piner & Mann 2001, Abecasis *et al*. 2008, Panfili *et al.* 2002), with otoliths being the most favoured (Campana 2001).

Otoliths are not the only hard structures used to age fish. Of the other structures used to age fish; scales are most common (Panfili *et al*. 2002). However, scales are mostly used for analysis of annual rather than daily increments. Szedlmayer *et al*. (1991) successfully used scales to determine daily growth increments of weakfish (*Cynoscion regalis*). An advantage of using scales is that the fish does not need to be killed to obtain the sample and therefore scales can be taken from the same individual at several time intervals and the deposition rate of ring formation can be easily validated (Szedlmayer *et al*. 1991, Jones 1992, Abecasis *et al*. 2008). Scales need to be taken from several areas of the fish and the scale with the highest count should be used to estimate the age of the fish as calcium is deposited from the time of scale formation and regenerated scales will underestimate age (Szedlmayer *et al*. 1991). Several problems with the use of scales exist, as (1) scales can be lost and regenerated, affecting the age estimate of fish as deposition would start at the time of new scale formation and (2) deposition ceases at older ages, resulting in an underestimation of age. Scales are lost throughout the life of a fish and when the scale is lost -if the scale pocket is undamaged - a new scale is formed in the empty space (Panfili *et al*. 2002).

Otoliths are generally chosen over scales for ageing seabreams because scales underestimate the age of older fish (Beamish & McFarlane 1987, Smale & Punt 1991, Buxton 1993, Potts & Cowley 2005, Abecasis *et al*. 2008) and it appears most success has been achieved using otoliths for ageing other species (Jones 1992).

Otolith Preparation Techniques (OPTs) can be divided into several categories; including whole, break-and-burn, slicing, staining and baking (Jones & Hynes 1950, Graynoth 1999, Casas & Piňeiro 2000, Piner & Mann 2001, Panfili *et al.* 2002, Dwyer *et al*. 2003, Stransky *et al*. 2005, Robilliard *et al*. 2009).

OPTs can affect the precision and bias of otolith readings by enhancing contrast between translucent and opaque bands and increasing accuracy of ring counts along the edge of the otolith, depending on the OPT used (Beckman 2002, Potts & Cowley 2005, Pajuelo *et al*. 2006, Abecasis *et al*. 2008). Estimates of age obtained from sliced otoliths are considered more reliable than estimates obtained from reading whole otoliths due to the stacking effect observed at the edge of otoliths for long-lived species (e.g. Potts & Cowley 2005, Pajuelo *et al*. 2006) and growth zones may not always be clearly discernable using whole otoliths (Radabe *et al*. 2002). Baking is believed to enhance the visibility of annual rings when viewed under transmitted light by darkening the translucent zone of the otolith. This is accomplished by burning the organic materials (to a caramel-brown colour) which occur in greater concentrations in the translucent zone which then contrasts sharply with the white opaque zone (Piner & Mann 2001, Panfili *et al.* 2002). Baking should provide more contrast between the opaque and translucent zones compared to unbaked otoliths which should make the identification of annuli easier. The effects of various baking time-temperature combinations have been used for otoliths of other fish species, ranging from 24 hours at 60°C (used to dry out otolith when dry weight of otolith is to be measured) to 1.5 – 2 minutes at 400°C (for browning of otolith) ( Robillard *et al*. 2009).

Like many other species, age estimates for South African seabreams have been based on reading of annual increments on otoliths (Mann-Lang & Buxton 1996, Chale-Matsau *et al.*

2001, Griffiths *et al*. 2002, Brouwer & Griffiths 2004, Fairhurst 2005). Deposition of rings are assumed to be annual; i.e. one translucent and one opaque band are deposited per year (Chale-Matsau *et al.* 2001, Fairhurst 2005). This was later confirmed by Potts & Cowley (2005) who tested this hypothesis.

The aim of this study is to find the optimum OPT for ageing *Rhabdosargus globiceps*. By comparing the precision and bias of baked and unbaked otoliths (read whole and sliced) I can determine if baking of otoliths improves precision of age estimates and reduces the level of bias, if any, inherent in each OPT.

This study will also compare several time-and-temperature combinations to find the optimal baking strategy to be used on *R. globiceps* otoliths.

## 4.2 METHODS

Sagittal otoliths were removed from *R. globiceps* caught at Saldanha Bay between 01 August 2004 and 19 October 2006 and were stored dry in envelopes or pill vials. *R. globiceps* were caught using a rod, reel and baited hooks. Prior to the comparison of otolith preparation techniques, a small experiment was conducted to find the optimal technique for baking otoliths, as this technique had never been applied to otoliths of this species before.

### 4.2.1 OTOLITH BAKING EXPERIMENT

Otoliths from 150 fish were used to test combinations of different baking temperatures and exposure times. The otoliths were baked in a CAHO muffle furnace. Sub samples of six otoliths each were subjected to different temperature and exposure times to determine the optimal time-and-temperature combination for browning. Caramel and caramel-brown has been considered to be the optimal colour for baking (Wischniowski & Bobko 1998). Temperatures were set at 100, 200, 300 and 400°C and exposure times were set at 1, 5, 10, 15, 20, 30 and 60 minutes. All combinations were tested. Otoliths were baked for the stipulated time or until they reached a brown to dark brown colour - further burning was unnecessary. If two or more time-temperature combinations were found to provide optimal results (i.e. caramel or caramel-brown), the least time-intensive of the combinations was considered best and all remaining whole otoliths were baked at that time and temperature.

### 4.2.2 OTOLITH PREPARATION TECHNIQUES

Paired saggital otoliths were used to compare OPTs. The number of otoliths compared varied due to e.g. loss of one otolith of an otolith pair or discarding of age estimates for an OPT due to inconsistencies between readings. One otolith per pair was sliced and read; the other was read whole. The whole otolith was subsequently baked and read again. Thereafter the baked otolith was sliced and read again. Precision and bias of the four OPTs were compared.

Those otoliths that were sliced were cast in resin, and a 0.5 mm transverse section was cut through the nucleus with twin diamond wafering blades (Panfili *et al*. 2002). Sections were mounted on glass slides with DPX mountant.

Whole otoliths were read submerged in freshwater on a black background under reflected light through a Nikon dissecting microscope at 16x magnification. Sliced otoliths were read using a dissecting microscope under reflected light through a Nikon dissecting microscope at 30x magnification on a black background.

Each otolith was read three times for each OPT (whole unbaked otoliths were read four times), allowing at least one week between readings, without prior knowledge of fish size or capture date. The first whole unbaked otolith count was used to set criteria for annulus interpretation and was subsequently discarded (Fairhurst 2005). An age estimate per OPT was obtained if two or more age counts agreed. Where there was no agreement, the sample was discarded.

### 4.2.3 STATISTICAL METHODS

Precision between and within OPTs were analysed by comparing CV, APE and the precision index *D* (Campana 2001) for each OPT and between pairs of OPTs.

Bias and precision between and within the four OPTs were analysed using a combination of age difference plots, age bias plots, CV plots as well as parametric and non-parametric statistical analysis (Campana *et al*. 1995, Power *et al*. 2006). Results were compared between and within OPTs to determine whether age estimates based on the various treatments were consistent.

CV was calculated using the equation:

$$CV = 100 \times \frac{\sqrt{\left( \frac{\sum_{i=1}^{n} \left( x_i - \bar{x} \right)^2}{n-1} \right)}}{\bar{x}} \tag{4.1}$$

where *i* is the otolith count; $x_i$ is the age estimate of otolith *x* for otolith count *i*; $\bar{x}$ is the mean age estimate and *n* is the number of times each otolith was read.

APE was calculated using the equation:

$$APE = 100 \times \left( \frac{1}{n} \right) \times \sum_{i=1}^{n} \frac{\left| x_i - \bar{x} \right|}{\bar{x}} \tag{4.2}$$

When comparing between OPTs, the APE and CV were calculated by subtracting the overall mean count from the mean of each OPT and then summing these differences for the numerator;

and

*D* was calculated as:

$$D = \frac{CV}{\sqrt{n}} \tag{4.3}$$

*D* was averaged for all otoliths in each OPT.

Both APE and CV provide an estimate of precision of ageing; but the APE incorporates the absolute deviation from the mean age (which is proportional to the mean age) whereas the CV incorporates the standard deviation. Both estimates produce similar values of precision but the CV is the more statistically rigorous procedure as there is no assumed proportionality between the standard deviation and the mean (Campana & Jones 1992).

Percentage agreement was calculated for paired OPTs using the equation:

$$\%Agreement = \sum_{i=1}^{n} \frac{A}{n} \times 100 \tag{4.4}$$

where *A* is the number of age counts accepted (i.e. where two or all three age counts agree) and *n* is the number of otoliths compared.

Within OPT bias was analysed by plotting the mean absolute residuals of the three age counts for each of the four OPTs.

Age difference plots were constructed by calculating the difference between the paired OPT (i.e. by subtracting the age estimate obtained by one OPT from the other OPT within the OPT pair being analysed) and plotting it as a function of one of the sets of ages. This graphical representation of the data is considered easier to interpret than the age frequency tables used by Campana *et al*. (1995) (Power *et al*. 2006). Observations were weighted by frequency of occurrence to facilitate in identifying patterns within the data (after Power *et al*. 2006); as unweighted observation points could represent any number of data points (Campana *et al*. 1995) thus hindering accurate interpretation of results.

OPT pairs were analysed to detect possible bias using simple linear regression; where an intercept other than zero would suggest that systematic age differences between the age estimates obtained from the two OPTs compared exist (perhaps due to different interpretation of the first increment formation) (Campana *et al*. 1995) and a slope other than one would suggest inconsistency in the interpretation of annuli by the reader for one of the OPTs (Power *et al*. 2006). A One Sample Sign test was performed to detect the presence of positive and negative ageing bias for paired OPTs (at α=0.05) by analysing the paired differences (Power *et al*. 2006). Age bias plots (Campana *et al*. 1995) were applied to paired OPTs and are read in relation to the 1:1 equivalence line where a significant difference indicated bias. By plotting the mean (± 95% confidence intervals) of age *x* for one OPT to the same age category for another OPT, differences in age estimates between the paired OPTs become easier to identify, as the range of the values of the first OPT shows for a particular age can be compared to the age group for the second OPT (Power *et al*. 2006).

To test for differences between paired OPTs, the nonparametric Wilcoxon two sample signed rank sum test (Conover 1980) was applied. The Wilcoxon test tests for imprecision or significant differences in age distribution by comparing the median age estimates of the paired OPTs (Campana *et al*. 1995). This test allows the user to determine whether differences between age estimates of OPT pairs were significantly different.

The CV was also compared to percentage agreement to determine which age classes showed the highest precision between age classes. The average CV of each age estimated by one OPT was determined and plotted relative to the average CV of each age estimated by another OPT. Plots comparing the CV to the percentage agreement are used to visually identify the ages at which differences between OPTs occur (Campana *et al*. 1995) and can be used to visually identify ages with low precision between OPTs.

## 4.3 RESULTS

From the initial analyses of baked otoliths, five minute at 300°C and five minutes at 400°C were chosen as optimal baking time-and-temperature combinations to produce caramel and brown baked otoliths respectively (Table 4.1). Colour differences between unbaked, caramel and brown otoliths are presented in Plate 4.1.

**Table 4.1: Colour of *R. globiceps* otoliths at various time-and-temperature combinations after baking. Six otoliths were used per treatment. Data in bold represent optimal time-and-temperature combinations**

| | 100°C | 200°C | 300°C | 400°C |
|---|---|---|---|---|
| 1 minute | White | White | White caramel | White |
| 5 minutes | White | White | **Caramel** | **Caramel-Brown** |
| 10 minutes | White | White | Caramel-Brown | Brown-dark brown |
| 15 minutes | White | White | Caramel-Brown | Brown-dark brown |
| 20 minutes | White | White caramel | Brown | - |
| 30 minutes | White | White caramel | Brown | - |
| 60 minutes | White caramel | White caramel | Brown (some dark brown) | - |

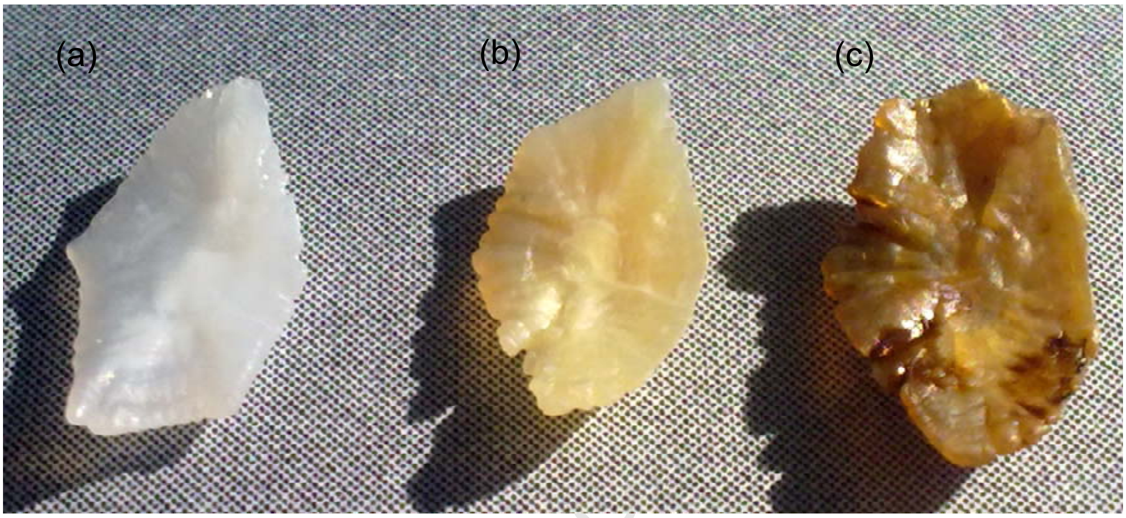
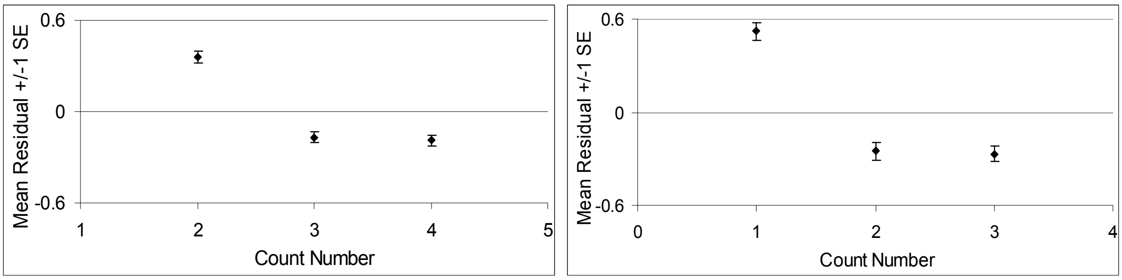


**Plate 4.1: The two otolith baking treatments used in this study and an unbaked otolith for comparison showing colour differences due to baking treatments: (a) unbaked, (b) baked to a caramel colour and (c) baked to a carmel-brown colour**

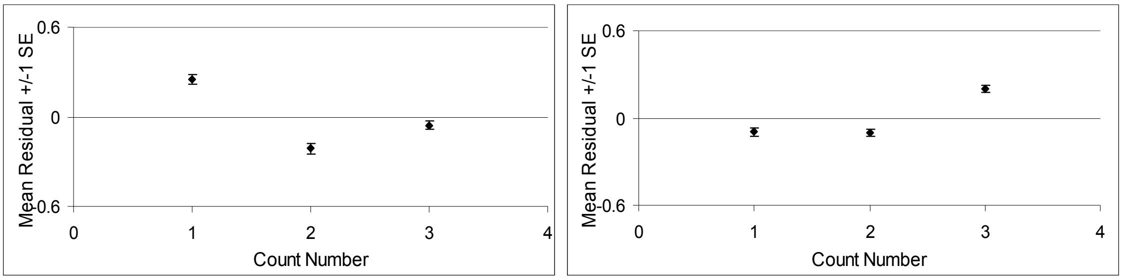
When within OPT bias was analysed, the first age count overestimated the age of individuals for all OPTs except baked-and-sliced; where age was overestimated by the last age count. Residuals were greatest for the sliced OPT (Figure 4.2).

APE, CV and D were lowest for baked-and-sliced otoliths and highest for whole unbaked otoliths (Table 4.4). Percentage rejected was lowest for baked-and-sliced otoliths and highest for whole baked otoliths.



(a) Whole

(b) Sliced



(c) Baked

(d) Baked&Sliced

**Figure 4.2: Mean residuals of (a) whole otoliths, (b) sliced otoliths, (c) baked otoliths and (d) baked-and-sliced otoliths showing standard error**

**Table 4.4: Ageing precision for otoliths of *R. globiceps* for the four OPTs used in the study showing sample size (*n*). W = Whole otoliths; S = Sliced otoliths; B = Whole-Baked otoliths; and B-S = Baked and Sliced otoliths**

| Parameter | W | B | S | B-S |
|---|---|---|---|---|
| **Average APE (%)** | 14.60 | 13.23 | 14.03 | 6.88 |
| **Average CV(%)** | 19.58 | 17.70 | 18.88 | 9.04 |
| **D** | 11.31 | 10.31 | 10.90 | 5.22 |
| **% rejected** | 18.24 | 23.32 | 7.14 | 3.09 |
| **n** | 307 | 280 | 193 | 194 |

When paired OPTs were compared, differences between the two OPTs were displayed using weighted counts, where compared age readings with a higher percentage of occurrence had larger data points (Figure 4.3). Bias, increasing with age, was evident for all comparisons except whole unbaked vs. sliced unbaked and whole baked vs. baked-and-sliced. Whole otoliths consistently underestimated age of fish when compared to other OPTs.

Results of a simple linear regression on each of the pairwise OPT comparisons are summarised in Table 4.5. Significant differences from a slope of one and an intercept of zero were evident for all OPT pairs except the sliced unbaked vs. whole baked comparison whose intercept was not significantly different from zero, indicating that inconsistencies between readings and systematic bias were highly significant. The non parametric one sample sign test (Table 4.5) showed that ageing bias was significant for all OPT pairs, with sliced unbaked vs. whole unbaked otoliths and whole baked vs. baked-and-sliced otoliths showing negative bias when the former was compared to the latter. Bias was positive for all other OPTs (i.e. when baked was compared to whole; baked-and-sliced was compared to whole; baked was compared to sliced; and baked-and-sliced was compared to sliced). Whole unbaked vs. whole baked and whole unbaked vs. baked-and-sliced showed a similar number of positive ranks and ties.

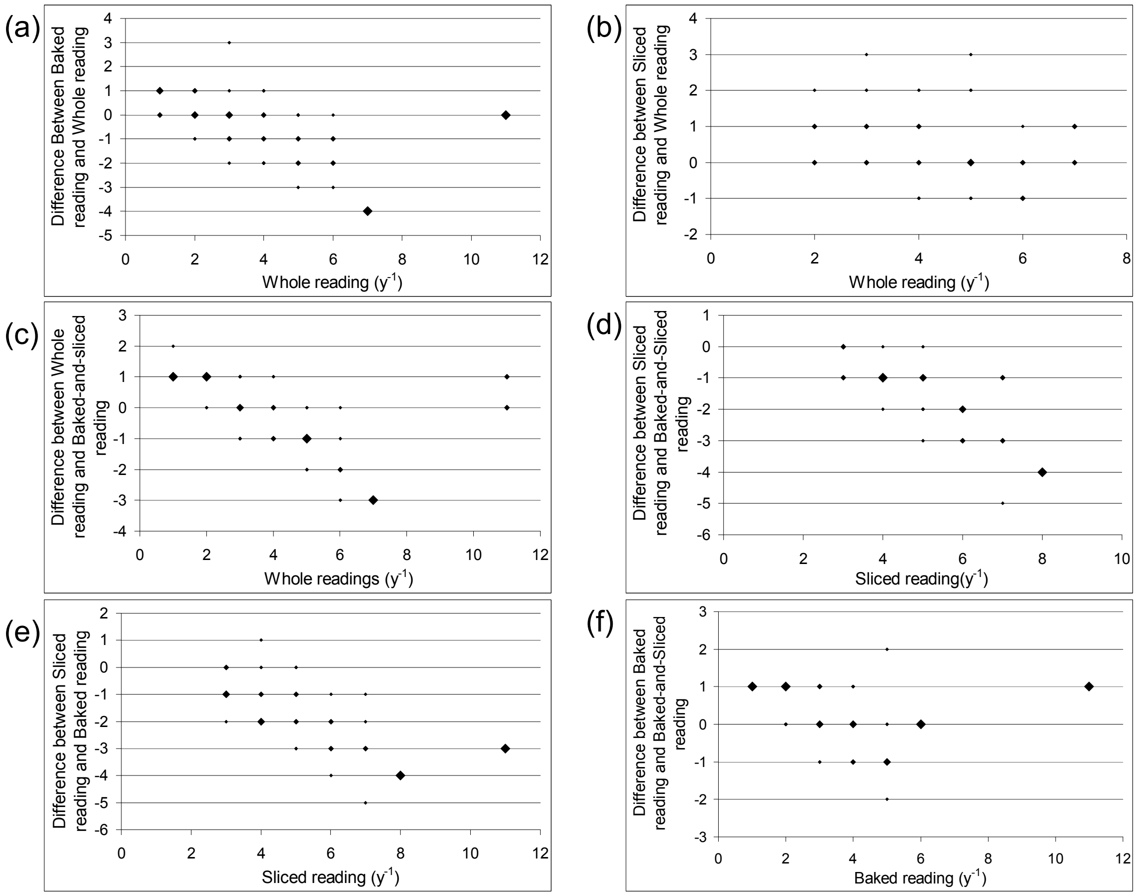


**Figure 4.3 Age difference plots for the pairwise comparisons between the four OPTs used in this study. Plotted points present one or more observations and are weighted by frequency of observations. (·) = 0-25%; (•) = 26-50%; (♦) = 51-75%; and (◆) = 76-100%**

Age bias plots, presented in Figure 4.4, showed that whole baked otoliths underestimated fish age when compared to sliced unbaked otoliths and baked-and-sliced otoliths underestimated fish age when compared to sliced unbaked otoliths. The trends for these OPT pairs are almost parallel to the 1:1 line, suggesting that differences are consistent. Differences between the other OPT pairs are hard to discern, though increasing differences between estimates of older fish are seen for all OPT pairs except whole unbaked vs. sliced unbaked, for which age estimates for all ages fall close to the 1:1 equivalence line.

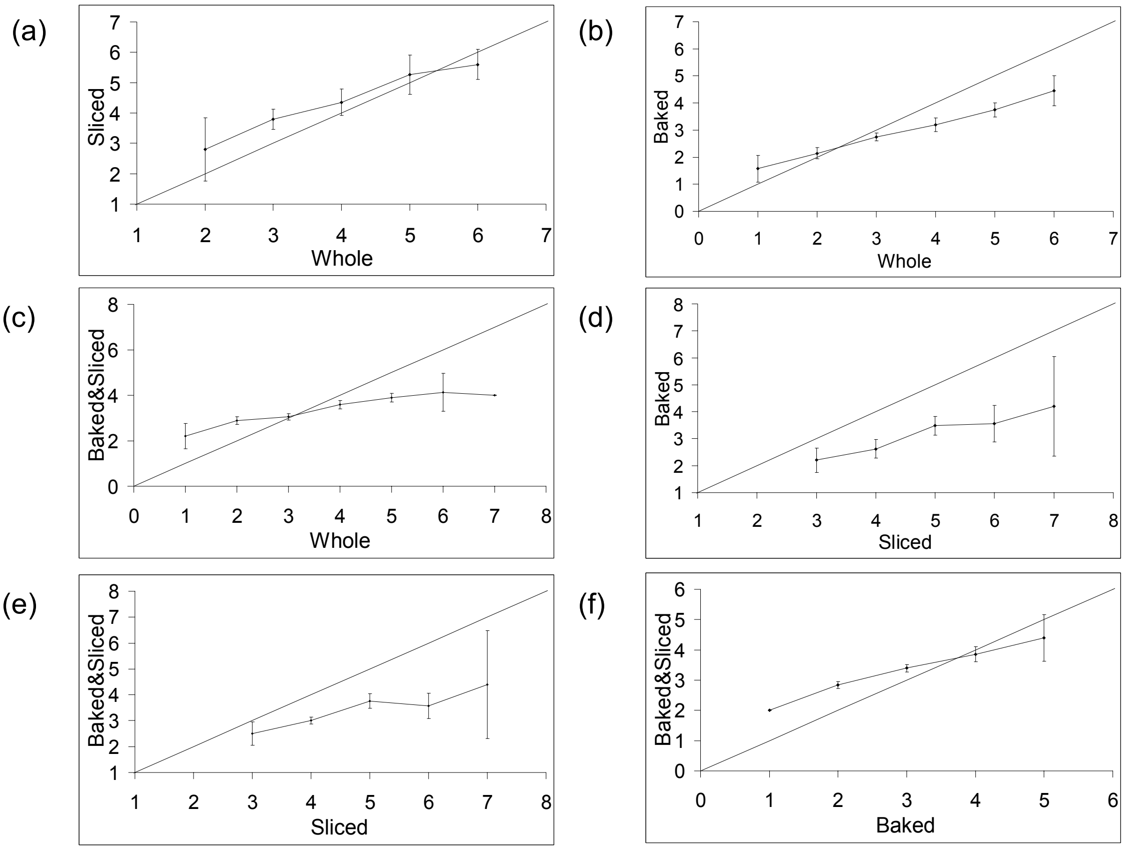


**Figure 4.4: Age bias plots for all paired OPTs. Error bars represent 95% CI around the average age assigned by one reader to an age class assigned by another reader. 1:1 equivalence line (solid line) is indicated. Note the different scales of both axes**

There was a significant difference between the medians of all OPT pairs (Wilcoxon two sample signed rank sum test)(Table 4.5). Percentage agreement, average CV, average APE and mean age difference for OPT pairs are presented in Table 4.6. The precision between OPT pairs were poor. The highest percentage agreement was found between whole unbaked vs. whole baked otoliths (46.05%) and the lowest between sliced unbaked vs. baked-and-sliced otoliths (9.24%). General trends observed using percentage agreement were confirmed using CV, with high average CV for the OPT pairs with low percentage agreement. OPT comparisons showed less variation in within OPTs than between OPTs (lower CV and APE), suggesting higher within than between precision of OPTs. Average APE were slightly lower than average CV for all OPT pairs, but still indicated low precision of comparative readings. A graphical representation of the trends between CV and percentage agreement were constructed by plotting the CV and percentage agreement of each age class for the OPT pairs (Figure 4.5). Agreement was generally low and CV high, especially for the older age classes.

**Table 4.5: Results of statistical analysis for inter-OPT bias. W = Whole otoliths; S = Sliced otoliths; B = Whole-Baked otoliths; and B-S = Baked and Sliced otoliths**

| Statistic | W:S (n=76) | W:B (n=215) | W:B-S (n=156) | S:B (n=75) | S:B-S (n=65) | B:B-S (n=174) |
|---|---|---|---|---|---|---|
| **Simple Regression Analysis** | | | | | | |
| Slope | 0.73 (±0.17) | 0.60 (±0.08) | 0.60 (±0.08) | 0.58 (±0.15) | 0.42 (±0.15) | 0.72 (±0.08) |
| P | 4.15E-13 | 2.26E-36 | 7.00E-31 | 5.72E-11 | 1.92E-07 | 1.66E-38 |
| Intercept | 1.49 (±0.72) | 0.87 (±0.29) | 1.23 (±0.33) | 0.40 (±0.75) | 1.38 (±0.7) | 1.24 (±0.27) |
| P | 7.96E-05 | 1.73E-08 | 6.69E-12 | 0.29 | 0.00019 | 1.71E-16 |
| **One Sample Sign Test** | | | | | | |
| Positive ranks | 12 | 98 | 60 | 66 | 59 | 17 |
| Negative ranks | 32 | 18 | 31 | 1 | 0 | 86 |
| Ties | 32 | 99 | 65 | 8 | 6 | 71 |
| P | 0.0026 | 0 | 0.0024 | 0 | 0 | 0 |
| **Wilcoxon Two Sample Signed Rank Sum test** | | | | | | |
| P | 0.0012 | 0 | 0.0008 | 0 | 0 | 0 |

Slicing of otoliths helped reduce CV and APE when compared to whole otoliths, though differences were not significant. There were, however, greater differences in the percentage of otoliths rejected, with whole otoliths having a higher percentage of rejected otoliths. Slicing therefore helped to make rings clearer, aiding in identification of rings. Baking of otliths only produced significant results when baked otoliths were subsequently sliced, providing the lowest CV, APE and percentage of otoliths rejected.

**Table 4.6: Pairwise comparison of age estimates to determine precision of OPTs. W = Whole otoliths; S = Sliced otoliths; B = Whole-Baked otoliths; and B-S = Baked and Sliced otoliths**

| | Ageing Method | | | | | |
|---|---|---|---|---|---|---|
| | **W:S** | **W:B** | **W:B-S** | **S:B** | **S:B-S** | **B:B-S** |
| **% Agreement** | 42.11 | 46.05 | 41.67 | 10.67 | 9.239 | 40.80 |
| **Mean Age Difference** | 0.72 | 0.71 | 0.70 | 1.67 | 1.342 | 0.60 |
| **CV** | 12.14 | 15.63 | 14.28 | 30.97 | 23.10 | 14.50 |
| **APE** | 8.59 | 11.05 | 10.10 | 21.90 | 16.33 | 10.25 |
| **n** | 76 | 215 | 156 | 75 | 65 | 174 |

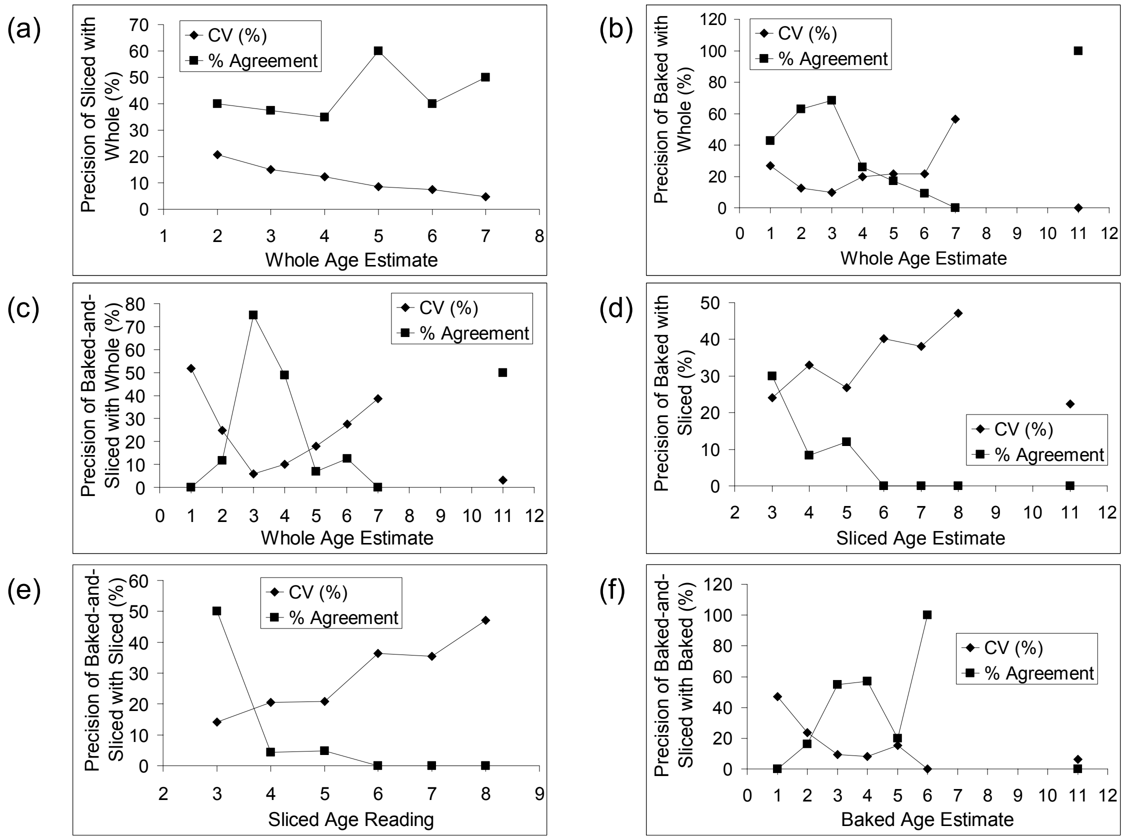


**Figure 4.5: Percentage agreement and CV at age for all paired OPTs. Scales of the axes differ between comparisons**

## 4.4. DISCUSSION

Studies comparing OPTs are generally used to determine the reproducibility of age estimates by the reader and to determine whether systematic differences exist between the different age readers or, in this case, OPTs (Campana *et al*. 1995, Power *et al*. 2006). The inexperience of the reader was evident in the higher CV obtained in this study (Table 4.4) compared to a precision and bias analysis performed by a more experienced reader (CV = 0.69%) based on a similar but larger data set (Laquar Consultants 2006). CV of inexperienced readers tend to be high and decrease as the reader gains experience (Walsh & Burnett 2002), therefore this result was not unexpected.

Within OPT bias was found for all OPTs; with sliced unbaked otoliths having the largest deviations from zero for the mean residuals (Figure 4.2). Deviations were as a result of either underestimating or overestimating consecutive age readings (Fairhurst 2005) and could be as a result of different interpretation of first annulus formation, due to different interpretations of the general annuli (Campana 2001) or due to the stacking effect at the edge of otoliths from older fish (Radabe *et al*. 2002) which leads to the underestimation of age of older fish (Brouwer & Griffiths 2004).

Within OPT precision was higher for baked than unbaked otoliths. Baked-and-sliced otoliths had the greatest precision with the lowest CV (9.04%); followed by whole baked otoliths (CV = 17.70%), sliced unbaked otoliths (CV = 18.88%) and whole unbaked otoliths (CV = 19.58%). Attwood *et al*. (2010) obtained age estimates from sliced unbaked otoliths for the same population, with a CV of 11.8%. Differences in the CV between the two studies are attributed to the difference in experience of the readers. The higher precision of the baked otoliths could be an artefact of the order in which otoliths were read, as the OPT with the highest CV was read first and the OPT with the lowest last. Greater precision could be as a result of increased experience and familiarity with identification of annuli in the later samples by the reader, though the difference between baked-and-sliced otoliths and the other OPTs are great enough to infer that this could not be the only causal factor.

Average CV and APE for this study (9.04-19.58% and 6.88-14.60% respectively) were generally higher than for the seabreams *Polysteganus undulosus, Spondyliosoma emarginatum, Pargus auriga* and *Rhabdosargus sarba* (ranging from 5.6-15.32% for CV and 4%-18.23% for APE) (Chale-Matsau *et al*. 2001, Radabe *et al*. 2002, Fairhurst 2005, Pajuelo *et al*. 2006).

Baked-and-sliced otoliths showed the highest precision among the OPTs compared. Baked otoliths generally showed lower CV than unbaked otoliths and sliced otoliths generally produced better results than whole otoliths. Baking otoliths before slicing was found to be the optimal OPT, increasing precision by 7-9% for APE and 7-11% for CV when compared to whole unbaked, sliced unbaked and whole-baked otoliths.

The age bias plot comparing sliced unbaked otoliths to whole baked otoliths showed that baked otoliths consistently underestimated ages when compared to sliced otoliths. Linear underestimation of age was therefore evident (Power *et al*. 2006) for this data set, accounting for the intercept close to zero as obtained by regression analysis, and the significant differences between OPT pairs (α = 0.05) obtained from a one sample sign test.

Ages were under- or overestimated by approximately one year for most age classes, suggesting different interpretation of the point of first annulus formation for different age counts and OPTs. Otoliths of *R. globiceps* have an opaque core (Tabot 1955, Griffiths *et al*. 2002), which is interpreted as a juvenile ring and not included in all ageing studies (Griffiths *et al*. 2002, Attwood *et al*. 2010). The juvenile ring was included in this study. Differing interpretation of the core in the present study could account for the differences in age estimates within and between OPTs. More rigid criteria for interpretation of the first annulus are suggested to improve within and between OPT precision. The above is suggested because *R. globiceps* have a protracted spawning period extending from October to February (Attwood *et al*. 2010), thus first increment formation can occur from mid spring to the end of summer resulting in differences in width of the first annulus. Differences in age estimates were higher for older age classes, and lower for younger age classes; with highest agreement at the 3-year age class. Large differences between age estimates of older age classes was accredited to the stacking effect at the edge of otoliths of older fish (Talbot 1955, Radabe *et al*. 2002), making counting of annuli difficult. Age counts based on baked otoliths underestimated the age of older fish when compared to unbaked otoliths for whole and sliced otoliths, though age estimates obtained reading baked otoliths were more consistent. Precision could be increased by increasing the sample size.

Percentage agreement between OPTs were found to be very poor, with the highest percentage agreement of 46.05% found between whole and unsliced baked otoliths (Figure 4.5). Average CV and APE were generally higher than within OPT comparisons (12.14-30.97% for CV and 8.58- 21.90% for APE), a general trend observed when comparing within to between OPT (or reader) precision (Walsh & Burnett 2002). This may suggests that different criteria were used to interpret the first annulus and/or it suggests that age of older fish were underestimated by one of the OPTs.

## 4.5 CONCLUSIONS

Significant bias was evident for both within OPT and between OPT analysis. Bias was mainly attributed to different criteria set for interpretation of first annulus formation for age counts and OPTs. A review of criteria used is suggested. Precision was generally low for all within OPT and between OPT analysis, with the most precise results obtained from baked-and-sliced otoliths. Whole unbaked and sliced unbaked otoliths showed the highest agreement of age estimates, suggesting that annulus interpretation was similar for the two OPTs. Whole baked and baked-and-sliced had the lowest CV and thus the highest reproducibility, suggesting that the two OPTs had the most consistent interpretation criteria. Baked otoliths generally had higher reproducibility. Very old and very young fish showed low agreement when comparing OPTs, with highest agreement for fish assigned to age class three. Slicing generally helped with distinguishing rings, and baked-and-sliced otoliths produced the best result, increasing reproducibility of results and making rings more distinguishable.

# CHAPTER 5

# A BRIEF REVIEW OF STOCK ASSESSMENT METHODS THAT COULD BE APPLIED TO *RHABDOSARGUS GLOBICEPS* IN SALDANHA BAY

This chapter serves as an introduction to the various stock assessment methods considered for modeling the *R. globiceps* population and outlines methods that could be applied. The various methods are listed and a brief summary of each is provided. The applicability and limitations of each method (or group of methods) to the current data set is discussed.

The types of assessments that can be performed are limited by the amount and type of data available. The discussion of these models is divided into (1) ways to estimate the natural mortality coefficient (*M*) and (2) the models that can be applied to catch data (i.e. population analysis studies).

## 5.1 NATURAL MORTALITY (*M*)

One of the most important biological parameters to be estimated in fisheries science is *M*. Although the importance of *M* is without question, most, (perhaps all) procedures used to estimate *M* are no more than informed guesswork and the assumptions inherit to each of these methods should be tested before any management decisions are made based on the results (Sparre & Venema 1998).

The two most commonly applied approaches to estimating *M* are (1) Correlation of life history and environmental parameters to *M* and (2) fitting of age-structure models to catch data, which may include mark-recapture experiments (Kolding & Giordano 2002).

### *5.1.1 M* AND LIFE HISTORY PARAMETERS

One of the life history parameters found to be related to *M* is the von Bertalanffy growth parameter *K*. As *K* is used to simulate rate of growth of an individual, species with low *K* values (i.e. a slow-growing species) should have low *M* as slow-growing species with a high *M* would soon become extinct because more fish would die than grow old enough to reproduce (Sparre & Venema 1998). This concept was demonstrated by Rikhter & Efanov (1976) who correlated high *M* with early maturity and early reproduction to compensate for the lower rate of survival. Confirmation of this concept was later given by Gunderson (1980) and Gunderson & Dygert (1988) who showed that a relationship exists between *M* and the gonado-somatic index (GSI), which stands to reason as fish with higher *M* may compensate by producing more eggs. Beverton & Holt (1959) found that values for the ratio *M/K* generally lie between 1.5 and 2.5.

Another of the von Bertalanffy growth parameters found to be related to *M* is the maximum predicted size an individual can obtain ($L_\infty$) or, alternatively the maximum weight of the species ($W_\infty$) as larger fish have fewer predators than smaller ones, and thus have a lower *M* (Sparre & Venema 1998).

The von Bertalanffy growth parameter *K* has been shown to be related to the longevity of a fish and longevity to be related to mortality (Sparre & Venema 1998). Hoenig (1983) found that *M* was correlated to the maximum age of a fish ($t_{max}$), which can be calculated by ageing several of the largest fish of a species. In Hoenig's (1983) model, *M* was calculated using the model:

$$\ln(M) = 1.46 - 1.01 \times \ln(t_{\max}) \tag{5.1}$$

By calculating the age at which 99% of a cohort had died, Alagaraja (1984) showed that, for an unexploited stock, *M* could be calculated using the equation:

$$M_{1\%} = \frac{-\ln(0.01)}{T_m} \tag{5.2}$$

where $M_{1\%}$ is the natural mortality corresponding to a 1% survival and $T_m$ is the longevity of a fish (i.e. the age at which 99% of a cohort had died).

Pauly (1980) made a multiple regression analysis of $M$ on a sample of 175 species and found that $M$ is most closely related to a combination of $K$, $L_\infty$ and the mean annual temperature $T$ (°C). The formula obtained indicated that smaller fish have high $M$; fast growing species have high $M$; and the warmer the mean annual temperature, the higher the $M$. The formula does imply that any other factor than the above-mentioned three are considered random noise, thus care should be taken when using the formula as factors such as fish behaviour (schooling, pelagic/demersal), the reproduction physiology and the natural environment of the fish (e.g. predator abundance) could prove to be influential to the $M$, but are not considered (Sparre & Venema 1998).

### 5.1.2 *M* AND CATCH DATA ANALYSIS

To estimate $M$ from catch data, estimates of total mortality ($Z$) over a range of fishing effort ($E$) need to be taken (Kolding & Giordano 2002). Paloheimo (1961) showed the relationship between $Z$ and $E$ with the following equations:

$$Z = M + F \tag{5.3}$$

where $F$ is the fishing mortality; and

$$F = qE \tag{5.4}$$

where $q$ is the catchability coefficient. Substituting (5.4) into (5.3) and rearranging we get

$$Z = qE + M \tag{5.5}$$

Thus a linear relationship is obtained with $q$ as the slope and $M$ the y-intercept when $E$ is regressed against $Z$.

Catch data were only available for a relatively short period (2006-2008), therefore the use of catch data analysis to determine $M$ was not applied as there was insufficient contrast in $E$ for applying (5.5). Estimates for the variables $L_\infty$ and $K$ were available for the population from Attwood *et al*.'s (2010) study and temperature data were known (MCM – unpublished data), therefore Pauly's equation was considered the most appropriate method to estimate *M* for the population.

## 5.2. POPULATION ANALYSIS

After an estimate of *M* has been obtained, a population analysis can be perfomed. Several methods are available for population analysis and can be generally described as either (1) models based on 'historic' catch data or (2) predictive models (Sparre & Venema 1998).

### 5.2.1 'HISTORIC' CATCH DATA MODELS

'Historic' catch data models use catch data collected over a period of time (usually several years) to simulate the effects a fishery has on a particular year class of a stock (Sparre & Venema 1998). The most widely applied of these methods are Virtual Population Analysis (VPA) and Pope's (1972) cohort analysis, a modified VPA (see, amongst others, Pope & Sheperd 1982, Aksland 1994, Mertz & Myers 1995, Xiao & Wang 2007).

VPA is used to estimate cohort strength and *F* by using a time series of catch-at-age data. By estimating cohort strength, recruitment into the fishery can be calculated by comparing the recruitment into different age classes over several years. In a recreational fishery total catch or a catch-curve that compares catch in numbers to corresponding age groups are used to estimate cohort strength. The idea behind a VPA is to analyze catch as a proxy for cohort strength or population size, as catch can be determined by methods such as roving creel surveys and can be used to calculate the population size needed at the beginning of a given year ($t_1$) to produce the catch obtained in that year (Butterworth *et al*. 1989, Sparre & Venema 1998). The population size for each year in a cohort is calculated using the above-mentioned method starting from the last age group and working backwards towards the first age group as each new $t_1$ that is calculated is used as the end population size of the previous age group $t_2$.

Two requirements for the successful application of a VPA are total catch in numbers by age and by cohort and estimates of natural mortality by age (Kolding & Giordano 2002). Also, the assumption that the recruiting cohort (size of population at beginning of analysis) must have been greater than the total catch taken from that cohort and, in the absence of fishing, a cohort declines exponentially with time due to natural mortality, must be met (Butterworth *et al*. 1989).

When a cohort has been followed for its entire life, the catch of each year for the cohort is then placed in an age-time matrix. The natural mortality is then estimated and an initial guess of the fishing mortality for the end group (i.e. last age group of the cohort) is made and can then be used to determine the number of fish there would have to have been at the beginning of that year to account for the catch for that year by using the Baranov catch equation (Sparre & Venema 1998):

$$C_{y,a} = \frac{F_{y,a}}{F_{y,a} + M}(N_{y,a} - N_{y+1,a+1}) \tag{5.6}$$

where: $C_{y,a}$ is the catch in year $y$ and with age $a$; $N_{y,a}$ is the initial number of survivors in year $y$ and with age $a$; $F_{y,a}$ is the fishing mortality in year $y$ and with age $a$; and $N_{y+1,a+1}$ is the number of survivors at the end of year $y$ with age $a$ (Kolding & Giordano 2002).

After the initial year class numbers ($N_{y,a}$) are estimated from the catch curve for the terminal group, $F_{y,a}$ is calculated from:

$$F_{y,a} = \ln(\frac{N_{y,a}}{N_{y+1,a+1}}) - M \tag{5.7}$$

The process is then repeated for the $y-1,a-1$ group using $N_{y,a}$ as an estimate of the number of survivors at the end of year $y-1$, and repeated again until the first age group of the cohort is reached (e.g. the number of survivors at the beginning of 2009 would be used as the number of survivors at the end of 2008).

If total landings for the species or population in question are unavailable the VPA can still be performed provided that (within reason) the ratio of fishing effort for the collected data to total fishing effort remained constant over the period considered. Care should, however, be taken when extrapolating the data to provide absolute recruitment and biomass estimates as the results can only be considered correct for relative year-to-year recruitment and biomass levels (Butterworth *et al*. 1989).

A VPA therefore provides a historic perspective of the population in question, which is then used to predict future behavior of the stock based on its history using predictive models.

Commonly used modifications of VPA include the previously mentioned Pope's (1972) cohort analysis (5.8), a modification of the VPA which assumes that all fish are born on the 1st of January and fishing occurs simultaneously in the middle of the year (i.e. pulse-fishing) with only natural mortality being active throughout the year (Kolding & Giordano 2002):

$$N_{y,a} = N_{y+1,a+1} \times e^{M} + C_{y,a} \times e^{\frac{M}{2}} \tag{5.8}$$

and; MacCall's (1986) slightly more accurate version (5.9) (Butterworth *et al*. 1989):

$$N_{y,a} = N_{y+1,a+1} \times e^{M} + \frac{C_{y,a} \times (1 - e^{-M})}{M} \tag{5.9}$$

Other modifications and applications of VPA include, amongst others, Pope & Shepard's (1982) modification of VPA which simultaneously predict population size and fishing mortality parameters in multiple cohorts, Jones' (1984) catch-at-length VPA which uses length composition data as opposed to the age based approach followed by most VPA's (with the underlying assumption that growth follows the von Bertalanffy growth curve) and Ueda *et al.*'s (2001) weight-based population analysis.

Although VPA provides estimates of population size and fishing mortality of the population, it is subject to a severely restraining criterion as data for all age groups need to be collected for as many years as there are age groups. This delays any useful assessment that may be made about the stock by several years which could prove to be fatal to the management of the stock. The population might have been driven over a threshold which could result in extinction of the population or could drive the population into a predator pit (Sparre & Venema

1998) before any useful insights about the population can be made. Also, the cost involved in collecting the necessary catch data could prove to be prohibitively expensive and if the survey is not properly planned (Lester *et al*. 1991), all fishing areas may not be covered which could result in inaccurate conclusions being drawn from the collected data (Dent & Wagner 1991).

VPA was therefore not used to predict population size of *R. globiceps* in Saldanha Bay as the number of years sampled is less than the estimated lifespan of *R. globiceps*. *R. globiceps* has a lifespan of approximately 21 years (Griffiths *et al*. 2002), therefore the use of VPA to determine the population size of *R. globiceps* in Saldanha Bay will only be feasible if data are collected on a continuous basis for an equivalent period.

As data are not always readily available over long periods for many species, other models have been adopted that do not require such intensive sampling. These models ignore the size and age structure of the stock and consider the stock as the basic unit as opposed to VPA which consider the individual as the basic unit (Kolding & Giordano 2002, Cadima 2003). These models, often termed surplus production models, deals with the entire stock, total fishing effort and total yield obtained for the stock while ignoring the effects of growth, mortality, gear selectivity, age of fish, etc. (Butterworth *et al*. 1989, Sparre & Venema 1998).

Surplus Production Models provide a mathematical formulation of the net growth rate of a population as a function of its biomass (Butterworth *et al*. 1989) and is used to determine optimal levels of effort that result in sustainable use of the resource (Sparre & Venema 1998). The models are limited to only being able to analyze the effects of fishing level changes on the stock and not changes in the exploitation pattern because the age/size structure of the stock is ignored (Cadima 2003).

To apply a surplus production model the following assumptions are made: (a) an unexploited resource tends to increase towards toward the maximum biomass level that an environment can maintain, the carrying capacity (*k*), and is dependent on factors such as available space, feeding facilities, competition with other species, etc.; (b) the rate at which the resource increases is zero when the biomass is zero, small when the biomass is small, increases when the biomass increases, becomes less when the population reaches *k*, and is zero at *k* (although the growth rate is not positive for the entire interval (*0,k*) the overall tendency is an increase towards *k* following a sigmoid curve) (5.10); and (c) the specific growth rate of the biomass is a function of the biomass.

$$\frac{dB}{dt} = G(B) \tag{5.10}$$

where *B* is the biomass, *t* is time and *G(B)* is the general change in biomass (Kolding & Giordano 2002).

These assumptions were formulated from the following postulates (from Sparre & Venema 1998) and are considered to act on a population in a 'steady state' or equilibrium conditions (i.e. the fishing pattern has been the same for such a long period that all fish have been exposed to fishing since they recruited). (1) When the biomass of a stock approaches *k*, efficiency of reproduction is reduced and often the number of recruits produced is less than at smaller densities, thus a reduction in stock would result in an increase in recruitment. (2) When food supply is limited, food is less likely to be used for individual growth in larger stocks than smaller ones as more food per individual would be used to sustain vital functions and less for growth in larger stocks. (3) An unfished stock tends to contain more older individuals than a fished stock which results in decreased production as larger fish tend to eat larger foods. This results in an extra step in the food chain of that individual and therefore the efficiency of utilization of energy derived from the food by that individual is reduced. Also, older fish convert a smaller fraction of food to physical growth as compared to egg production.

The three most commonly used models that describe the change in biomass are the Schaefer (1954) Model which assumes that the specific rate of biomass growth is linearly related to the stock biomass (5.11), the Fox (1970) Model which assumes that the specific rate of biomass growth is linearly related to the natural logarithm of the stock biomass (5.12) and the Pella and Tomlinson (1969) Model, also known as GENPROD after the statistical software the authors created to implement their model which assumes that the specific rate of biomass growth is linearly related to the stock biomass raised to the power *p* (5.13).

$$\frac{dB}{dt} = rB(1 - \frac{B}{k}) - C \qquad (5.11)$$

$$\frac{dB}{dt} = rB(1 - \frac{\ln B}{\ln k}) \qquad (5.12)$$

$$\frac{dB}{dt} = rB(1 - \frac{B^{p-1}}{k^{p-1}}) \qquad (5.13)$$

where $r$ is the intrinsic rate of population growth and $C$ is the catch rate.

These models are used to provide Biological Target Reference Points (TRPs) such as the Maximum Sustainable Yield (MSY), the Biomass for MSY ($B_{MSY}$), the fishing mortality rate for MSY ($F_{MSY}$), the Catch Per Unit Effort (CPUE) for MSY ($U_{MSY}$), the fishing effort for MSY ($f_{MSY}$) and the level at which fishing mortality reduces the Biomass to 10% of its pristine level ($F_{0.1}$) (Butterworth *et al*. 1989).

These models were not applied to *R. globiceps* because the time series of CPUE and catch are too short (4 years) compared to the maximum age (21 years).

### 5.2.2 PREDICTIVE MODELS

Predictive models deal with the prediction of future exploitation of a stock and the effects of various levels of exploitation on that stock. These models transform the formulas used for VPA and cohort analysis in such a way that knowledge of past stock behavior can be used to predict future stock yields and biomass at varying fishing effort and as such provide a direct link between stock assessment and resource management (Sparre & Venema 1998).

The two most widely applied predictive models are the Thomson and Bell (1934) model and Beverton and Holt's (1957) Yield per Recruit and Spawner Biomass per Recruit models (which now also includes Egg Production per Recruit models). The wide use of these two models, especially the latter due to the amount of data required for analysis, can be seen in the literature (Jensen 1996, Booth & Buxton 1997, Griffiths 1997, Sparre & Venema 1998, Kirchner 2001, Brouwer & Griffiths 2006, Govender *et al*. 2006) and some have even incorporated the models into software packages such as PC-YIELD II (Punt 1992) designed to provide outputs based on the Beverton and Holt model such as Yield per Recruit, Spawner Biomass per Recruit and Egg Production per Recruit, amongst others.

The Thompson and Bell (1934) Model predicts the effects of changes in the fishing effort on future yields and consists of two main stages: (1) the provision of essential and optional inputs and (2) the calculation of outputs such as preditions of future biomass levels and yields (Sparre & Venema 1998).

The main input for the model is the so-called ‘reference *F*-at-age-array’, an array of *F*-values for each age group. The *F*-array, along with many other inputs for the model are obtained from analysis of historic data, mainly VPA analysis. The other inputs include the number of recruits, though this is optional as the model can express, for example, yield per 1000 recruits as opposed to absolute values and a ‘weight-at-age-array’, the weight of individual fish for each age group (Sparre & Venema 1998).

Outputs of the model include predictions, all per age group, of the catch in numbers, the total number of deaths, the yield, and the mean biomass. The *F* values that are used as the input can also be altered by a factor, say *X*, to simulate the effects of various management measures such as changing minimum size, changing the fishing effort on the stock or the effects of closed seasons, though the use of a computer is essential for the numerous calculations and the model has only gained favor in recent years as the processing power of computers has increased (Sparre & Venema 1998).

The Thompson and Bell (1934) model was not used for *R. globiceps* as outputs for a VPA were not available for this stock due to the limited data available.

The Beverton and Holt (1957) model can be considered a special application of the Thompson and Bell (1934) Model. The model describes the state of a stock and the yield obtained from the stock when it is in a ‘steady state’ (Sparre & Venema 1998).

The model has six underlying assumptions which are as follows: (1) recruitment is constant, yet not specified; (2) all fish of a cohort were born on the same day; (3) recruitment and selection are ‘knife edged’; (4) fishing and natural mortalities are constant from the moment of entry into the fishery; (5) mixing within the stock is complete; and (6) the length-weight relationship is defined as:

$$W = aL^b \tag{5.14}$$

where $W$ is the weight of the individual, $L$ is the length of an individual and $a$ and $b$ are constants.

Though not all assumptions hold true for *R. globiceps,* as the spawning period is protracted (Attwood *et al.* 2010) and fishing and natural mortality are not constant, the Beverton and Holt model was considered the most appropriate model given the data available.

Per-recruit models produce a quantitative assessment of the stock using a number of biological reference points which will help in assessing the effectiveness of current regulations regarding the stock (Govender 1995, Sparre & Venema 1998). These refrence points include, amongst others, $F_{\max}$ , the fishing mortality rate at which yield-per-recuit is maximized and $F_{0.1}$ , the fishing mortality rate that corresponds to a point on the catch curve where the slope is 10% of that of the origin (Gulland & Boerema 1973, Butterworth *et al*. 1989)). $F_{0.1}$ is considered the better of the two reference points as it produces the same yield as $F_{\max}$ without reducing the spawning biomass too severely (Sissenwine & Shepherd 1987). Other biological reference points useful in the management of stock are $SB_{20}$ and $SB_{35}$ which correspond to the spawning biomass of 25% and 40% of the unfished level (Griffiths *et al*. 1999). These reference points are considered to be important because a stock with a spawning biomass below $SB_{20}$ might result in recruitment failure (Govender *et al*. 2006) whereas a population with a spawning biomass equal to or greater than $SB_{35}$ will provide high yield with low risk even where little is known about the yield curve or the spawner-recruit relationship (Govender 1995).

The use of and outputs of the methods used to determine *M* and harvesting parameters and the application of per-recruit models are described in Chapter 6.

# CHAPTER 6

# PER-RECRUIT STOCK ASSESSMENT AND AN EVALUATION OF ALTERNATIVE MANAGEMENT SCENARIOS

## 6.1 INTRODUCTION

The population of *Rhabdosargus globiceps* in Saldanha Bay forms the basis of a local recreational and commercial fishery. Approximately 92 tons were landed in a one year period in 2006 and 2007 (Næsje *et al.* 2008). Telemetry and tagging data suggests that although the population is mobile, it does not leave the confines of Saldanha Bay, and it appears to be isolated from the nearest population in False Bay (Kerwath *et al*. 2009). Because of rapid development in the Saldanha Bay area and increasing recreational activity (including fishing) of the bay, there are concerns about the sustainability of the fishery for *R. globiceps* and other species (Attwood *et al*. 2010).

Recreational anglers are limited by output controls which include a bag limit and a minimum size limit (i.e. open access fishery), while commercial fishermen are limited by both input (permits) and output (size limit only) controls (i.e. closed-access fishery). There is currently no closed season imposed for the fishery (Marine Living Resources Act No. 18 of 1998) although the Marine Protected Area (MPA) in the southernmost part of Langebaan Lagoon, where no fishing is allowed, provides some protection for the population (Kerwath *et al*. 2009). The recreational fishery, which consists of more than 550 boats and several hundred shore anglers; account for approximately 59% of the *R. globiceps* catch (Næsje *et al.* 2008). The impact of both fishery sectors on the population of *R. globiceps* is unknown.

This chapter aims to provide estimates of mortality rates as well as per-recruit estimates of yield, spawner biomass and recruitment potential (measured as ovary mass) as a basis for management of the stock. The model results are used to suggest revisions to the regulation of the fishery where applicable.

## 6.2 METHODS

### 6.2.1 DATA SOURCES

Marine and Coastal Management (MCM) initiated a fisheries monitoring programme in Saldanha Bay in 2005. Three components of the fishery, namely shore angling, recreational boat angling and commercial fishing were monitored separately. Catch and effort were surveyed by an observer from 2006-2008. Shore-based fishing activities were monitored by roving creel surveys and boat-based fishing (which includes recreational boat and commercial fishing) were measured by access point surveys (see Phippen & Bergersen 1987, Dent & Wagner 1991, Pollock 1991, Sztramko 1991 for examples of similar studies). Fish that were inspected by the observer were identified, counted and measured to the nearest mm (TL). The size structure data emerging from these surveys were used in this chapter.

Biological parameters of the population were reported by Attwood *et al.* (2010). They produced a length-weight regression for the population; and an age-length key. Fish were aged by counting annual rings on otoliths and von Bertalanffy and Schnutte models were fitted to the age-at-length data. A summary of the above-mentioned parameters used in this study is presented in Table 6.1.

**Table 6.1: Parameters used in the per-recruit analysis**

| Parameter | Value | Source |
|---|---|---|
| $L_\infty$ (TL) (Schnutte) | 416.7 mm | Attwood *et al*. 2010 |
| K (Schnutte) | 0.138 $y^{-1}$ | Attwood *et al*. 2010 |
| $t_0$ (von Bertalanffy) | -2.0 y | Attwood *et al*. 2010 |
| a (length-weight) | $2.018 \times 10^{-5}$ | Attwood *et al*. 2010 |
| b (length-weight) | 3.011 | Attwood *et al*. 2010 |
| $a_0$ (ovary mass-fish mass) | -4.46 | Attwood *et al*. 2010 |
| $b_0$ (ovary mass-fish mass) | 1.22 | Attwood *et al*. 2010 |
| $t_{m50}$ (♀) | 2.26 y | Attwood *et al*. 2010 |

A slight but significant difference between the growth rates of male and female *R. globiceps* was found (Attwood *et al*. 2010); the females reaching a larger size. Unfortunately it was not possible for the observer to sex fish externally with high reliability and for this reason it was not possible to take advantage of sex-specific growth rates. For this reason, the combined sex growth rate was used in this analysis.

## 6.2.2 ESTIMATES OF FISH MORTALITY RATE

An age-length key was created by converting length frequencies to age frequencies using a normalised age-length key (Butterworth *et al*. 1989). The age-length key was created using a sample of 558 fish collected from September 2004-December 2006 from the boat based recreational fishery (Appendix 6.1).

Data were available for both boat- and shore based fishing for the years 2006, 2007 and 2008. The mean size of fish was compared among years and between shore- and boat-caught fish. The purpose of this comparison was to consider the feasibility of lumping data either between years or between survey types. Of particular concern was the possibility of a size-selectivity difference between shore and boat angling. Should such a difference exist it follows that estimates of mortality would depend on the data source. Differences in fish size between years and surveys (boat vs shore) were tested using a general linear model (GLM). If differences existed, the data sets (boat- and shore based fishing) would either be combined or if this was not feasible, the data set which most accurately described the population after it has fully recruited into the fishery would be used.

The annual relative instantaneous mortality rate (*Z*), was estimated by catch curve analysis (Ricker 1975), i.e. by plotting the frequency of catch vs. age. An exponential regression was fitted to the data after discarding the initial ages for which catch frequencies were below the highest age-specific catch. These early years represent fish which by virtue of their small size have not fully recruited into the fishery. A hook size effect was presumed to limit the catchability of small fish. The model equation was:

$$f_t = ae^{-Zt} \tag{6.1}$$

where $f_t$ is the frequency of fish of age $t$ (in years) in the catch and $a$ and $Z$ (mortality rate) are estimated parameters.

The model was fitted by least squares regression procedure, yielding a coefficient of determination ($r^2$) and a significance value. Confidence intervals on $Z$ were obtained using regression analysis on the t-test statistic (Zar 2010).

A one-tailed runs test was performed on the catch curve(s) to check for positive serial correlation of the residuals. This was done to determine whether the exponential model described the relationship approximately (Zar 2010). If the data failed the runs test (i.e. the residuals showed positive serial correlation), the model did not accurately describe the data and another model was fitted.

After estimating $Z$, the natural mortality ($M$) was calculated using Pauly's equation (Pauly 1980):

$$\log(M) = -0.0066 - 0.279 \times \log(L_\infty) + 0.6543 \times \log(K) + 0.4634 \times \log(T) \tag{6.2}$$

where $L_\infty$ and $K$ are the Schnutte estimates of the growth parameters for mean asymptotic total length (measured in cm) and growth rate respectively; and $T$ is the mean environmental temperature for the distribution range of the population measured in degrees Celsius (°C). The average temperature experienced in the channels in Saldanha Bay was used as an estimate of the mean environmental temperature. $L_\infty$ was converted from FL to TL using the linear equation:

$$TL = 1.1136(FL) - 0.2448 \qquad r^2 = 0.9922 \qquad n = 558 \tag{6.3}$$

obtained by plotting the FL vs TL of 558 fish (Figure 6.1).

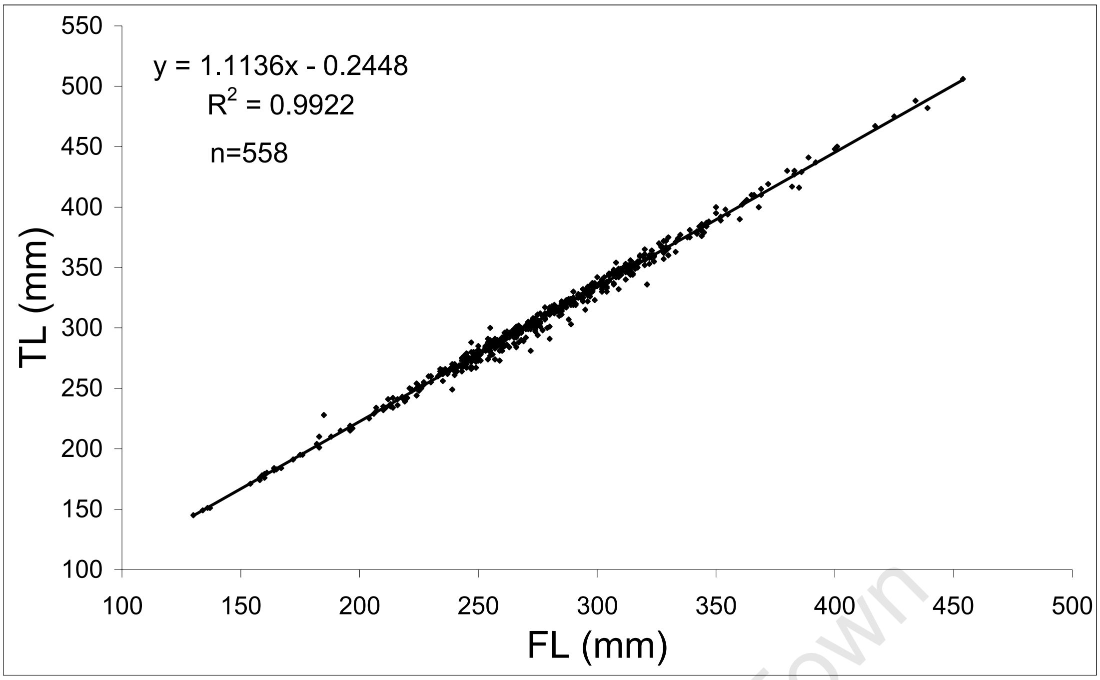


**Figure 6.1: FL-TL regression for *R. globiceps* in Saldanha Bay**

To account for errors associated with estimating *M* for exploited populations (Brouwer & Griffiths 2006) and the low precision of the *M*-estimate (Butterworth *et al*. 1989), the 95% confidence interval (CI) for the *M*-estimate was calculated. The upper and lower values obtained were used as alternative *M*-estimates in the per recruit analysis to determine the sensitivity of the results to alternative values. $\overline{M}$ ± 95% CI were calculated for Pauly's *M*-estimate using the equation:

$$M \pm 95\%CI = 10^{\log(M) \pm 1.96 \times sd} \qquad (6.4)$$

where *sd* = 0.245 is one standard deviation of log *M* when the asymptotic size (TL) is measured in cm (Pauly 1980). The 95% CI around Pauly's *M*-estimate were used as alternate *M*-estimates instead of the 'half and half' approach where $\overline{M} - 0.5\overline{M}$ and $\overline{M} + 0.5\overline{M}$ are used (e.g. Lapointe *et al*. 1989, Brouwer & Griffiths 2006) due the high variability in *M*-estimates obtained based on empirical equations as opposed to analysis of catch data (Götz *et al*. 2008).

A second estimate of *M* was obtained using the approach proposed by Hoenig (1983), where a general regression equation was used to relate the longevity of a species to *M*:

$$\ln(M) = 1.46 - 1.01 \times \ln(t_{\max}) \qquad (6.5)$$

where $t_{max}$ was set to 21 years (obtained from Griffiths *et al*. 2002). Only the Pauly estimate of *M* was used in subsequent analyses.

After obtaining estimates of *Z* and *M*, *F* was calculated using the equation:

$$F = Z - M \tag{6.6}$$

Standard error around *F* was calculated using the property of variances which states that the variance of the sum of two normally distributed variables is the sum of the variance of each of those variables plus twice the covariance (Zar 2010). Estimates of *Z* and *M* were assumed to be uncorrelated, and therefore the variance of *F* was calculated as the sum of the variance of *Z* and the variance of *M*.

### 6.2.3 PER-RECRUIT ANALYSIS

Maturity curves estimated by Attwood *et al.* (2010) were used to model the proportion of mature females in each age group and the proportion of fish that exceeded the size limit in each age group.

Yield-per-recruit (*Y/R*), spawner biomass-per-recruit (*SB/R*), ovary mass-per-recruit (*OM/R*) and other biological parameters were estimated for *F*-values ranging from 0-1 $y^{-1}$ with increments of 0.05, at $\overline{M}$ , $\overline{M} + 95\%CI$ and $\overline{M} - 95\%CI$ .

*Y/R*, and *SB/R* were determined using the following equations (Butterworth *et al*. 1989):

$$\frac{Y}{R} = FW_{\infty}e^{-Mt_c}\left[\frac{1}{(M+F)} - \frac{3e^{-K(t_c-t_0)}}{(M+F+K)} + \frac{3e^{-2K(t_c-t_0)}}{(M+F+2K)} - \frac{e^{-3K(t_c-t_0)}}{(M+F+3K)}\right] \tag{6.7}$$

where $W_\infty$ is the mean asymptotic weight of an individual; $t_c$ is the time at first capture; and $t_0$ is the theoretical age at which an individual has zero length. Estimates of *M* and *F* were assumed to be independent of age. $W_\infty$ was calculated using the equation:

$$W_{\infty} = a \times L_{\infty}^{b} \tag{6.8}$$

where *a* and *b* are the constants in the length-weight relationship (Attwood *et al*. 2010, Table 6.1);

$$\frac{SB}{R}=W_{\infty}e^{-Mt_m-F(t_m-t_c)}\left[\frac{1}{(M+F)}-\frac{3e^{-K(t_m-t_0)}}{(M+F+K)}+\frac{3e^{-2K(t_m-t_0)}}{(M+F+K)}-\frac{e^{-3K(t_m-t_0)}}{(M+F+3K)}\right]$$

($t_m \geq t_c$) (6.9)

where $t_m$ is the age at full recruitment.

*OM/R* was calculated following Brouwer & Griffiths (2006):

$$\frac{OM}{R}=\sum_{t=0}^{14}P_t\left(e^{-\sum FS_i+M}\right)O_t \qquad (6.10)$$

where $P_t$ is the proportion of mature females at age *t*; $S_i$ is the selectivity function associated with the minimum size *i*, calculated as the proportion of mature fish above the minimum size limit assuming knife-edge selectivity; and $O_t$ is the estimated individual fecundity of fish; measured as the ovary mass each fish produces at age *t*. The estimated annual fecundity of fish was divided by 2 because only females were used in estimation of ovary mass per recruit (adapted from Brouwer & Griffiths 2006).

$O_t$ was calculated using the ovarian mass-fish mass regression:

$$O_t = e^{a_0}\times m_t^{b_0} \qquad (6.11)$$

where: $a_0$ = -4.46 and $b_0$ = 1.22 are constant in the ovary mass-fish mass relationship and $m_t$ is the average fish mass (g) at age *t* (Attwood *et al*. 2010, Table 6.1).

Average fish mass per age class ($m_t$) was calculated using the weight-based von Bertalanffy growth equation (Sparre & Venema 1998):

$$m_t = w_{\infty}\times(1-e^{-K\times(t-t_0)})^3 \qquad (6.12)$$

Average mass of fish caught was calculated using:

$$\overline{m}=W_{\infty}\left[1-\frac{3e^{-K(t_c-t_0)}\times(M+F)}{(M+F+K)}+\frac{3e^{-2K(t_c-t_0)}\times(M+F)}{(M+F+2K)}-\frac{e^{-3K(t_c-t_0)}\times(M+F)}{(M+F+3K)}\right] \qquad (6.13)$$

(after Butterworth *et al*. 1989).

Per recruit models were constructed for minimum sizes ($L_c$) set to 210 mm, 250 mm (current) and 290 mm TL to determine the effects of increasing and decreasing the minimum size on per-recruit outputs. $L_c$ was converted to $t_c$ by re-arranging the von Bertalanffy growth equation:

$$t_c = \frac{\ln\left(1 - \frac{L_c}{L_\infty}\right)}{-K} + t_0 \qquad (6.14)$$

A 25% $SB/R_{F=0}$ and 40% $SB/R_{F=0}$ level was calculated for the population as these are considered the default target reference points for South African linefish because of their robustness to a wide range of life history strategies and spawner-recruit relationships (Mace 1994, Booth & Buxton 1997, Penney *et al*. 1997, Brouwer & Griffiths 2006). A 25% $OM/R_{F=0}$ and 40% $OM/R_{F=0}$ level was also calculated; as egg production is considered a more appropriate estimate of spawner potential than *SB/R* as it incorporates age-specific fecundity (Brouwer & Griffiths 2006). Ovarian mass was used as a proxy for egg production.

The effects of implementing various daily bag limits on F were modelled using the equation proposed by Attwood & Bennett (1995):

$$P_k = \begin{cases} \left(\sum_{i-1}^{10}\left(f_i \times \left(B - DBL_i\right)\right)\right) \times 100 & if \ldots B > DBL_i \\ 0 & if \ldots B \le DBL_i \end{cases} \qquad (6.15)$$

where $P_k$ is the percentage reduction achieved by implementing a DBL of *i*; $f_i$ is the relative frequency of the catch per unit effort (*CPUE*) values; *B* is the number of fish caught per angler per day; and $DBL_i$ is the proposed daily bag limit.

The modelling of the effects of implementing several bag limits was done to determine the reduction in catch that could be achieved. The reduction in catch achieved by implementing the various bag limits were compared to *SB/R* to determine the best management practice for the species.

# 6.3 RESULTS

## 6.3.1 ESTIMATES OF FISH MORTALITY RATE

The average and confidence interval of total length of landed *R. globiceps* for each of the three years and fishing sectors are listed in Table 6.2. The result of the GLM of these data showed that size of fish caught by shore anglers was consistently lower than the size of fish caught by boat anglers for all years (Figure 6.2). Differences in the size of fish caught between the three years surveyed and boat- and shore based fishing were statistically significant, though no interaction effects were evident (Table 6.3).

*R. globiceps* recruit in the surf zone (Clark 1997, Griffiths *et al*. 2002, Chapter 2) and move to deep channels as they grow older (Kerwath *et al.* 2009). As boat anglers have access to these deep channels, catch data collected from slipway surveys would more accurately represent the older age classes (which were used in the construction of the catch curve) than data based on shore angler catch, which would underestimate larger size classes as these fish become progressively less accessible to these anglers with age.

Combining the data sets would be preferred to maximise sample size, but the degree to which each data set represents the age-structure of the population was not known. It was unclear how these data should be weighted when combining. Bias existed in both the shore and boat angler data sets. The bias inherent in the boat angler data set underestimated the frequency of occurrence of younger fish whereas the bias in the shore angler data set underestimated the occurrence of older fish. Since the younger age groups were not used in catch curve analysis, the boat angler data set was considered optimal and the shore angler data set was discarded. The boat angling data were therefore used in isolation, as the best available reflection of the age structure of the post-recruit fish.

**Table 6.2: GLM showing unweighted mean length (TL) of fish for roving creel and slipway surveys for 2006, 2007 and 2008. F (2, 7622) = 0.957, p = 0.384**

| Year | Survey Type | TL mean | TL Std. Error | TL –95% CI | TL +95% CI | n |
|---|---|---|---|---|---|---|
| 2006 | Roving Creel | 31.10 | 0.26 | 30.60 | 31.60 | 988 |
| 2006 | Slipway | 34.69 | 0.16 | 34.38 | 35.00 | 2517 |
| 2007 | Roving Creel | 29.56 | 0.37 | 28.84 | 30.29 | 474 |
| 2007 | Slipway | 33.86 | 0.18 | 33.50 | 34.22 | 1924 |
| 2008 | Roving Creel | 29.84 | 0.36 | 29.14 | 30.54 | 505 |
| 2008 | Slipway | 33.77 | 0.23 | 33.32 | 34.22 | 1220 |

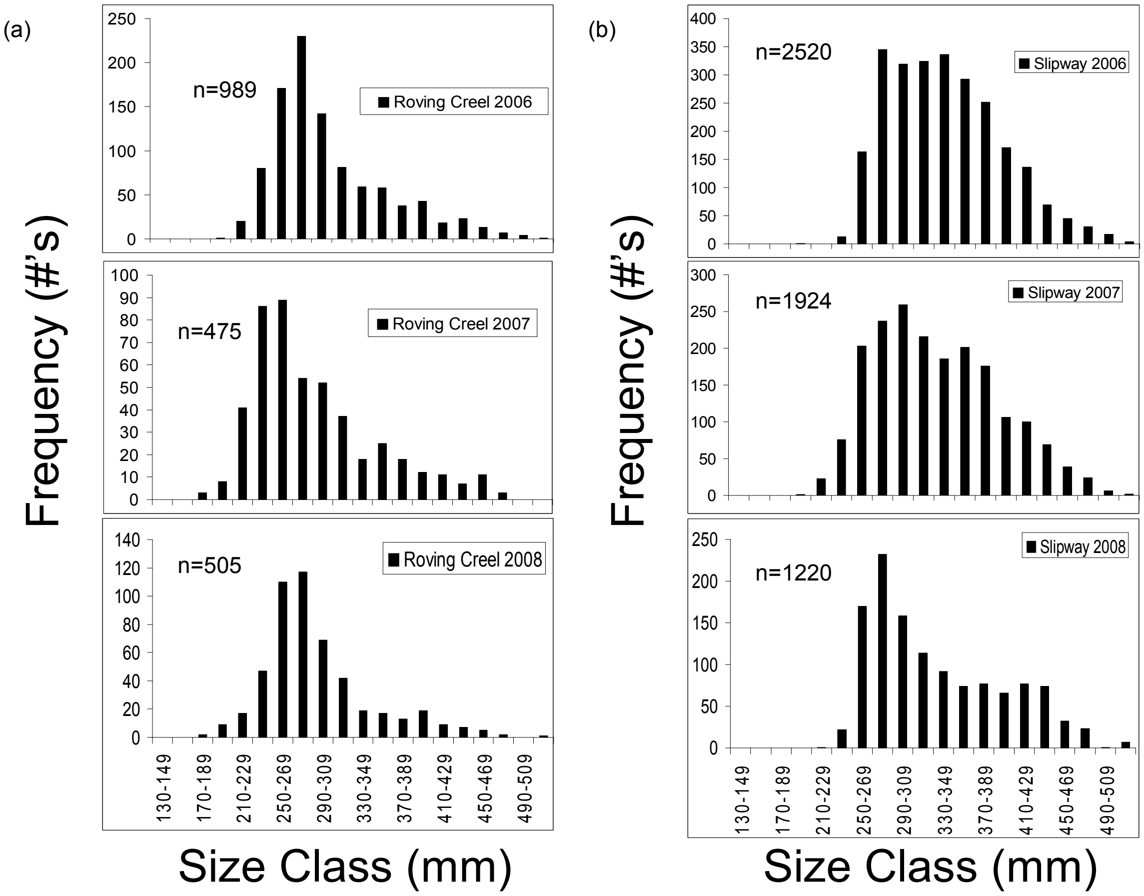


**Figure 6.2: Size distribution of *R. globiceps* for (a) shore and (b) boat angler data for the period 2006-2008**

**Table 6.3: Differences in size of *R. globiceps* caught between years and survey types for the period 2006-2008, where SS and MS represents the sum of squares and mean square of the length frequency data respectively**

| Effect | Degrees of Freedom | TL SS | TL MS | TL F | TL p |
|---|---|---|---|---|---|
| **Intercept** | 1 | 5436584 | 5436584 | 84002.55 | 0.000000 |
| **Year** | 2 | 1879 | 940 | 14.52 | 0.000001 |
| **Survey Type** | 1 | 20436 | 20436 | 315.76 | 0.000000 |
| **Year X Survey Type** | 2 | 124 | 62 | 0.96 | 0.38 |
| **Error** | 7622 | 493290 | 65 | | |
| **Total** | 7627 | 516469 | | | |

An exponential equation was fitted to the data points above and including the highest age-specific catch (Figure 6.3). Annual *Z*-estimates increased from 2006-2008, and the combined estimate was 0.40 $y^{-1}$ (Figure 6.4). The interannual differences were insignificant, and the overall estimate ranged between lower and upper 95% confidence intervals of 0.25 and 0.54 $y^{-1}$. The coefficient of variation (*cv*) of the Z-estimate was 0.166.

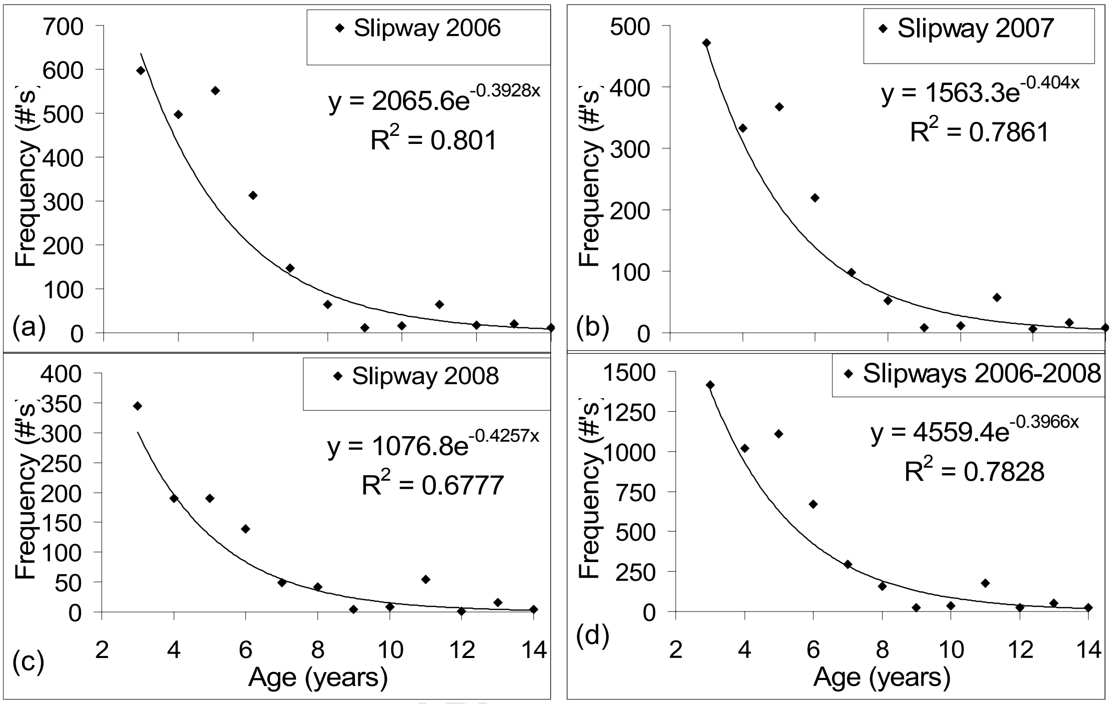


**Figure 6.3: Catch-at-age estimates for *R. globiceps* caught from the recreational and commercial boat-based fisheries sectors in Saldanha Bay for the period 2006-2008.**

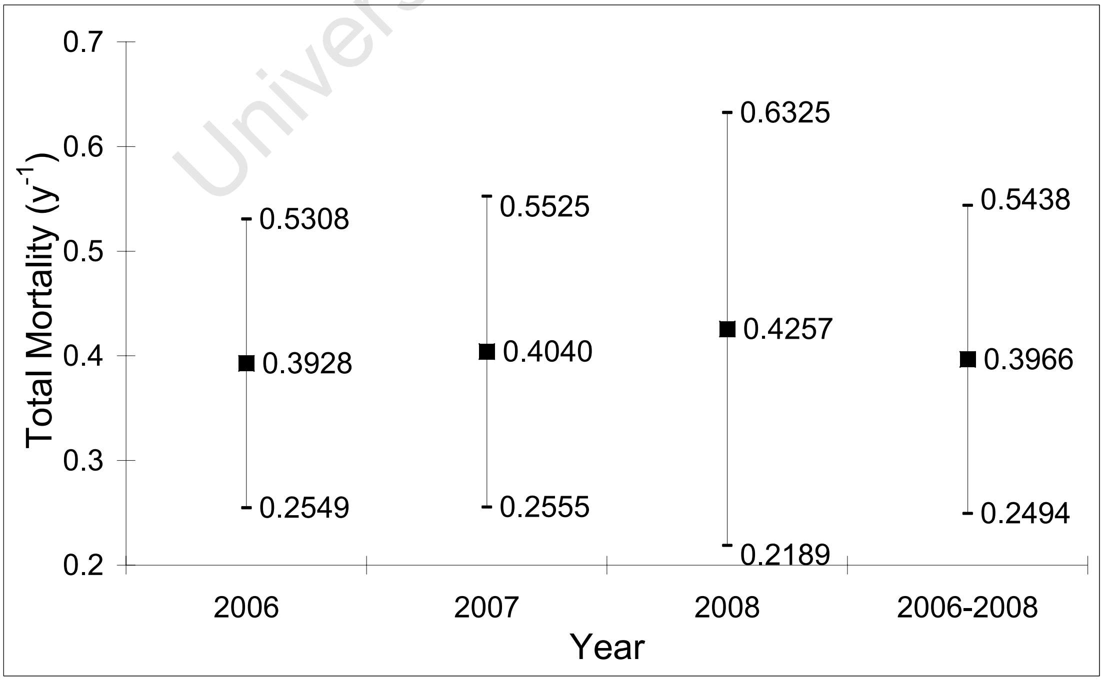


**Figure 6.4: Total mortality estimates based on Pauly's equation obtained from catch curve analysis with 95% confidence intervals for *R. globiceps* in Saldanha Bay based on slipway survey data**

A one-tailed runs test fitted to each data set showed no significant serial positive correlation for any of the years, nor the combined data (Table 6.4).

**Table 6.4: Results of a one-tailed runs test on slipway surveys for positive serial correlation at the α=0.05 level. No serial correlation was found**

| Year | + correlation |
|---|---|
| 2006 | 0.424 |
| 2007 | 0.279 |
| 2008 | 0.955 |
| 2006-2008 | 0.279 |

Temperatures measured in Saldanha Bay in channels frequented by *R. globiceps* obtained from MCM (unpublished data) ranged from 10.7-25.9°C. For the Pauly model, a point estimate of 16.5°C, equal to the average temperature in the data set, was used.

$\overline{M}$ was calculated as 0.178 $y^{-1}$ using equation (6.2). The standard deviation of log (*M*) was 0.245 $y^{-1}$ (from Pauly 1980), giving a *cv* of 0.47. The 95% confidence limits (1.96 standard deviations/errors either side of the mean) on $\overline{M}$ were calculated as 0.059 and 0.54 $y^{-1}$. The large confidence interval was attributed to the variability inherent in determining *M* from Pauly's empirical equation (Götz *et al*. 2008), which used a sample of 175 fish stocks, none of which fall in the family Sparidae, to relate the parameters $L_\infty$, *K* and *T* to *M*. The sensitivity of the *M*-estimate to temperature was evaluated by changing the temperature used in Pauly's equation to several values that fall within the range of temperatures recorded in Saldanha Bay (Figure 6.5).

Hoenig's equation provided an *M-estimate* of 0.199 $y^{-1}$, a result very similar to that provided by Pauly's equation. The two *M*-estimates were not averaged because 95% CI could not be calculated for the *M*-estimate based on Hoenig's equation because sample size is not taken into consideration (Hoenig 1983).

An *F*-estimate of 0.232 $y^{-1}$ was obtained using equation (6.6) and the lower and upper 95% confidence limits on *F* were calculated as 0.0183 and 0.446 $y^{-1}$ respectively.

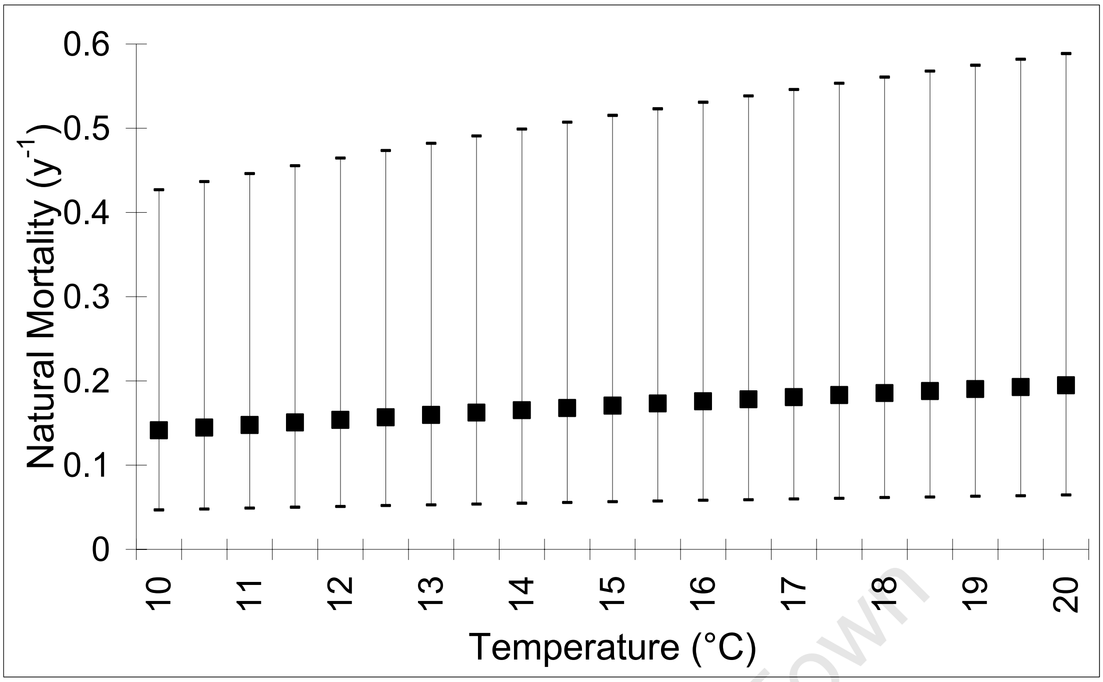


**Figure 6.5: Changes in natural mortality (*M*) estimated using Pauly's equation when varying temperature. Bars indicate 95%confidence intervals**

## 6.3.2 PER-RECRUIT ANALYSIS

The age at which 100% of female *R. globiceps* were above the minimum size limit changed from five years to four years when the minimum size limit was reduced from 250 mm TL to 210 mm TL and increased to 6 years when it was increased to 290 mm TL (Table 6.5). The age at which 100% of females were fully mature was five years.

**Table 6.5: Proportion-at-age key for female *R. globiceps* in Saldanha Bay. Three minimum sizes were simulated in this study and proportion of fish above the minimum size are given (where 1 refers to 100%). Proportions of mature fish were determined by transformation of proportions of mature females per length class**

| Age (years) | Proportion Mature | Proportion of fish larger than size limit | | |
|---|---|---|---|---|
| | | 210 mm TL | 250 mm TL | 290 mm TL |
| 1 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2 | 0.43 | 0.58 | 0.24 | 0.03 |
| 3 | 0.79 | 0.88 | 0.72 | 0.37 |
| 4 | 0.88 | 1 | 0.82 | 0.70 |
| 5 | 1 | 1 | 1 | 0.96 |
| 6 | 1 | 1 | 1 | 1 |
| 7 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 |
| 9 | 1 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 |
| 11 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 |
| 13 | 1 | 1 | 1 | 1 |
| 14 | 1 | 1 | 1 | 1 |

At *F*-current, *Y/R* was similar when minimum size was varied (Figure 6.6 (a)). Differences in output became more distinct at $F > 0.4$, where higher $L_c$ resulted in greater yields. There were no significant difference in *Y/R* at the lower limit of the 95% CI for *F*, and a difference of ~13% was seen between curves of the lowest and highest minimum sizes at the upper bound. In contrast, Y/R differed substantially when *M* was varied, with *Y/R* being consistently higher at lower *M* (Figure 6.6 (b)). At the lowest *M*-estimate, *Y/R* showed a maximum at *F* < *F*-current. At the highest *M*-estimate no maximum was observed. At the lower limit of the 95% CI of *F*, differences between *Y/R* curves were small because of its proximity to $F = 0$. At the upper limit of the 95% CI of *F*, *Y/R* was highest when $M = 0.059\ y^{-1}$ and lowest when $M = 0.538\ y^{-1}$.

*SB/R* differed substantially between the three minimum size limits at *F*-current (Figure 6.7 (a)). Slight differences were evident between *SB/R* curves at the lower limit of the 95% CI, with all curves at ~88% of pristine levels. *SB/R* curves were below 40% $SB/R_{F=0}$ at the upper limit of the 95% *CI*, with levels ranging from ~18% $SB/R_{F=0}$ at $L_c = 290$ mm to ~5.5% $SB/R_{F=0}$ at $L_c = 210$ mm. At *F*-current, *SB/R* was below 25% $SB/R_{F=0}$ at $M = 0.178$ (Figure 6.7(b)). Within the range of uncertainty for *F*, the stock could be healthy and underutilised if the true *F*-value falls close to the lower bound of the 95% *CI* or the stock could be overfished and *SB/R* could be well below the target reference points. At $M = 0.538$ *SB/R* is above 40% $SB/R_{F=0}$ if *F* is assumed to equal *F*-current.

Changes in $L_c$ did not affect *OM/R* across the range of uncertainty of *F* (Figure 6.8(a)). *OM/R* was high for all values of *F* within the range of uncertainty, ranging from 95% of pristine at the lower limit of the 95% CI to 64% at the upper limit. *OM/R* was consistently higher at lower *M* (Figure 6.8 (b)). *OM/R* was above 40% $OM/R_{F=0}$ for all values of *F*, with the lowest level (~63%) reached at the upper limit of the 95% *CI* for $M = 0.538\ y^{-1}$.

Average mass of a fish caught was consistently higher at larger $L_c$ (Figure 6.9 (a)), and the average mass per fish was higher at lower *M* (Figure 6.9 (b)) within the range of uncertainty of *F*. At *F*-current, increasing $L_c$ resulted in a slightly higher average mass than decreasing *M*.

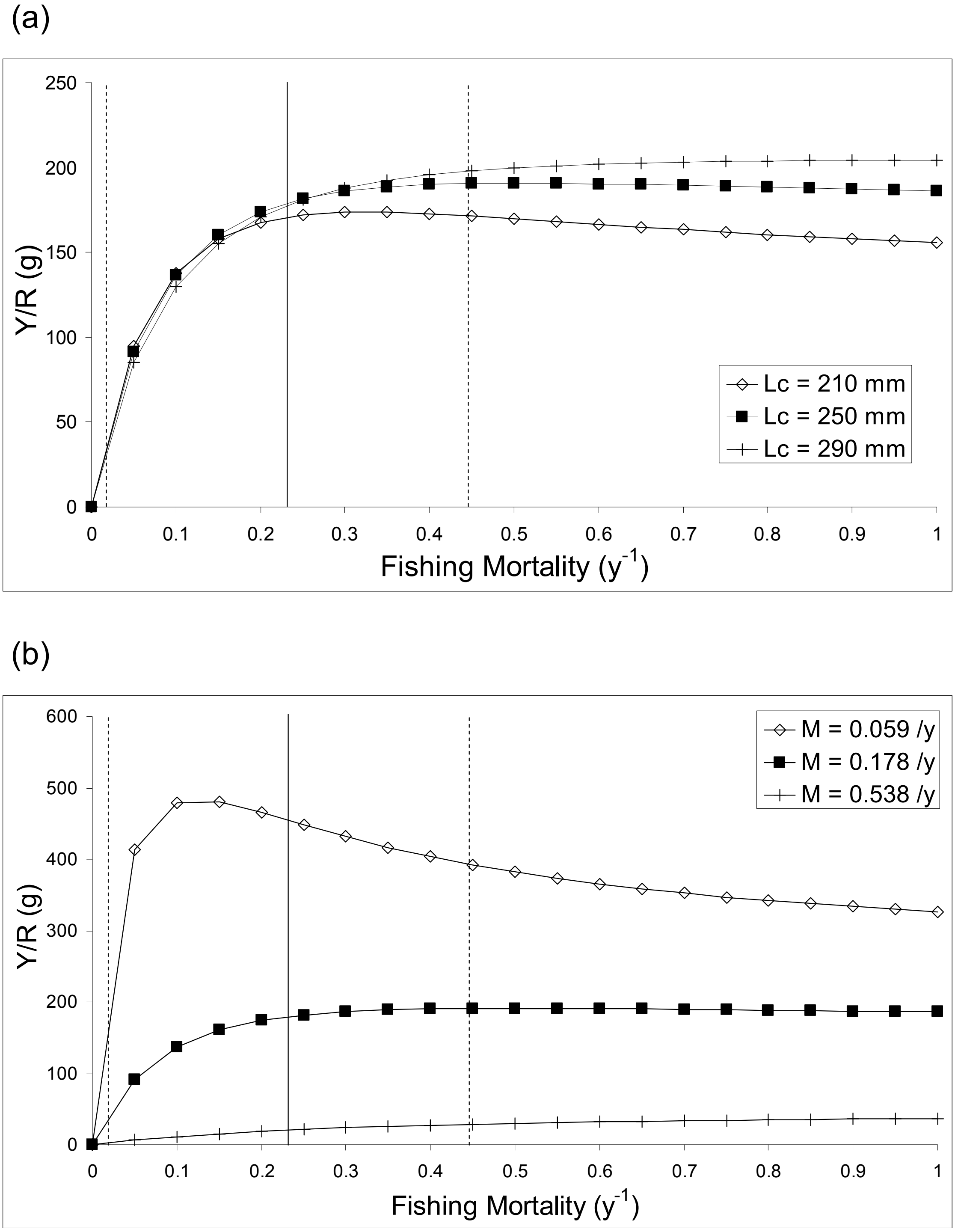


**Figure 6.6: Yield-per-recruit for *R. globiceps* in Saldanha Bay at (a) varying minimum sizes with natural mortality set to 0.178 $yr^{-1}$ and (b) varying natural mortality with the minimum size set to 250 mm. The solid vertical line represents *F*-current and the dashed vertical lines represent the 95% confidence interval**

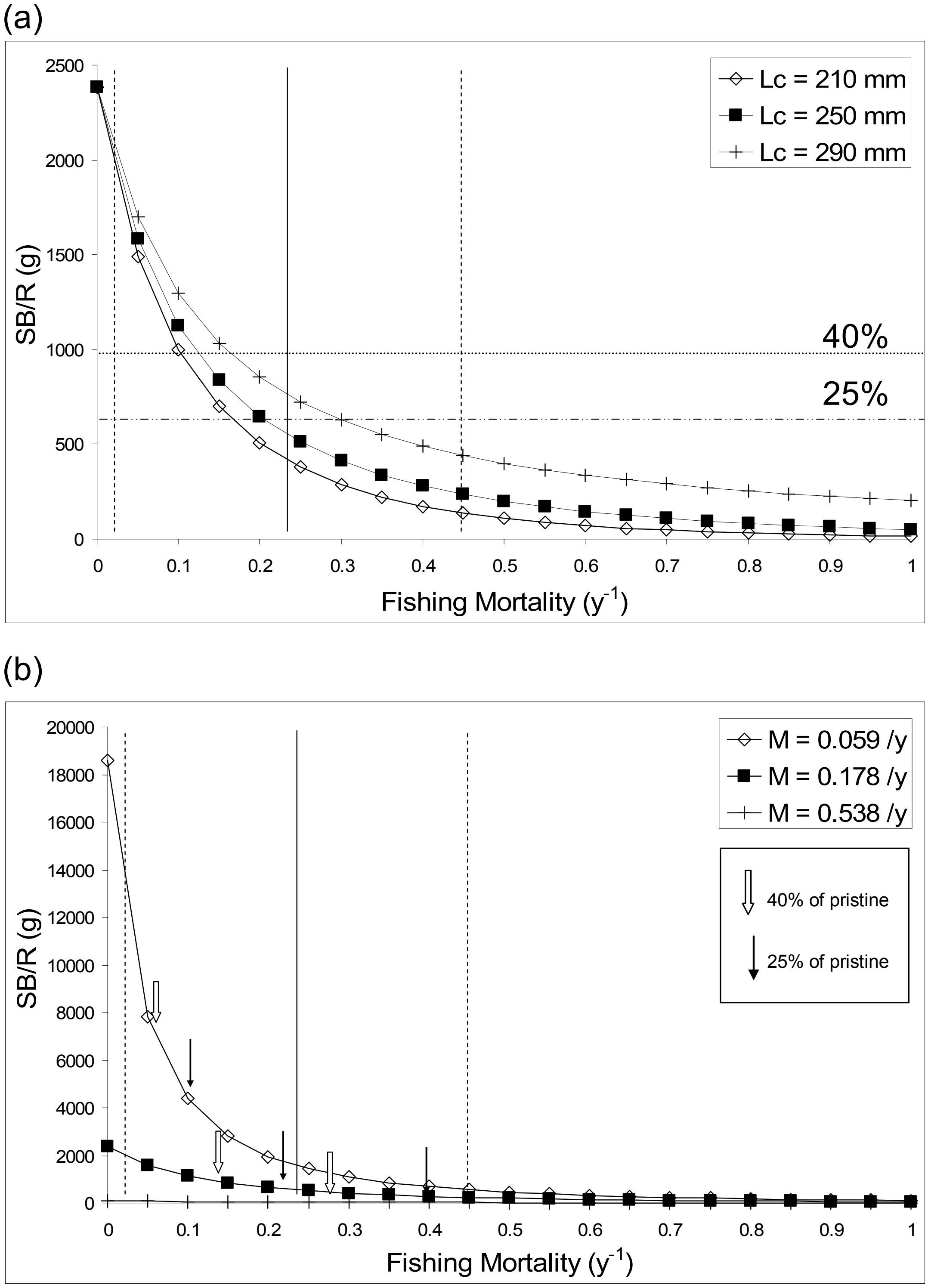
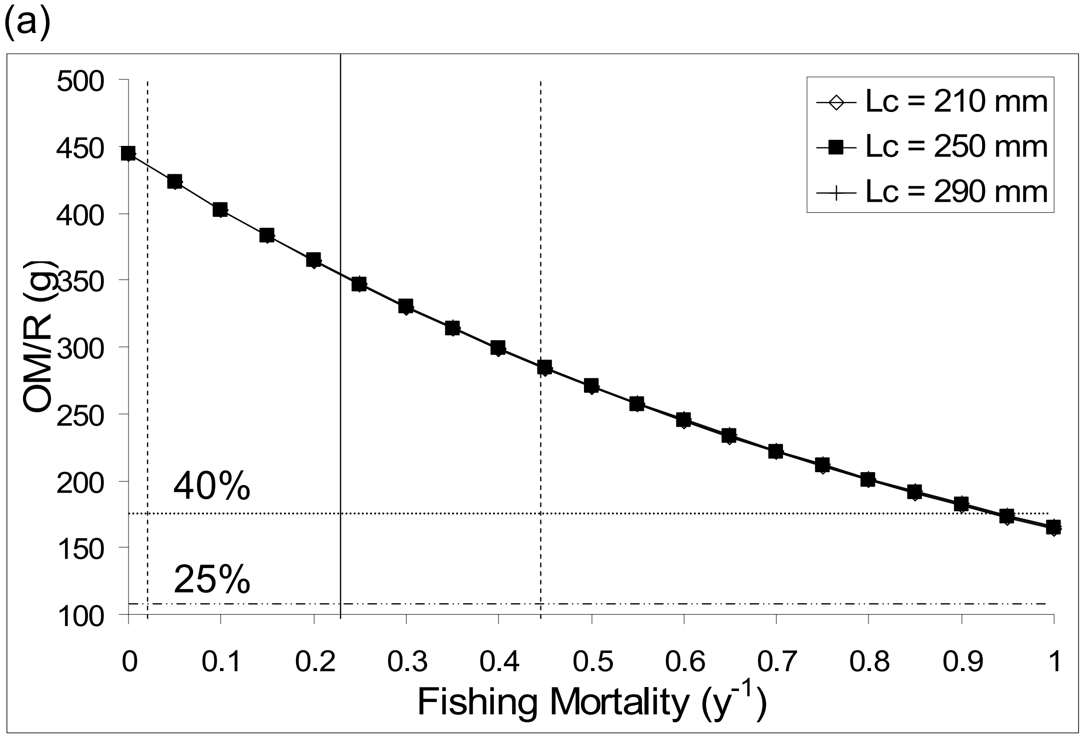


**Figure 6.7: Spawner biomass-per-recruit for *R. globiceps* in Saldanha Bay at (a) varying minimum sizes with natural mortality set to 0.178 yr$^{-1}$ showing target reference points and (b) varying natural mortality with the minimum size set to 250 mm. The solid vertical line represents *F*-current and the dashed vertical lines represent the 95% confidence interval**



**(b)**

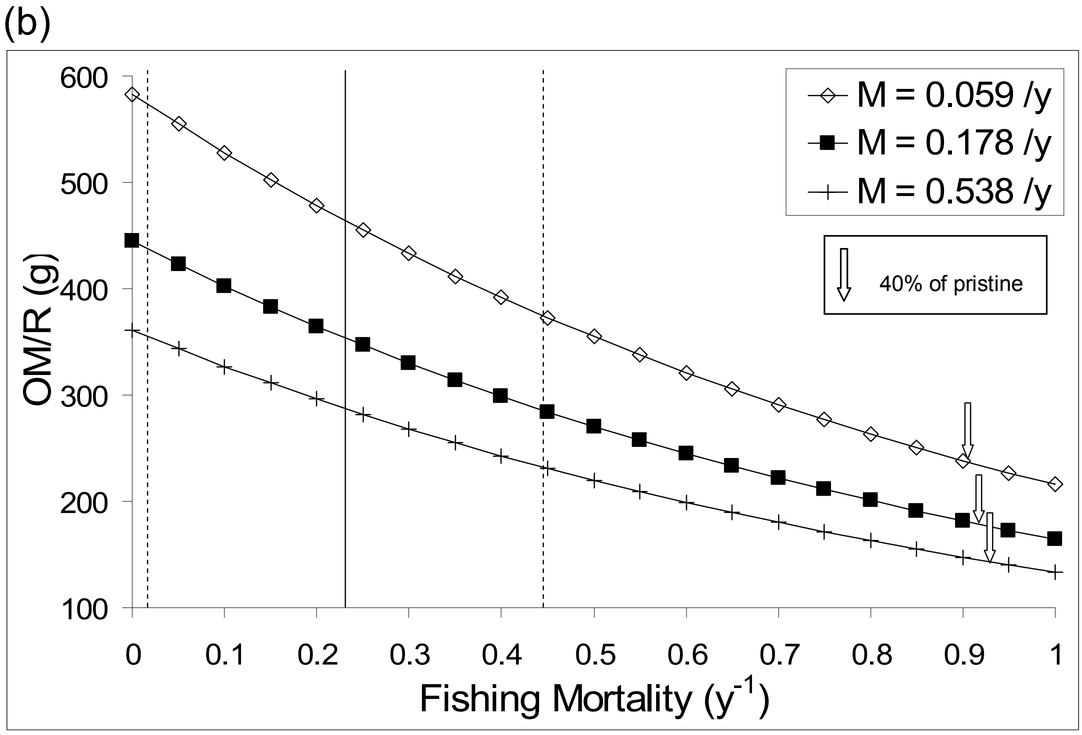


**Figure 6.8: Ovarian mass production per-recruit for *R. globiceps* in Saldanha Bay at (a) varying minimum sizes with natural mortality set to 0.178 yr$^{-1}$ showing target reference points and (b) varying natural mortality with the minimum size set to 250 mm. The solid vertical line represents *F*-current and the dashed vertical lines represent the 95% confidence interval. Lines in Figure 6.8 (a) overlap almost completely. A 25% reduction in *OM/R* occurs at *F>F=1***

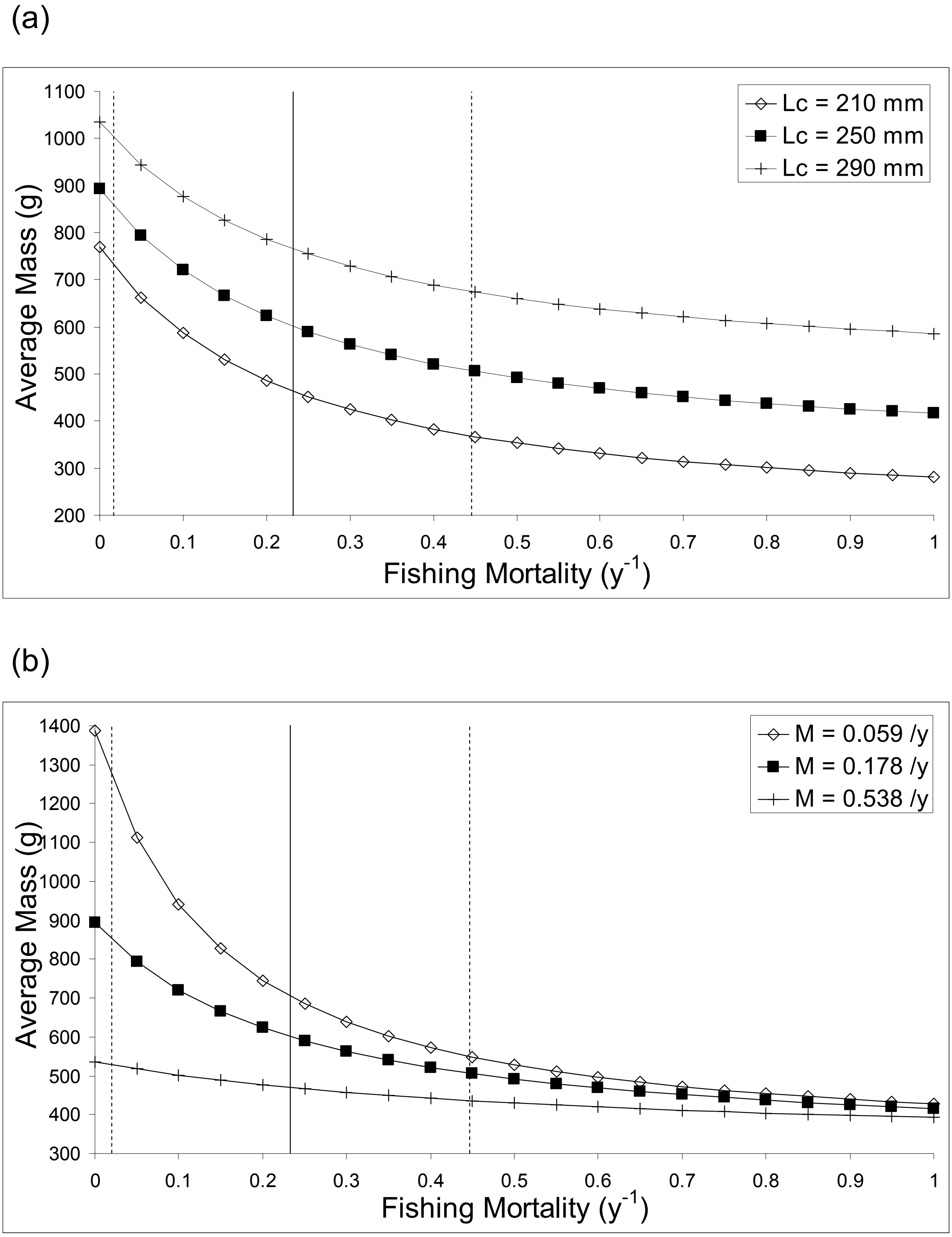


**Figure 6.9: Average mass for *R. globiceps* in Saldanha Bay at (a) varying minimum sizes with natural mortality set to 0.178 yr$^{-1}$ and (b) varying natural mortality with the minimum size set to 250 mm. The solid vertical line represents *F*-current and the dashed vertical lines represent the 95% confidence interval**

Differences were more marked at lower *F* and the curves converged as *F* increased. By converting the average mass at *F*-current to length using the mass-length equation and the parameters *a* and *b* in Table 6.1, a length of 29.5 cm TL was obtained. This value was below the observed mean TL for boat surveys for all years of 34.11 cm, obtained by averaging the mean TL for slipways for 2006-2008 in Table 6.2. When the average mass was converted to age using equation (6.14), an average age estimate of 6.92 years was obtained. The average length obtained above was used as the estimate of $L_c$ in equation (6.14). This age estimate was more than double the modal age of 3 years, obtained by converting the length frequency distribution of catch to an age frequency.

If spawner biomass at *F*-current is assumed to be accurate, an ~20% reduction in *F* is required to increase spawner biomass to above 40% of pristine, which could be achieved by implementing a daily bag limit of five fish/angler/day (Table 6.6).

**Table 6.6: Observed recreational bag frequencies of *R. globiceps* sampled during access point surveys in Saldanha Bay between 2006 and 2008 and the potential percentage reduction in catch that can be achieved by enforcing various bag limits. $f_i$ is the relative frequency of the catch per unit effort**

| B/DBL$_i$ | $f_i$ | Catch (#) | % Reduction in catch |
|---|---|---|---|
| 0 | 163 | 0 | 100 |
| 1 | 599 | 599 | 78.3 |
| 2 | 605 | 1210 | 59.5 |
| 3 | 621 | 1863 | 43.62 |
| 4 | 604 | 2416 | 30.75 |
| 5 | 536 | 2680 | 20.79 |
| 6 | 385 | 2310 | 13.42 |
| 7 | 285 | 1995 | 7.91 |
| 8 | 354 | 2832 | 3.78 |
| 9 | 220 | 1980 | 1.36 |
| 10 | 281 | 2810 | 0 |

## 6.4 DISCUSSION

The short time-series of data for *R. globiceps* in Saldanha Bay precluded the use of statistical tools such as virtual population analysis and surplus production models. The use of Beverton and Holt’s per recruit analysis was the most appropriate model for the available data (Brouwer & Griffiths 2006).

Serial correlation was not evident when all boat angler data were combined and therefore this catch curve was considered suitable to describe the mortality rate of the Saldanha Bay population of *R. globiceps* (Figure 6.3 (d)). There was a slight (statistically insignificant) increase in *Z* between 2006 and 2008, with the width of the 95% CI increasing from 2006 to 2008 (Figure 6.4), possibly due to lower catch rates in late 2007 and early 2008 compared to the rest of the study period (MCM – unpublished data).

Growth curves fitted to the data by Attwood *et al*. (2010) showed that both sexes displayed asymptotic growth. The Schnutte growth model provided the best fit to the data (Attwood *et al*. 2010), suggesting that growth within and across age classes was constant, a prerequisite of catch curve analysis (Ricker 1969). Based on the length frequency data from the boat fishery (Figure 6.2 (b)), it can be assumed that size of recruitment into the fishery remained relatively constant, although lower recruitment into the 330 mm – 390 mm size classes were noted in 2008. This suggests that fish in these size/age classes may be experiencing higher fishing mortality compared to older fish (Marteinsdottir & Thorarinsson 1998), though a one-tailed runs test showed that the increase was not significant (Table 6.4). Further investigation based on a longer time series of data is suggested to determine whether fishing mortality is increasing for the population.

Many studies have noted the difficulty associated with obtaining a reliable estimate of *M*, with various assumptions about the nature of *M* and approaches applied to obtain an estimate of the parameter (Pauly 1980, Booth & Buxton 1997, Chale-Matsau *et al*. 2001, Brower & Griffiths 2006, Wang & Liu 2006, Götz *et al*. 2008, Wang *et al*. 2009). Despite the numerous studies and approaches available for determining *M*, most approaches provide estimates with wide confidence intervals (Götz *et al*. 2008). Also, estimates of *M* using differing approaches may vary considerably even though they are based on the same data set (Booth & Buxton 1997, Götz *et al*. 2008).

The large confidence intervals associated with the *M*-estimate obtained from this study (Figure 6.4) was attributed to the variability associated with estimating *M* using an empirical formula. Pauly's equation was considered the best estimate of *M* given the limited data. The large CI suggests that the estimate should be used with caution as the large error in the estimate could result in misinterpretation of results (Götz *et al*. 2008), though the similarity in estimates obtained using Pauly's and Hoenig's equations do provide support for the *M*-estimate. Hoenig's equation was not incorporated into the analysis because no confidence intervals could be obtained for the estimate. The effects of migration on the *M*-estimate were not incorporated into the analysis because emigration and immigration, which would overestimate (Appledoorn 1996) and underestimate (Brouwer & Griffiths 2006) *M* respectively, were assumed to be negligible (Kerwath *et al*. 2009). Changes in temperature resulted in minimal changes to the *M*-estimate obtained, though confidence intervals were wide (Figure 6.5). The large confidence interval was attributed to the low precision of estimating parameters by indirect methods.

*F* showed large confidence intervals because the variance associated with *F* was calculated as the sum of the variance of *M* and *Z*.

Greater changes in *Y/R* were obtained when *M* was varied compared to changes in $L_c$. Within the range of uncertainty for *F*, changes in $L_c$ have little effect on *Y/R* and would therefore not be a good management measure to increase *Y/R*. At *F*-current *Y/R* is below maximum and an increase in *F* could result in increases in *Y/R*, though the increase would be minimal.

From tagging data, evidence suggests that the spawning stock is protected from recruitment overfishing because of the protection provided to individuals by the MPA (Kerwath *et al*. 2009). *SB/R* showed spawning biomass at *F*-current was slightly below the 25% $SB/R_{F=0}$ level, suggesting that the stock is overexploited. *F* should thus be carefully monitored as an increase in *F* could result in (greater) overexploitation of the stock and possibly a drastic reduction of spawner stock as was evident of the other *R. globiceps* populations (Griffiths *et al*. 2002) and many other sparid fisheries (Booth & Punt 1998, Chale-Matsau *et al*. 2001, Brouwer & Griffiths 2006). A reduction in *F* to approximately 0.1 $y^{-1}$ or an increase in $L_c$ to 290 mm TL would ensure that *SB/R* is above 25% $SB/R_{F=0}$ despite the large variability in *M* and *F*.

Ovarian mass per recruit was used as a proxy for egg production per recruit. Brouwer & Griffiths (2006) suggested that egg production be used as an alternative to *SB/R* as it takes into account age-specific fecundity of individuals. This provides a more realistic estimate of spawning potential as older fish produce more eggs. Differences between the curves when the minimum size was altered were minimal (Figure 6.8(a)); suggesting that altering the minimum size for *R. globiceps* within the range used in the analysis would not have any effect on egg production as younger fish do not have large ovary mass and hence contributes less to the reproductive output of the population (Brouwer & Griffiths 2006). Full maturity for *R. globiceps* occurs at 5 years (Table 6.5), therefore selectivity between the chosen $L_c$ values have little effect on *OM/R* as not all fish within the range of $L_c$ are mature and therefore do not contribute significantly to the *OM/R* for the population. There were, however, slight differences between the curves when *M* was altered, with higher production being achieved when *M* decreased and vice versa (Figure 6.8 (b)). At *F*-current, *OM/R* is well above $OM/R_{F=40\%}$, suggesting that the current egg production is high enough to prevent recruitment failure due to low spawning potential, assuming environmental factors remain favourable for recruitment. Differences between *SB/R* and *OM/R* were attributed to the greater contribution of older fish to the spawning potential of the population. A possible problem with the *OM/R* model are that older fish are more fecund and produce larger eggs of higher quality. Ovary mass may therefore not be proportional to the number of eggs produced (Brouwer & Griffiths 2005, Law 2007). The relationship between ovary mass at size and the number of eggs produced should be investigated for *R. globiceps* before inferences can be made.

Greater changes in average mass were noted for *F*-values below *F*-current than above it (Figure 6.9), therefore changes in average mass would become less pronounced as *F* increases. Using the mean TL for slipways (Table 6.2) as an input value, an average mass of fish for all years was calculated using equation (6.8). An average mass of 853.69 g was obtained. This suggests that the average mass was underestimated using equation (6.13), possibly as a result of an overestimation of *M* or *F* which is incorporated into equation (6.13).

Age estimates were based on counts of annual bands deposited on otoliths. Bands were assumed to be annual in nature, as is the case with many other sparids (Chale-Matsau *et al*. 2001, Radabe *et al*. 2002, Potts & Cowley 2005). This was confirmed by Attwood *et al*. 2010 who noted that, viewed under transmitted light, a hyaline edge was most common on otoliths during mid and late summer whereas a translucent edge was most common for the rest of the year. The sample was collected over a one year period. *R. globiceps* is considered to be of intermediate longevity (Griffiths *et al*. 2002) and the *M*-estimate of 0.178 $y^{-1}$ was considered acceptable, as sparids are generally long-lived (Chale-Matsau *et al*. 2001) and slow-growing. Long-lived sparids generally have an *M*-estimate below 0.2 $y^{-1}$ (Brouwer & Griffiths 2006).

The per-recruit analysis suggests that the population output is currently below the optimum level of exploitation. This is highlighted by *SB/R* which is below 25% at *F*-current. Stocks need to be kept between or above the 25% and 40% *SB/R* threshold level to ensure that recruitment overfishing does not occur and are also target reference points for South African linefish (Penney *et al*. 1997, Griffiths *et al*. 1999, Brouwer & Griffiths 2006, Silberchneider *et al*. 2009). The protection offered by the MPA might offset the chances of recruitment overfishing occurring, but due to its partial protection and the high mobility of the species (Kerwath *et al.* 2009) it does not offer protection against growth overfishing which could later lead to recruitment failure (Silberchneider *et al*. 2009). This is illustrated by Figure 6.3 where <10% of the catch fall in the 8 year and older age classes.

The reduction in *F* by implementing a stricter bag limit was modelled under the assumption that the percentage reduction in catch is equivalent to the percentage reduction in *F*, regardless of catch per unit effort (Attwood & Bennett 1995). To reduce *F* to 0.1 $y^{-1}$ (equivalent to *SB/R* ≈ 25% of pristine) at $M = 0.059$ $y^{-1}$ and $L_c = 250$ mm TL, a 15% reduction in catch is required which can be achieved by implementing a bag limit of five fish/angler/day. To increase *SB/R* to 25 and 40% of $SB/R_{F=0}$ at $M = 0.178$ and $L_c = 250$ mm TL respectively, reductions in catch of 7% and 45%, equivalent to daily bag limits of seven fish/angler/day and two fish/angler/day is required. Due to the uncertainty in *M*, a bag limit of five fish/angler/day is suggested.

If current mortality estimates are considered a true reflection of mortality for the population, an increase in $L_c$ to 290 mm TL would increase *SB/R* to 32% of pristine. To increase *SB/R* to 40% of pristine (one of the default target reference points of South African Linefish – Griffiths *et al*. 1999), an 8% increase in *SB/R* is required, equivalent to implementing a bag limit of seven fish/angler/day. Thus a combination of increasing the length at first capture to 290 mm TL and implementing a bag limit of seven fish/angler/day can be implemented for the population.

The above management measures are site specific and would not work for other populations of *R. globiceps* due to differences in the growth rate of the four populations of *R. globiceps* and differences in fishing gear used by the various fisheries sectors targeting the species (i.e. recreational/commercial linefisheries on the west and south-west coasts vs. commercial trawl fisheries on the south and south-east coasts (Griffiths *et al*. 2002)

## 6.5 CONLUSIONS

The population of *R. globiceps* in Saldanha appears to be a fully exploited resource, despite uncertainty in the estimation of *M*. A more concerted effort therefore needs to be made to obtain an *M*-estimate with a higher level of precision. The use of a longer time series of data or, preferably, another model based on catch data is recommended e.g virtual population analysis (VPA) (as discussed in Chapter 5).

Adopting a precautionary approach, a reduction in effort by either (a) increasing the minimum size to 290 mm TL; or (b) reducing fishing effort by 7-45% is recommended. The latter can be achieved by reducing the bag limit to five fish/angler/day (a ± 20% reduction in fishing effort is obtained). The increase in minimum size would account for error in the *F*-estimate whereas the introduction of the bag limit would increase *SB/R* to what is considered a sustainable level, assuming the *M*-estimate is correct. To increase the *SB/R* to above 40% of pristine, increasing the minimum size limit to 290 mm TL and implementing a bag limit of seven fish/angler/day could also be implemented. Continued monitoring of the resource is advised.

# CHAPTER 7

# RECOMMENDATIONS FOR FUTURE RESEARCH AND MONITORING OF *RHABDOSARGUS GLOBICEPS* IN SALDANHA BAY

This chapter aims to provide an overview of further studies needed to provide a more holistic understanding of the fisheries biology of *R. globiceps* in Saldanha Bay. Several aspects of the life history of *R. globiceps* were not investigated, due either to time constraints or constraints imposed by the limited data available. These aspects are listed, possible experiments are discussed and where feasible an outline of the experimental design is provided.

## 7.1 EGG AND LARVAL STAGES

Due to time constraints, the egg and larval stages of *R. globiceps* were not investigated in this dissertation. These aspects are by no means less important than the stages investigated in this study, therefore a brief discussion of the importance of these stages as well as an outline of the type of investigation needed will be outlined.

The egg and larval stages are arguably the most important stages of development as most of the mortality the population will experience (exceeding 95%) occur during these two stages of development (Fuiman & Werner 2002, Houde 2002). Changes in the survival rate of individuals within the egg and larval stages could significantly affect the size of the breeding population, as even small changes in the mortality rate of eggs and larvae can produce vastly different numbers of individuals who survive to the juvenile stage (Houde 2002). Juvenile habitat quality and high fishing pressure could, however, also influence the size of the breeding stock (Houde 2002).

Notwithstanding the above, a significant decrease in the survival of the egg and larval stages could result in failed or poor recruitment (Houde 2002). A better understanding of egg and larval movement and larval behaviour will provide a link between the important period between spawning events and juvenile distribution.

Juvenile habitat selection is believed to be related to two factors; water circulation and active selection of favourable habitat (Fuiman & Werner 2002). The role of spawning location in relation to most favourable habitats needs to be investigated to determine if the selection of spawning sites by adults are influenced by water currents. The Saldanha Bay population of *R. globiceps* is assumed to spawn within the bay based on Kerwath *et al*.'s (2009) study. This could be related to the favourable habitat Saldanha Bay presents. The behaviour of adults of the Saldanha Bay population need to be compared to other populations that spawn offshore to determine if selection of spawning sites by adults in Saldanha Bay is influenced by the prevalent water currents of the area or if other factors (e.g. temperature gradients) are limiting the offshore movement of the Saldanha Bay population as postulated by Griffiths *et al*. (2002).

By relating hatch date analysis to spawning events, an assessment of the factors which influence the survival of young fish (larvae and juveniles) can be done (Jones 1992). Increased survival of certain cohorts can also be identified by comparing observed number of hatchlings in a particular habitat type to numbers back calculated from hatch date analysis (Campana & Jones 1992). The age and number of individuals per habitat can also be compared to the time of spawning events, especially spawning peaks, to determine if habitat selection criteria are different for different spawning events. This could help identify environmental factors (e.g. temperature) that influence habitat selection and survival of individuals (Fuiman & Werner 2002).

Egg samples can be collected over the spawning period (September-February) (Attwood *et al*. 2010) in the major channels within the Lagoon between the major spawning areas in the southern part of the lagoon (Kerwath *et al*. 2009) and areas of high juvenile abundance along the northern shores of Saldanha Bay (Chapter 2). Concurrently, a study on the water movement needs to be done to determine the level of passive movement of larvae to juvenile habitats with the highest abundance. Alternatively, reproductively active adults can be laboratory reared during the reproductive period to obtain fertilised eggs. Fertilised eggs can be hatched (thereby knowing the hatch date) and, by periodically sacrificing individuals and counting the number of bands on their otoliths, periodicity of ring formation and the time when the first ring is formed can be determined (see e.g. Ibrahim *et al*. 2006 for a more detailed outline of the procedure to be followed).

## 7.2 POPULATION SIZE – A MARK AND RECAPTURE EXPERIMENT

An important requirement for effective and successful management and policy-making for any fish species is a reliable estimate of population size. Several methods are available to determine population size. These include direct census, mark and recapture, catch-effort methods and estimation of mortality and survival based on age data (Seber 2002).

The mark and recapture experiment is a particularly useful tool for the Saldanha Bay *R. globiceps* population because the Saldanha stock assumed to be a closed population due to the limited movement of individuals beyond the mouth of Saldanha Bay (Kerwath *et al.* 2009).

The use of the mark-recapture experiment on the stock is also favourable because entry to Saldanha Bay via ski boat is limited by the number of slipways (Chapter 1, Figure 1.1) and shore based angling can be effectively quantified and monitored using Roving Creel census.

Another unique feature of Saldanha Bay which facilitates the use of mark-recapture experiments is the Stumpnose Derby which attracts several hundred anglers to the region; an annual event where prizes are given for the heaviest fish caught.

The Stumpnose Derby is subject to approval by SANParks, thus implementation of new rules can be achieved by running the project jointly with SANParks. The successful implementation of a new rule was demonstrated in the 2008 Stumpnose Derby in which only live fish were eligible for prizes (Pierre Nell, SANParks – pers. comm.). The Stumpnose Derby is a period of increased fishing pressure on the *R. globiceps* stock and should be used as the recapture period.

The following procedure is suggested for estimating the population size of the Saldanha Bay population:

First, a rough estimate of population size is needed, which was obtained using a modified Baranov catch equation:

$$N = \frac{C}{\left(1-e^{-Z}\right)} \times \frac{Z}{F} \qquad (7.1)$$

where: *N* is the population size; and *C* is the annual catch. The Baranov catch equation was modified to make *N* the subject and annual catch (147,000 fish) was obtained from Næsje *et al.* (2008). The time period was set to one year for ease of interpretation and to allow annual catch to be used in the calculations. Population size was estimated at 1,209,104 fish. The *Z* and *F*-estimates used in (7.1) were obtained from Chapter 6.

After an estimate of the population size was obtained, the level of accuracy required was determined. As a rough estimate of population size was calculated using (7.1), a more accurate estimate would be preferred, therefore population size can be determined at one of two accuracy levels with higher accuracy than the Baranov catch equation (i.e 0.5 (50%) and 0.25 (75%) respectively). By using the Robinson & Regier (1964) chart illustrated in Seber (2002) to determine sample size and the rough estimate of population size from (7.1); an estimate of the amount of resource allocation needed to obtain a reliable estimate of population size was calculated (Table 7.1).

Several local anglers were interviewed and asked about their willingness to participate in and their opinions about the suggested experiment. The replies were favourable and an estimated 20 anglers indicated their willingness to dedicate approximately 30 days of their time to the experiment. Calculations were based on these estimates. The amount of time allocated for checking for clipped fish should be limited to 60 days to prevent overestimation of population size because of regrowth of clipped fins (Lukey *et al*. 2006). A sample data sheet for recording catch/recapture date was compiled (Appendix 7.1).

**Table 7.1: Estimated sample sizes and effort required to obtain estimates of population size at 50% and 75% accuracy levels using a fin-clipping experiment in Saldanha Bay**

| Accuracy | 50% | 75% |
|---|---|---|
| Estimated Population Size | 1000000 | 1000000 |
| $N_1$ | 3000 | 7000 |
| $N_2$ | 6000 | 10000 |
| Days for clipping sample $n_1$ | 30 | 30 |
| Fish clipped per day | 100 | 234 |
| Number of anglers required | 20 | 20 |
| Number of fish clipped per angler | 150 | 350 |
| Number of days for checking sample $n_2$ | 60 | 60 |
| Number of fish checked per day | 100 | 167 |
| Expected number of clipped fish | 18 | 70 |

The number of fish clipped per day was calculated by dividing the sample size of the clipped fish ($n_1$) by the number of days allocated for clipping individuals. The number of fish clipped per angler was calculated by dividing $n_1$ by the estimated number of anglers participating in the experiment. The average number of fish that needed to be checked per day was calculated by dividing the estimated total number of fish checked ($n_2$) by the number of days allocated to checking of fish for fin clips. The expected number of clipped fish was calculated using the equation:

$$Expected = \frac{n_2 \times N}{n_1} \qquad (7.2)$$

## 7.3 MONITORING

The continued monitoring of the stock is essential if long term management goals are to be achieved. With a long time series of data, modeling techniques such as VPA become possible and could aid in more accurate estimates of population parameters as well as lead to better management of the stock.

As of 01 July 2009 the NORSA 2.3 project was handed over to SANParks and all monitoring is now conducted by Coastcare staff. Continued monitoring is essential if accurate estimates of catch and population size are to be obtained.

The monitoring duties of the observer as outlined in Chapter 6 are listed below. The four major slipways in Saldanha Bay are monitored four times per month each, for approximately four hours (either in the morning or the afternoon). Anglers are interviewed upon returning from their fishing trips and angler number, trip duration, areas targeted, fish targeted and caught, bait used and the number of fish returned and kept are recorded. For the roving creel census, four sections of Saldanha Bay comprising of the areas around Langebaan, Club Mykonos, the iron ore jetty and the port of Saldanha (i.e. the entire area where fishing is allowed) were monitored. Each section is monitored four times per month. Anglers met during the census are interviewed and areas targeted for the day, bait used, time spent at each location and species targeted, returned and kept are recorded. Kept fish (for both slipway surveys and roving creel census) are identified to species level and measured to the nearest cm TL. Instantaneous boat counts are done at intervals throughout the month to determine areas most targeted by boat anglers.

After each survey, collected data are recorded in a database for further analysis.

# APPENDICES:

**Appendix 6.1: Raw age-length key for *R. globiceps* in Saldanha Bay. n=558**

| TL Class (mm) | AGE (years) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Total |
| 130-149 | 2 | | | | | | | | | | | | | | 2 |
| 150-169 | 2 | | | | | | | | | | | | | | 2 |
| 170-189 | 3 | 7 | 1 | | | | | | | | | | | | 11 |
| 190-209 | | 6 | 2 | | | | | | | | | | | | 8 |
| 210-229 | | 3 | 1 | 2 | | | | | | | | | | | 6 |
| 230-249 | | 15 | 7 | 1 | | | | | | | | | | | 23 |
| 250-269 | | 18 | 19 | 2 | 1 | | | | | | | | | | 40 |
| 270-280 | | 27 | 56 | 20 | 6 | 1 | | | | | | | | | 110 |
| 290-309 | | 10 | 60 | 18 | 7 | 4 | | 1 | | | | | | | 100 |
| 310-329 | | | 32 | 23 | 22 | 7 | | | | | | | | | 84 |
| 330-349 | | | 5 | 28 | 23 | 14 | 5 | | | | | | | | 75 |
| 350-369 | | | 1 | 14 | 19 | 7 | 5 | 1 | | | | | | | 47 |
| 370-389 | | | | 3 | 9 | 2 | 4 | 1 | 1 | | | | | 1 | 21 |
| 390-409 | | | | 2 | 4 | 3 | 2 | | | | | | | | 11 |
| 410-429 | | | | | 2 | 2 | 1 | 1 | | 1 | 2 | | | | 9 |
| 430-449 | | | | | | 1 | | 1 | | | 2 | | | | 4 |
| 450-469 | | | | | | 1 | | | | | | | | | 1 |
| 470-489 | | | | | | | | 1 | | | | | 2 | | 3 |
| 490-509 | | | | | | | | | | | | 1 | | | 1 |
| Total | 7 | 86 | 184 | 113 | 93 | 42 | 17 | 6 | 1 | 1 | 4 | 1 | 2 | 1 | 558 |

**Appendix 7.1: Data sheet to be used by anglers for fin clipping experiment in Saldanha Bay**

# Fin-Clipping Experiment - Langebaan Lagoon/Saldanha Bay

Boat Number/Name:

Number of Anglers:

Start Time:

Location Fished:

End Time:

Number of fish Clipped:

GPS Position (If Available):

**White Stumpnose measurements only – Total length (TL)**

| Size in mm (TL) | Size in mm (TL) | Size in mm (TL) | Size in mm (TL) |
|---|---|---|---|
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