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**A re-evaluation of the life history strategy of Cape horse mackerel, *Trachurus capensis* in the southern Benguela.**

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## Declaration

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

Demersal survey data was provided by and used with the permission from Tracey Fairweather (DAFF) and Dr. Deon Durholtz (DAFF). Acoustic survey data was provided by and used with the permission from Janet Coetzee (DAFF) and Dagmar Merkle (DAFF). Ichthyoplankton (SARP line) data was provided by and used with permission from Dr. Jenny Huggett (DEA) and Britta Grote (Centre for Tropical Marine Ecology, Germany). All biological data collected between June and December 2011 from fish sampled from commercial catches was collected by Cliff Hart and me with the help of other DAFF staff.

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## Abstract

The life history strategy of the Cape horse mackerel, *Trachurus capensis* in the southern Benguela, relating to distribution and reproductive ecology, was re-evaluated. It is possible that certain aspects of the species' life history may have changed since the previous assessment by Barange *et al.* (1998), as a result in this study, the conceptual hypotheses about the life history of horse mackerel proposed by Barange *et al.* (1998) were re-evaluated and possible revisions proposed. Distribution patterns were analysed using acoustic and mid-water trawl data (1997-2010), and demersal trawl data (1984-2011) collected during bi-annual surveys of pelagic and demersal fish. Results show that the size-specific distribution proposed by Barange *et al.* (1998), holds in general, but with two important differences: evidence of an adult population on the west coast in St. Helena Bay, which was previously thought to no longer exist following heavy fishing pressure in the 1950s and, although the west coast remains the primary nursery area, this study showed an increasing occurrence of south coast recruits particularly in last 5-6 years, which implies that recruitment on the south coast may not be as insignificant as once thought or has possibly increased in recent years. The reproductive ecology of horse mackerel was analysed on a temporal basis using egg and larval abundance measures from the SARP line (1995 to 2011) and horse mackerel gonads from biological samples collected on the eastern Agulhas Bank (EAB) (June to December 2011). Results show that spawning occurs across the Agulhas Bank primarily in winter, (June to August), with a secondary peak in summer (December). Eggs spawned on the western Agulhas Bank (WAB) and, possibly, some from the central Agulhas Bank (CAB) are transported to the primary nursery area on the west coast by the jet current. The eggs spawned on the CAB and EAB are retained on the south coast. Following two strong year classes of horse mackerel in the 1950s, eight years of heavy fishing followed, during which, most of the adult population on the west coast were thought to have been fished out, after which the stock collapsed. Based on these past observations, and the occurrence of two strong year classes in 2010 and 2011, it is hypothesized that horse mackerel are likely to be abundant for the next few years.

## **Chapter 1: Literature review**

### ***Upwelling Systems***

Eastern boundary upwelling systems, such as the Benguela, Canary, California and Humboldt Current Systems are among the most productive areas of the ocean (Anderson and Lucas 2008, Checkley *et al.* 2009, Fréon *et al.* 2009). The Earth's rotation and Coriolis force cause wind to deflect water bodies to the left and right in the Southern and Northern Hemispheres respectively, resulting in coastal water in the surface Ekman layer being driven away from the continent and replaced by nutrient-rich water from below (Philander 1998, Frances and Guerrero 2006, Anderson and Lucas 2008). This nutrient-rich upwelled water stimulates high primary productivity in the form of phytoplankton growth, which itself, supports higher trophic level species including fish, birds, seals and whales, as well as some of the world's major commercial fisheries (Frances and Guerrero 2006, Anderson and Lucas 2008, Fréon *et al.* 2009).

### ***The Southern Benguela Ecosystem***

The continental shelf surrounding South Africa is particularly unusual because of its position at the tip of a continent and the resulting interaction between two major ocean currents, the Agulhas and the Benguela (Figure 1.1) (Branch *et al.* 1987, van der Lingen and Huggett 2003, Coetzee *et al.* 2008, Checkley *et al.* 2009, Beal *et al.* 2011). The warm south-westerly flowing Agulhas current hugs the east coast of the continent before being forced offshore by the shallow central Agulhas Bank (Figure 1.1). The current travels south before it retroflects and continues in an easterly direction (Figure 1.1). As a result of the retroflexion, intermittent injections of warm Agulhas water are forced into the Atlantic causing simultaneous increases in coastal upwelling (Figure 1.1) (Branch *et al.* 1987, Checkley *et al.* 2009, Hutchings *et al.* 2009, Beal *et al.* 2011). The Benguela current flow is part of the South Atlantic circulation. Prevailing south easterly winds cause upwelling of cold nutrient-rich water on the west coast. The most intense upwelling in the southern Benguela occurs from late spring (September to November) to early autumn (March to May) (van der Lingen and Huggett 2003). The sudden deepening of the continental topography off the south west coast causes a fast, north-westerly-flowing jet current along the shelf edge and is a prominent summer feature (Figure 1.1) (Shelton and Hutchings 1990, Boyd and Nelson 1998, Huggett *et al.* 1998, Huggett *et al.* 2003, Mullon *et al.* 2003, Grote *et al.* 2007). Moving eastwards along the south coast, the continental shelf begins to widen on the western Agulhas Bank (WAB),

and is at its widest on the central Agulhas Bank (CAB) before narrowing towards the eastern Agulhas Bank (EAB). A cool ridge of subsurface water, formed by the interaction between coastal upwelling on the south coast and the Agulhas Current, extends south-westwards from the EAB to the CAB (Huggett *et al.* 2003, Hutchings *et al.* 2009).

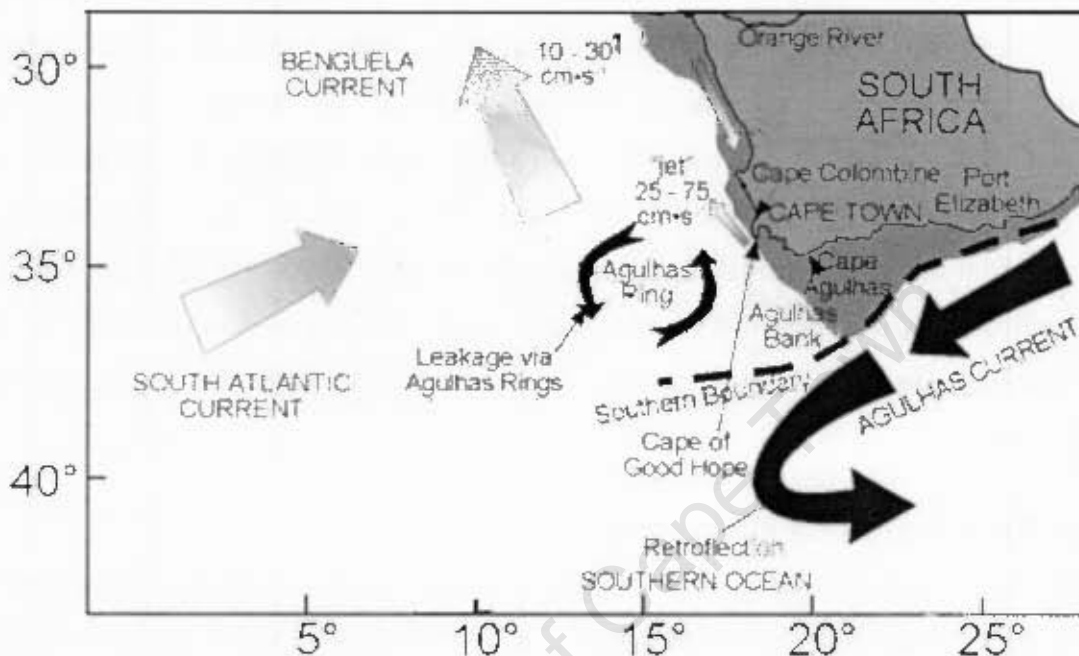


Figure 1.1: A map of the South African coastline outlining the main ocean currents and the layout of the continental shelf that make up the southern Benguela ecosystem (adapted from Hutchings *et al.* 2009).

Upwelling systems are variable and unpredictable. In the southern Benguela, changes in wind strength can vary on short time scales, causing upwelling strength to vary dramatically. Cycles of intense upwelling followed by reduced upwelling lasting between seven and ten days are especially evident in the southern region of the west coast (Branch *et al.* 1987). Upwelling intensity is usually highest in summer or early spring (Branch *et al.* 1987, Hutchings *et al.* 2009), and long term events, reoccurring at approximately ten year intervals, lead to warm water being forced up against the west coast, interrupting upwelling (Branch *et al.* 1987). Upwelling not only varies on a temporal scale but also spatially, with upwelling events concentrated at particular areas along the coast (Branch *et al.* 1987, Hutchings *et al.* 2009). These changes in upwelling intensity and duration lead to spatiotemporal variations in nutrient supply and, as a result, the life histories and behaviour of organisms that live in these upwelling centres have to be adapted accordingly (Anderson and Lucas 2008). Physical

variability has an overriding influence on the dynamics in the southern Benguela, with factors such as natural climate variability, circulation patterns, and the strength and duration of upwelling influencing productivity and food availability, ichthyoplankton survival and recruitment success, and population variability of many species (Branch *et al.* 1987, Anderson and Lucas 2008).

### **Small Pelagics**

The population numbers and inter-annual variability of small pelagic fish in the southern Benguela upwelling area are notoriously unstable (Branch *et al.* 1987, van der Lingen *et al.* 2006). These fluctuations are common in pelagic species, including commercially important species such as sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*), particularly in upwelling areas where fish appear to have periodic outbreaks of successful recruitment followed by periods of poor recruitment (Branch *et al.* 1987, van der Lingen and Huggett 2003, van der Lingen *et al.* 2006, Checkley *et al.* 2009). The commercial importance of pelagic species as well as the difficulties in stock management created by the unpredictable fluctuations in stock size have resulted in an increased focus on life history strategies of pelagic fish species in the southern Benguela (Branch *et al.* 1987, van der Lingen and Huggett 2003, van der Lingen *et al.* 2006).

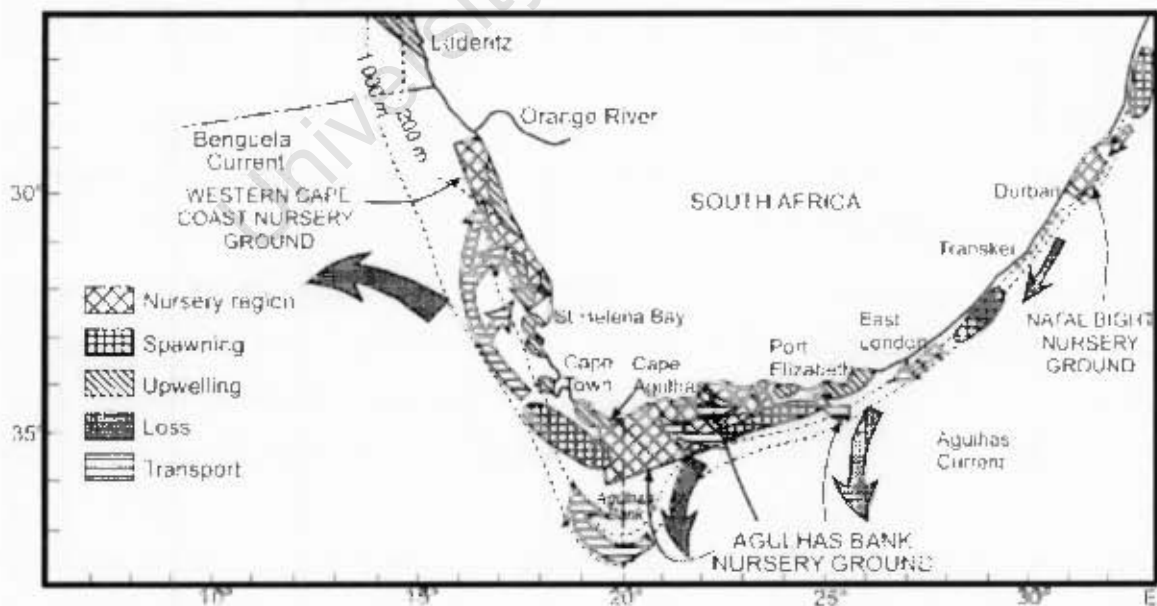


Figure 1.2: The network of spawning, transport and nursery areas and the regions of upwelling and offshore losses commonly utilised by pelagic fish in the southern Benguela current system (taken from Hutchings *et al.* 2002).

For small pelagic fish species in the region, such as anchovy and sardine whose life history strategies are best understood, spawning occurs across the EAB, CAB and WAB near the continental shelf edge (Figure 1.2) (Hutchings *et al.* 2002, van der Lingen and Huggett 2003, Hutchings *et al.* 2009). Eggs and larvae are transported north to the food-abundant west coast nursery area by the jet current or retained on the south coast (Figure 1.2) (Boyd and Nelson 1998, Huggett *et al.* 1998, Huggett *et al.* 2003, Mullon *et al.* 2003, Miller *et al.* 2006). Larvae develop into recruits that form mixed shoals and move southwards with age, returning to the Agulhas Bank as adult fish (Hecht 1990, Barange *et al.* 1998, Huggett *et al.* 2003, Anon. 2004, Lehodey *et al.* 2006). Although the life history strategy of another pelagic species, the Cape horse mackerel *Trachurus capensis*, is less understood it is likely to be similar to that of sardine and anchovy.

### **The Genus *Trachurus***

The *Trachurus* genus belongs to the family Carangidae, consisting of several jack and horse mackerel species and sub-species all over the world. *Trachurus* species are closely related and morphologically similar, making them difficult to differentiate without knowing their geographical origin, which is often the main distinguishing feature (Nichols 1920, Geldenhuys 1973, Naish 1990, Salem 1995). According to the most recent classification there are 15 species within the *Trachurus* genus (Salem 1995). These include: *T. trachurus* (Linnaeus, 1758) which is abundant along the west coast of north Africa, extending to the coast of northern Europe and the Mediterranean, *T. picturatus* (Bowdich, 1825) which is found in the eastern Atlantic, extending to the coast of southwest Europe, *T. mediterraneus mediterraneus* (Steindachner, 1868) and *T. mediterraneus ponticus* (Aleev, 1956) which are both found on the south west coast of Europe and in the Mediterranean, *T. declivis* (Jenyns, 1841) which is found on the south coast of Australia and on the west coast of New Zealand, *T. novaezelandiae* (Richardson, 1842) which is found on the south and east coast of Australia, *T. japonicus* (Temminck and Schlegel, 1844) which is found surrounding Japan and adjacent seas, *T. symmetricus* (Ayres, 1855) which is found off the southwest coast of North America, *T. murphyi* (Nichols 1920) which is found on the west coast of South America, *T. lathami* (Nichols 1920) which is found on the east coast of North and South America, *T. longimanus* (Norman, 1935) which is found offshore in the Indian Ocean, *T. indicus* (Necrassov, 1966) which is found in the Arabian Sea in the northern Indian Ocean, *T. trecae* (Cadenat, 1949) which is found on the coasts of Angola and northern Namibia, *T. delagou* (Necrassov, 1970) which is found on the east coast of southern Africa and *T.*

*capensis* (Castelnau, 1861) which is abundant off the south and west coasts of South Africa and off Namibia (Nichols 1920, Geldenhuys 1973, Crawford 1989, Salem 1995, Yankova *et al.* 2008).

As a result of the close resemblance between the northern European species *T. trachurus* and the Cape horse mackerel *T. capensis*, they were initially not recognised as separate species (Geldenhuys 1973). Instead, following DNA analyses conducted by Naish (1990), the Cape horse mackerel became a sub-species of *T. trachurus* and was recognised as *T. trachurus capensis*. The Cape horse mackerel has since been recognised as a separate species from *T. trachurus* and is known as *T. capensis* in recent classifications (Salem 1995). Cape horse mackerel will be referred to as *T. capensis* in this research and is considered identical to the species referred to as *T. trachurus capensis* in some of the most recent publications, including Barange *et al.* (1998), Sardinha (2002), Axelsen *et al.* (2003), and Barange *et al.* (2005).

### **Cape horse mackerel *T. capensis***

The Cape horse mackerel is a shoaling fish species occurring off the coasts of Namibia and South Africa in the southern Benguela ecosystem. The species is distributed from the west coast southwards until just past Port Elizabeth on the east coast, and is known to occur across the full extent of the Agulhas Bank (Barange *et al.* 1998, Anon. 2004). In the past, it was assumed that the west and south coast horse mackerel populations formed separate stocks (Hecht 1990, Kerstan and Leslie 1994). However, these populations are genetically homogenous and believed to be a single stock, physically separated from the Namibian stock by the Luderitz upwelling cell, a strong, thermal environmental barrier (Hecht 1990, Kerstan and Leslie 1994, Barange *et al.* 1998, van der Lingen and Huggett 2003, Anon. 2004, Coetzee *et al.* 2008, Hutchings *et al.* 2009). As a result, there is limited exchange of fish between the Namibian and South African stocks (Barange *et al.* 1998). The species prefers cool coastal waters found on the west and south coasts and can occur to approximately 500m deep. The species is long-lived and individuals can live to between eight (Anon. 2004) and 10 years (Geldenhuys 1973, Hecht 1990, Naish *et al.* 1991). It has a slow rate of growth and can grow to a maximum length of between 50cm (Geldenhuys 1973, Naish *et al.* 1991) and 70cm in total length (TL) (Crawford 1989, Anon. 2004).

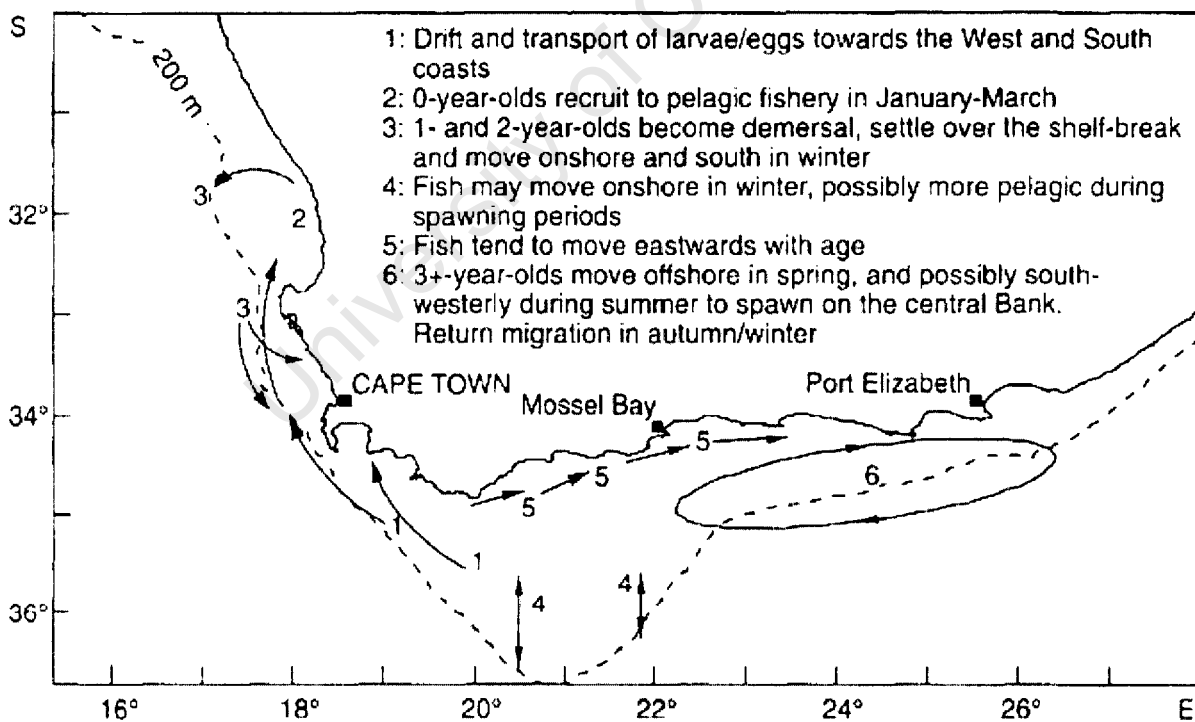
### **Spawning**

Cape horse mackerel spawn indeterminately and intermittently in batches throughout the year, although they appear to have two major spawning periods which occur from May to

August and October to January (Hecht 1990, Kerstan and Leslie 1994, Barange *et al.* 1998). There also appears to be some variation in spawning time across the Agulhas Bank with peak spawning being recorded in winter (June) and spring (November) on the EAB and in summer (February) and winter (August) on the WAB (Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004).

### ***Distribution and Life History Strategy***

The species exhibits spatial variations in distribution on different scales, including regionally in an east-west direction and across-shelf in an inshore-offshore direction over several kilometres, and vertically within the water column on a diurnal scale and over several tens of meters (Hecht 1990, Barange *et al.* 1998, Anon. 2004). Distribution is influenced by age, food availability, individual level of sexual maturity, spawning, time of day and seasonal environmental factors (Barange *et al.* 1998, Anon. 2004). During summer, a portion of eggs and larvae from fish spawning on the CAB and WAB are transported northwards in the jet current (Figure 1.3) (Barange *et al.* 1998). Recruitment primarily occurs on the west coast



**Figure 1.3:** Schematic of Cape horse mackerel life history, migration and spawning strategies off the South African south and west coasts proposed by Barange *et al.* (1998). Number 1 represents the jet current.

and the arrival of new recruits is reflected by a peak in purse-seine landings from January to March (Figure 1.3) (Barange *et al.* 1998). Recruitment is greatest along the west coast

because of the high food availability in the form of plankton as a result of the high primary production that occurs in the nutrient-rich upwelled water (Philander 1998, Anderson and Lucas 2008).

Eggs retained on the south coast are scattered along the coast in small localised areas, where secondary recruitment occurs in sheltered bays (Hecht 1990, Barange *et al.* 1998). At 1-2 years of age the juveniles mature and enter the spawning cycle becoming demersal and moving offshore to settle over the shelf break (Figure 1.3) (Barange *et al.* 1998). In winter and assisted by the poleward flow of bottom water along the shelf break, individuals on the west coast tend to move onshore and southwards whereas those on the south coast move offshore and eastwards (Figure 1.3) (Barange *et al.* 1998). During this time the fish become less demersal and more pelagic in their distribution, particularly during spawning periods (Figure 1.3) (Booth and Hecht 1998). This behaviour can explain the seasonality found in landings of the inshore demersal trawl industry, which shows smallest catches coinciding with periods of peak spawning from November to December (Barange *et al.* 1998). However, this diurnal movement is thought to be not nearly as important as the west-east or offshore-onshore movement of fish with age.

As they grow older the fish tend to move eastwards, with the oldest (usually >3 years) and largest (>30cm TL) horse mackerel occurring the furthest east (Figure 1.3) (Barange *et al.* 1998). Large individuals are also known to migrate south and westwards to spawn in summer on the WAB and CAB and perform their eastward return migration in autumn and winter (Figure 1.3) (Barange *et al.* 1998, Booth and Hecht 1998). Migratory routes can take several years to complete, with older adult fish migrating more than sub-adults or juveniles (Barange *et al.* 1998).

On a much smaller scale, the distribution of horse mackerel vertically in the water column is thought to be influenced by feeding aggregations, predator avoidance and spawning strategy (Barange *et al.* 1998, Booth and Hecht 1998). Horse mackerel reside close to the seafloor, exhibiting demersal behaviour during the day, whereas at night they migrate to shallow mid-water and become more pelagic (Kerstan and Leslie 1994, Barange *et al.* 1998, Axelsen *et al.* 2003, Anon. 2004).

## **Feeding**

Cape horse mackerel are mainly non-specialist planktivores, filter feeding primarily on zooplankton. There is evidence of horse mackerel changing diet with size, with small and medium individuals being mainly planktivorous and large individuals (>30cm in TL) becoming opportunistic omnivores and piscivores in their feeding habits (Hecht 1990, Kerstan and Leslie 1994, Anon. 2004). During the day, horse mackerel feed on small *Calanus* copepods that reside on the seabed in high concentrations; this is thought to explain their day-time demersal behaviour (Barange *et al.* 2005). At night, the copepods leave the seafloor and move up in the water column. The horse mackerel do the same, becoming more pelagic (Barange *et al.* 2005). It is possible that horse mackerel follow the copepods up into the water column at night to feed. However, at night the copepods are widely distributed within the water column and more difficult to feed on, unlike during the day where they can be found in higher concentrations. Therefore it is also argued that horse mackerel do not become more pelagic at night to feed but rather to reduce being preyed on in conditions of reduced visibility by the permanently demersal hake (*Merluccius capensis*) (Barange *et al.* 2005).

## **Fishery**

The semi-pelagic nature of horse mackerel means it is commonly found shoaling with both pelagic and demersal species, including anchovy, sardine and hake (*Merluccius capensis* and *M. paradoxus*). As a result, horse mackerel come into contact with and make up a large proportion of the catch and by-catch of three different fishing sectors (Barange *et al.* 1998, Anon. 2004, Anon. 2010). The surface pelagic purse-seine fishery takes juvenile horse mackerel as by-catch on the west coast, the demersal trawl fleet takes adult horse mackerel as by-catch on the south and west coasts, and the mid-water trawl fishery targets adult horse mackerel on the south coast (Anon. 2010).

Commercial fishing of horse mackerel commenced in 1943 through pelagic fishing in and around St. Helena Bay on the west coast (Geldenhuys 1973). As no catch statistics were kept during the first few years, estimates were made from the production output of fish meal and canned fish (Geldenhuys 1973). The first detailed catch statistics were recorded in 1950 when annual catches were increasing as the industry continued to expand (Figure 1.4) (Geldenhuys 1973, Barange *et al.* 1998, Anon. 2010). Initially the pelagic purse seine fishery on the west coast targeted adult horse mackerel, but switched to targeting sardine following a decline in horse mackerel in the late 1950s. Since the switch, juvenile horse mackerel are taken as by-

catch by the pelagic fishery (Barange *et al.* 1998, Anon. 2010). Large catches (>50 000 tons) of adult horse mackerel were made from 1950 to 1958 and, according to age composition data, these large catches coincided with the presence of two exceptionally strong year classes (Geldenhuys 1973). The largest pelagic catch of adults was 118 142 metric tons, landed in 1954 (Figure 1.4) (Geldenhuys 1973, Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004, Anon. 2010). Following peak catches in the early 1950s, purse seine catches of adult

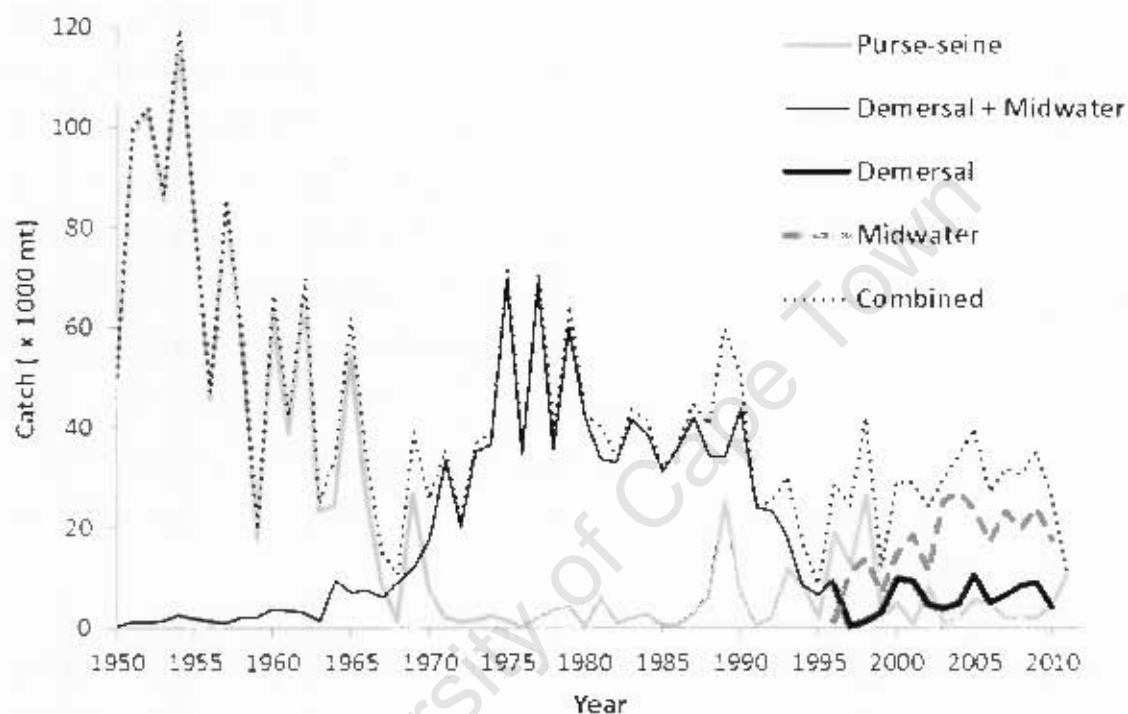


Figure 1.4: Historical catch according to fishery type of South African horse mackerel from 1950 to 2010 (Anon 2010).

horse mackerel decreased steadily (Figure 1.4) (Geldenhuys 1973, Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004, Anon. 2010).

It is thought that the decline in catches following the period 1950 to 1958 was due to the disappearance of strong year classes, which were heavily fished and accounted for the bulk of the catches within the eight year period (Geldenhuys 1973). It is believed that, as a result of these large purse-seine catches on the west coast in the early 1950s, the large schools of adult horse mackerel, once common to the South African west coast, disappeared (Anon, 2010). Purse seiners began to target juvenile horse mackerel in the 1990s in the same area of the west coast, and by 1998 the catches of juveniles on the west coast had climbed to just over 26 000 metric tons (Figure 1.4). This increase in pelagic catches of juveniles prompted

modelling assessments in the late 1990s to determine what impact targeting juveniles would have on recruitment of adult horse mackerel to the south coast (Anon. 2010). Based on these models, a precautionary upper catch limit of 5 000 tons of juvenile horse mackerel was introduced for the purse-seine fishery (Anon. 2010).

In the 1960s the demersal inshore fishery and foreign trawlers (mainly Japanese) began targeting sub-adult and adult horse mackerel on the south coast (Barange *et al.* 1998, Anon. 2010). From 1969 onwards, these age groups accounted for approximately 80% of landings in the demersal and mid-water trawl-directed fishery on the Agulhas Bank. Landings peaked in 1977 with a catch of 78 000 metric tons (Kerstan and Leslie 1994, Anon. 2004, Anon. 2010) (Figure 1.4). Following the declaration of South Africa's exclusive economic zone (EEZ) in 1977, most foreign fishing fleets were withdrawn from the South African coastline in 1978. The Japanese fleet legally continued fishing for horse mackerel under licence until 1991 (Anon. 2010, Atkinson *et al.* 2011). With the exclusion of most foreign fishing vessels in 1978, catches levelled off to between 30 000 and 45 000 metric tons (Anon. 2010). After the Japanese withdrawal in 1991, annual catches decreased from almost 45 000 metric tons to between 10 000 and 25 000 metric tons landed by South African vessels, and remained at this level until 1996 (Anon. 2010).

In 1991, there were initiatives to start a local mid-water trawl horse mackerel-directed fishery on the Agulhas Bank (Barange *et al.* 1998, Anon. 2004). This prompted the then Sea Fisheries to commence modelling studies in order to provide scientific management advice (Barange *et al.* 1998, Anon. 2004). The shortage of dependable long term data sets initially delayed the modelling studies and many of the evaluations carried out had large uncertainties (Kerstan and Leslie 1994, Barange *et al.* 1998). The lack of long term data sets also meant that, prior to 1996, catches between the demersal and mid-water trawl fishery could not be separated (Figure 1.4). Whereas demersal trawl catches remained low since 1991, the successful re-establishment of the mid-water trawl horse mackerel-directed fishery in 1996 and 1997 resulted in an increase in the annual catch from under 9 000 metric tons in 1995 to above 28 000 metric tons in 2006 (Figure 1.4) (Anon. 2010). Currently, the largest concentration of adult horse mackerel that remains on the South African coastline is found on the EAB.

The southern and eastern areas of the Agulhas Bank have exploitable quantities of large fish and the mixture of size and sheer volume of fish makes the mid-water trawl fishery

economically viable (Anon. 2004). As a result, the majority of horse mackerel is caught by the dedicated mid-water trawl fishery off the south east coast. The greatest fishing effort

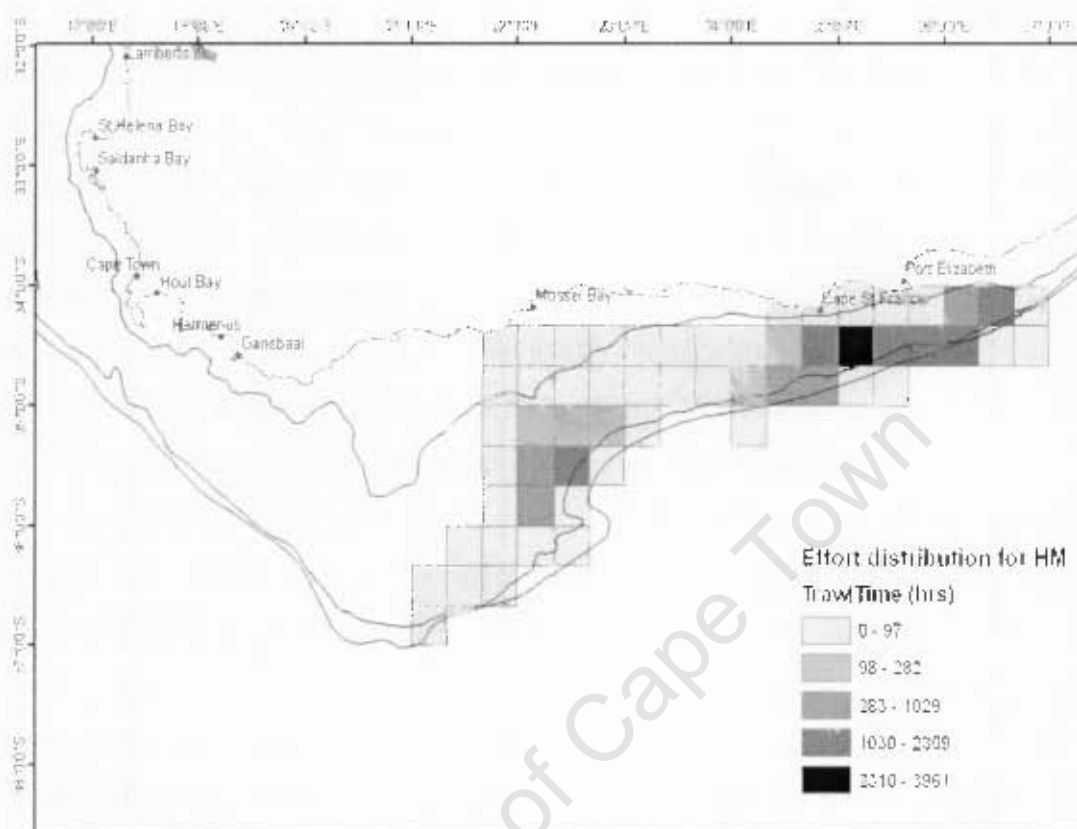


Figure 1.5; The distribution of fishing effort by the mid-water trawl horse mackerel-directed fishery. Fishing effort is represented as trawl time (hours) (Smith *et al.* 2011).

occurs on the EAB, followed by a small area offshore on the eastern edge of the CAB (Figure 1.5) (Anon. 2004, Smith *et al.* 2011).

Fishing vessels need to be powerful enough to tow large mid-water nets containing up to 100 metric tons of fish at speeds of up to 6 knots for a few hours (Anon. 2004, Anon. 2010). They also require high storage capacity for freezing the catch following processing, which can take up to 12 hours for a single 100 metric ton haul (Anon. 2004). Due to expensive operational costs, a single vessel needs large volumes of catch, more than 14 000 tons annually (Anon. 2004, Anon. 2010). No value-adding occurs as the main product is frozen whole and most of it is exported to markets in Central and West Africa due to poor demand for the fresh fish in the South African market (Naish *et al.* 1991, Barange *et al.* 1998, Anon. 2004). Consequently, the vessels in the dedicated horse mackerel mid-water trawl fishery are generally large factory trawlers (Anon. 2004). Although research shows that horse mackerel

is potentially the largest single fishery on the Agulhas Bank, it is an economically marginal species that is capital-intensive, providing minimal employment (Anon. 2004).

### **Management**

Since 2001, horse mackerel has been managed using a constant catch strategy (Anon. 2010). A precautionary maximum catch limit of 44 000 metric tons is set, mostly allocated to the mid-water trawl horse mackerel-directed fishery, with some of the catch limit, 12 500 metric tons, allocated to incidental by-catch of horse mackerel in the demersal hake-directed fishery (Anon. 2004, Anon. 2010, Smith *et al.* 2011). There is a desire for two dedicated mid-water trawl vessels in this sector, but it is only economically viable for one vessel to operate, currently the *F.V Desert Diamond* (Anon. 2004, Anon. 2010, Smith *et al.* 2011). This vessel catches approximately 85% of the allocated precautionary maximum catch limit; the remainder is caught by four smaller inshore vessels in the sector. Since 2000, a precautionary upper catch limit of 5 000 metric tons, which is not part of the precautionary maximum catch limit of 44 000 metric tons, has been placed on the pelagic purse-seine fishery on the west coast for juvenile horse mackerel (Furman and Butterworth 2011, van der Lingen *et al.* 2011). This precautionary upper catch limit came about following a 1999 age-structured model assessment of the horse mackerel resource that showed that the horse mackerel stock was very sensitive to purse-seine catches of juveniles, with even a small catch having a substantial negative impact on the demersal catch of adult horse mackerel that can be sustained on the south coast (Anon. 2010).

The western spawning migration of large sub-adult and adult horse mackerel means they are not always found on the EAB, so a vessel's catch is largely dependent on local availability. Consequently, the four smaller vessels in this sector do not only target horse mackerel but are eligible to hold several fishing rights simultaneously and carry both mid-water trawl gear for targeting horse mackerel and demersal trawl gear for targeting hake (*Merluccius capensis*) or sole (*Austroglossus pectoralis*) (Anon. 2010). This improves the economic viability of these smaller vessels by making them more adaptable to target species based on their availability. The inshore hake and sole trawlers catch about 1 500 tons per year of horse mackerel as by-catch but are known to specifically target horse mackerel when availability is high (Anon. 2004).

Mid-water trawling for horse mackerel is not permitted in water shallower than 110m or less than 20 nautical miles from the coast (Anon. 2004), as poor targeting practices and fishing

too close to the seafloor leads to unwanted by-catch and incidental catch of other species. The most common by-catch species are ribbonfish (*Lepidopus caudatus*), sunfish (*Mola mola*), chub mackerel (*Scomber japonicus*) and some marine mammal species such as common dolphin (*Delphinus delphis*) and bottlenose dolphin (*Tursiops species*) (Anon. 2004). The species of particular commercial concern is hake (*Merluccius capensis*) targeted by the demersal trawl fishery, because by-catch of this species in the mid-water trawl horse mackerel-directed fishery is unavoidable, a reserve amount of 2% of the current hake Total Allowable Catch (TAC) is set (Anon. 2004, Anon. 2010). Dumping of any by-catch or offal is not permitted, and tori lines are mandatory for every vessel while towing, in order to reduce bird casualties (Anon. 2004, Anon. 2010). In order to monitor the above-mentioned ecosystem considerations, the sector is currently subjected to 100% observer coverage (Anon. 2010).

An age-structured production model was developed in 1999 to assess the horse mackerel resource. The results suggested that the level of demersal catch of horse mackerel on the south coast is sensitive to, and could be negatively affected by, pelagic catches of juvenile horse mackerel on the west coast (Anon. 2010). As a result, a reduced precautionary maximum catch limit of 34 000 metric tons was set for 2001 and the by-catch of juvenile horse mackerel in the pelagic fishery was limited to 5 000 metric tons (Anon. 2010). In 2001, the age-structured model was updated and used to determine resource responses to certain management options (Anon. 2010). The results suggested that, as long as no negative consequences were identified, the annual precautionary maximum catch limit could be increased from 34 000 to 44 000 metric tons for the next few years until 2005 (Anon. 2010). Since 2003, annual horse mackerel landings were approximately 30 000 metric tons, being much lower in 2006 and 2008 (Anon. 2010). An assessment was carried out in 2007, giving similar results to those previously obtained and being used to set the annual precautionary maximum catch limit and make recommendations in the fishery (Anon. 2010). It was concluded that no negative consequences of the current catch limit from the previous few years of fishing was evident and, as a result, the precautionary maximum catch limit from 2007 to present should remain 44 000 metric tons per annum.

### ***Stock Assessment***

The first acoustic assessment cruises for horse mackerel were run every October from 1991 to 1994, between Mossel Bay and East London, in an attempt to estimate the available biomass

of horse mackerel there and begin long term data sets of abundance (Barange *et al.* 1998, Anon. 2010). The main advantage of acoustics is its ability to sample large volumes of water with high accuracy and resolution on both horizontal and vertical planes (Axelsen *et al.* 2003). However, it remains difficult to obtain reliable estimations when the fish are dispersed (Barange *et al.* 1998). Furthermore, acoustic surveys fail to detect a large portion of the horse mackerel stock over the shelf or close to the seafloor, where they are known to occur during the day (Barange *et al.* 1998). Conversely, bottom trawling during the day was successful in detecting horse mackerel in some areas, such as the inner shelf around Mossel Bay (Kerstan and Leslie 1994, Barange *et al.* 1998, Axelsen *et al.* 2003, Anon. 2010). However, trawling is only effective during the day and ineffective at the shelf break, where a substantial portion of the horse mackerel population extends beyond the routine survey area and over untrawlable grounds (Kerstan and Leslie 1994, Barange *et al.* 1998, Axelsen *et al.* 2003, Anon. 2010).

Hence, the outcomes of stock assessments based on a single survey method are inaccurate, and neither bottom trawl nor acoustic data can be treated as reliable independent estimates of abundance (Barange *et al.* 1998, Anon. 2010). Combined bottom trawl and acoustic surveys appear to be the only effective means of assessing the total abundance of horse mackerel (Barange *et al.* 1998). However, horse mackerel surveys have not been conducted since 1994. The current population model for horse mackerel incorporates commercial catch data and demersal survey data in order to estimate variations in recruitment and compare this to the November pelagic survey abundance results (Furman and Butterworth 2011), but it appears that either the November survey estimates are a weak predictor of incoming horse mackerel recruitment strength or the data supporting the model are inaccurate, because the size of the resource is underestimated (Kerstan and Leslie 1994, Furman and Butterworth 2011). The biomass of horse mackerel on the west coast is five times smaller than on the south coast, making the west coast less important when assessing total stock size (Barange *et al.* 1998). The species is currently believed to be under-exploited, but maintaining the current catch limits is considered appropriate according to the last model assessment carried out in 2007 (Aukland and Ninnes 2004, Anon. 2004, Anon. 2010).

### ***Aims***

It is believed that a strong horse mackerel year class in 2010 led to a substantial increase in juvenile horse mackerel on the west coast (Furman and Butterworth 2011). This resulted in large by-catch of juvenile horse mackerel by pelagic purse-seiners, particularly those in the

anchovy-directed fishery (van der Lingen *et al.* 2011). This became problematic for the pelagic industry, and despite adaptive measures (e.g. area closures) being implemented landings of horse mackerel continued to increase and, as a result, the precautionary upper catch limit was increased from 5 000 to 10 000 metric tons (5<sup>th</sup> April 2011) and then to 12 000 metric tons (8<sup>th</sup> July 2011) (Furman and Butterworth 2011, van der Lingen *et al.* 2011). Exceeding the precautionary upper catch limit can lead certain fisheries to stop fishing before reaching their full quota for their target species. This occurred in 2002, when 8 000 metric tons of horse mackerel was caught early in the year as by-catch in the pelagic fishery, necessitating a temporary, three-week closure of the anchovy-directed fishery (van der Lingen *et al.* 2011). Such closures can have large economic implications for the fishing industry, emphasizing the need to update the current understanding of the life history of this species. However, updating understanding is not just motivated by the fishing industry but also by the need to understand the impact of consistently-changing environmental conditions in both the long and short term.

The most recent summary of knowledge of horse mackerel life history, including distribution patterns and spawning strategies, can be found in Barange *et al.* (1998). It is possible that certain aspects of the species' life history may have changed since then as a result of fishing pressure or environmental influences, or both. In this study, the conceptual hypotheses about the ecology and life history of horse mackerel proposed by Barange *et al.* (1998) will be re-evaluated and possible revisions proposed. This re-evaluation will fill gaps in and add to our understanding of key features of horse mackerel life history in the southern Benguela ecosystem, such as distribution on a spatial scale and reproductive strategies on a temporal scale. The re-evaluation will be based on 14 years of acoustic survey data collected subsequent to acoustic data used by Barange *et al.* (1998), and 28 years of demersal survey data, as well as some new biological data relating to spawning seasonality. All this information will be synthesized to answer the main research questions.

- (1) Does the new information support or refute the hypothesised horse mackerel life history strategy proposed by Barange *et al.* (1998) (Figure 1.3)?
- (2) Does the synthesis of information improve our understanding about horse mackerel life history strategy?
- (3) If the life history strategy of horse mackerel has changed, are there management changes that need to be made or considered?

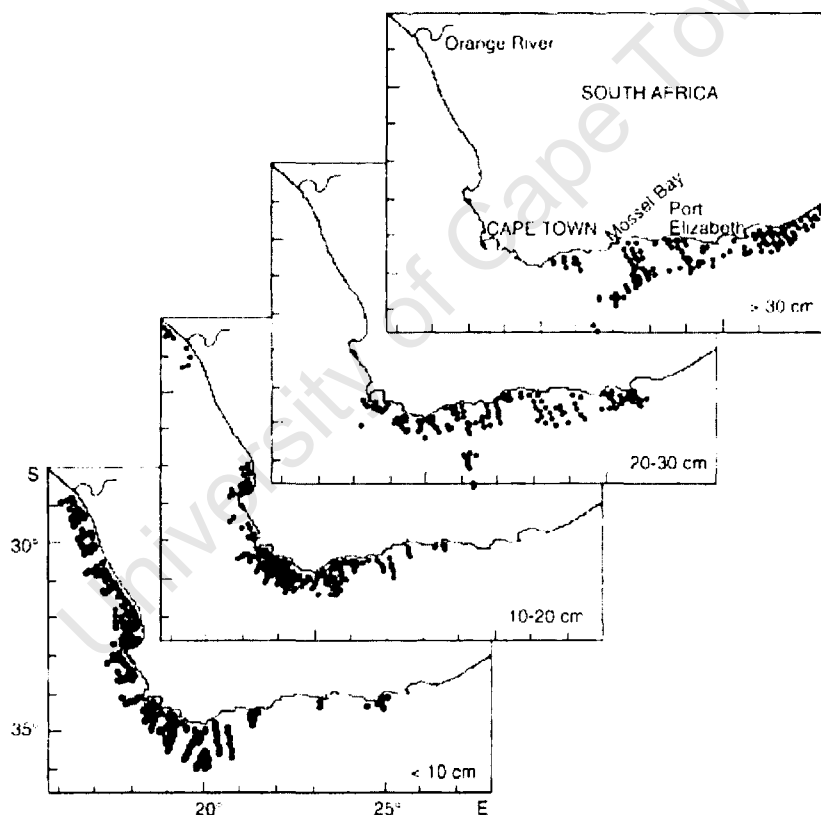
## **Chapter 2: The distribution by size of horse mackerel *Trachurus capensis* in the southern Benguela**

### ***Abstract***

The distribution of Cape horse mackerel *Trachurus capensis* in the southern Benguela was analysed using acoustic and mid-water trawl data collected during bi-annual surveys of pelagic fish conducted over the period 1997-2010, and demersal trawl data collected during bi-annual surveys of demersal fish conducted over the period 1984-2011. Consistent patterns were seen from both surveys, with horse mackerel showing size-specific distribution patterns and exhibiting an eastward shift with size. Small fish <10cm total length (TL) are prevalent along the west coast and western Agulhas Bank (WAB), and are often found on the central Agulhas Bank (CAB) and extending onto the eastern Agulhas Bank (EAB). Medium-size fish of 10-19.9cm TL and 20-29.9cm TL are common across the CAB, with the latter often found further east. The largest fish >30cm TL are found on the CAB and EAB, increasing in prevalence eastwards to Port Alfred. Both pelagic and demersal surveys show that horse mackerel are most abundant on the CAB and EAB, but are also consistently found in St. Helena Bay on the west coast. The distribution patterns observed in this study are broadly comparable with previous studies, but show an increase in abundance of juveniles on the CAB and EAB and of adults in St. Helena Bay. Horse mackerel recruitment estimated from pelagic surveys was high in 2000, possibly linked to unusual large-scale oceanographic events. Survey and catch data also show a strong year class in 2010. Based on these results, horse mackerel is expected to be abundant for the next few years. Previously, strong year classes recorded in the 1950s resulted in a short (<10 year) period of high catches followed by a stock collapse.

## Introduction

The distribution of horse mackerel, *Trachurus capensis*, in the southern Benguela appears to be greatly influenced by fish size. The species exhibits variations in distribution in an alongshore, east-west direction as well as in an inshore-offshore direction (Hecht 1990, Barange *et al.* 1998, Anon. 2004). Fish tend to move further offshore and eastwards as they increase in size (Kerstan and Leslie 1994), and are mostly <30cm TL to the west of 24°E whereas to the east they are mostly >25cm TL (Figure 2.1) (Barange *et al.* 1998). Horse mackerel recruits (<10cm TL, ~ 6 months of age) occur primarily on the west coast which serves as their nursery area (Figure 2.1) (Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004). The abundance of food as a result of nutrient rich upwelled water on the west coast makes it ideal for recruitment of small fish, not only horse mackerel (Hutchings *et al.* 2002).



**Figure 2.1:** The distribution of Cape horse mackerel along the South African coast according to size class. The fish sizes were derived from acoustic/mid-water trawl surveys carried out in South African waters for the period 1984-1996 (Barange *et al.* 1998).

Some horse mackerel recruitment is also known to occur irregularly in sheltered bays along the south coast (Hecht 1990, Barange *et al.* 1998). However, the recruitment that occurs on the south coast is much smaller than that on the west coast (Figure 2.1). The abundance of

horse mackerel juveniles on the west coast has previously resulted in them being targeted by the pelagic fishery there, with peak purse-seine landings occurring from January to March (Barange *et al.* 1998).

Horse mackerel mature at approximately 2 years of age and enter the spawning cycle, becoming demersal and moving offshore to settle over the shelf break on the west coast (Kerstan and Leslie 1994, Barange *et al.* 1998). During winter, bottom water moves poleward along the shelf break, assisting the fish in their southwards movement to the Agulhas Bank (Kerstan and Leslie 1994, Barange *et al.* 1998), and fish tend to move eastwards as they age (Kerstan and Leslie 1994, Barange *et al.* 1998). These movements result in size-specific distribution patterns, with small, young fish (juveniles and sub-adults of 10-20cm TL, ~ 1-2 years of age) occurring on the WAB and medium-sized fish (young adults of 20-30cm TL, ~ 2-3 years of age) found both in shallow bays and across the shelf on the CAB (Figure 2.1) (Barange *et al.* 1998, Anon. 2004). The oldest, largest fish (>30cm TL, ~ 3-4 years of age) generally occur the furthest east and are abundant on both the south and east coasts (Figure 2.1) (Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004), with the oldest and largest horse mackerel seeming to have an affinity for the shelf edge region of the EAB (Barange *et al.* 1998).

Where the EAB extends offshore and westwards, the continental shelf edge forms a sharp corner in the ocean topography. The fast-flowing Agulhas current flows along the shelf edge, causing topographically-driven upwelling (Hutchings *et al.* 2009). This creates a small, localised area of enhanced primary productivity offshore on the inside edge of the Agulhas Current. The abundance of food could be an explanation for the large densities of horse mackerel found in this area. The presence of a cool ridge of upwelled water extending southwards from the EAB onto the CAB is also thought to affect the distribution of small pelagic fish in the area (Hutchings *et al.* 2009). This region of abundant food near the shelf edge is also thought to be a factor motivating the offshore movement of large individuals (Figure 2.1) (Barange *et al.* 1998).

The largest, oldest individuals participate in a spawning migration, moving southwards and westwards in summer to the WAB and CAB, returning to the EAB in autumn and winter (Barange *et al.* 1998). Fish tend to move offshore with age while still remaining on the continental shelf, and they only move inshore to spawn (Barange *et al.* 1998). Their distribution around the coast in an east-west direction is more marked than onshore and

offshore movements. Minimum abundances of horse mackerel occur at approximately 24°E between Plettenberg Bay and Cape St Francis, apparently caused by the narrowing of the continental shelf which brings the 100m isobath close to the coast in that region (Figure 2.1) (Japp *et al.* 1994, Barange *et al.* 1998). The adult horse mackerel that used to occur in and around St. Helena Bay on the west coast, have not been seen there since the 1950s and are thought to have been fished out by the pelagic purse-seine fleet from 1950 to 1958 (Geldenhuys 1973).

The aim of this chapter was to determine whether horse mackerel still show a clear distribution pattern based on size, as described by Barange *et al.* (1998). This analysis will be based on 14 years of new pelagic-survey data and 28 years of demersal-survey data not previously analysed for this species. Changes in distribution patterns in sardine and anchovy have been seen in the past two decades (Roy *et al.* 2007, Coetzee *et al.* 2008) and, as a result, some change in distribution patterns of horse mackerel might also be expected.

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## Methods

Acoustic and mid-water trawl data collected over the period 1997-2010 during the May pelagic recruit-survey (Figure 2.2) and the November pelagic spawner biomass-survey (Figure 2.3), and demersal-survey data (Figure 2.4) collected over the period 1984-2011 from both the south and west coasts were analysed. Two pelagic surveys have been conducted annually since 1984 to estimate abundance and recruitment strength of anchovy, sardine and round-herring and to collect data on other species, including horse mackerel (van der Lingen and Iluggett 2003, Coetzee *et al.* 2008). Each year, recruitment is estimated in May between the Orange River and Port Alfred (Figure 2.2) and spawner biomass is estimated in November between Hondeklip Bay and Port Alfred (Figure 2.3) (Coetzee *et al.* 2008). The surveys are divided into standard strata transects, A-I in the May recruit-survey (Figure 2.2) and A-F in the November spawner biomass-survey (Figure 2.3) with randomly spaced, parallel transects, along which continuous acoustics and directed mid-water trawling is conducted to obtain unbiased estimates of stock size (Coetzee *et al.* 2008). Not all strata were sampled each year.

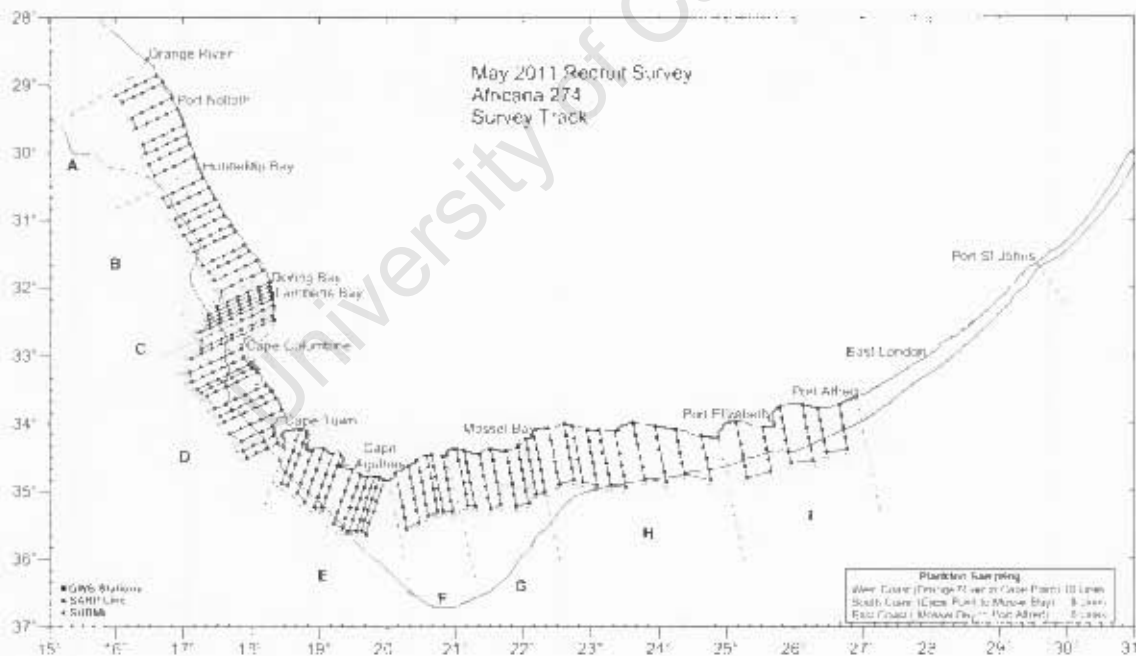
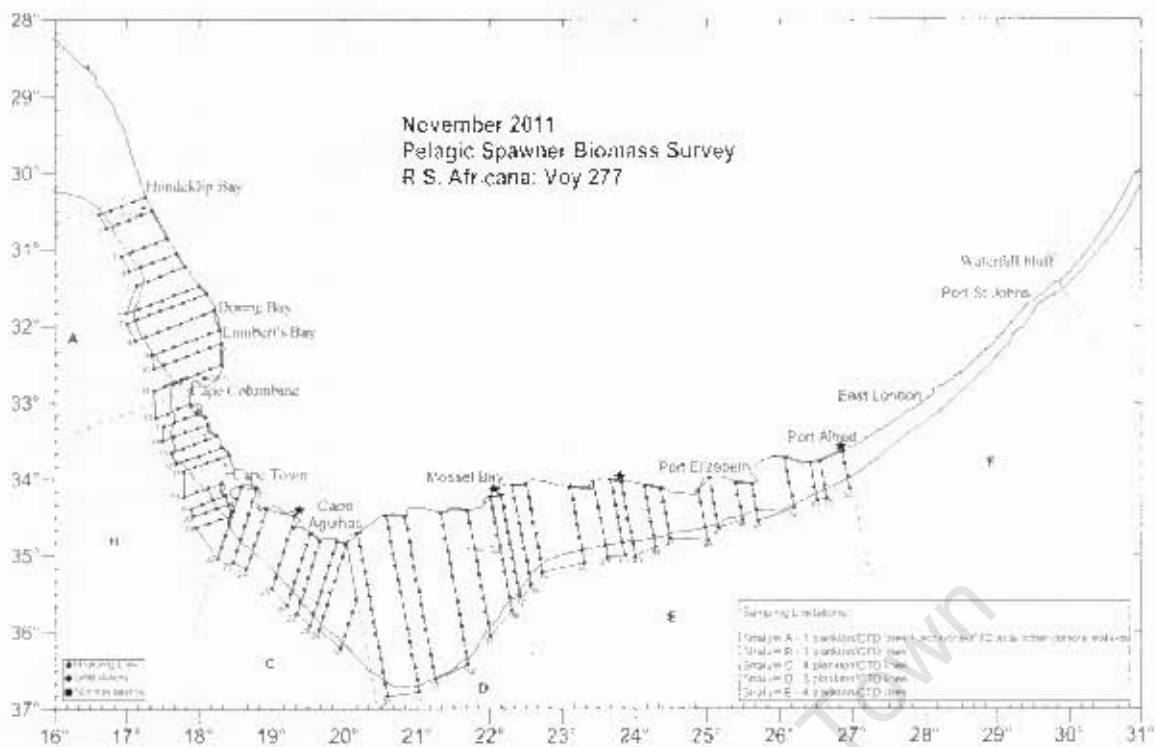


Figure 2.2: A map of the survey track chart for May recruit surveys showing the dividing lines between strata A-H. Lines = survey tracks along which continuous acoustic sampling and directed trawling is conducted.

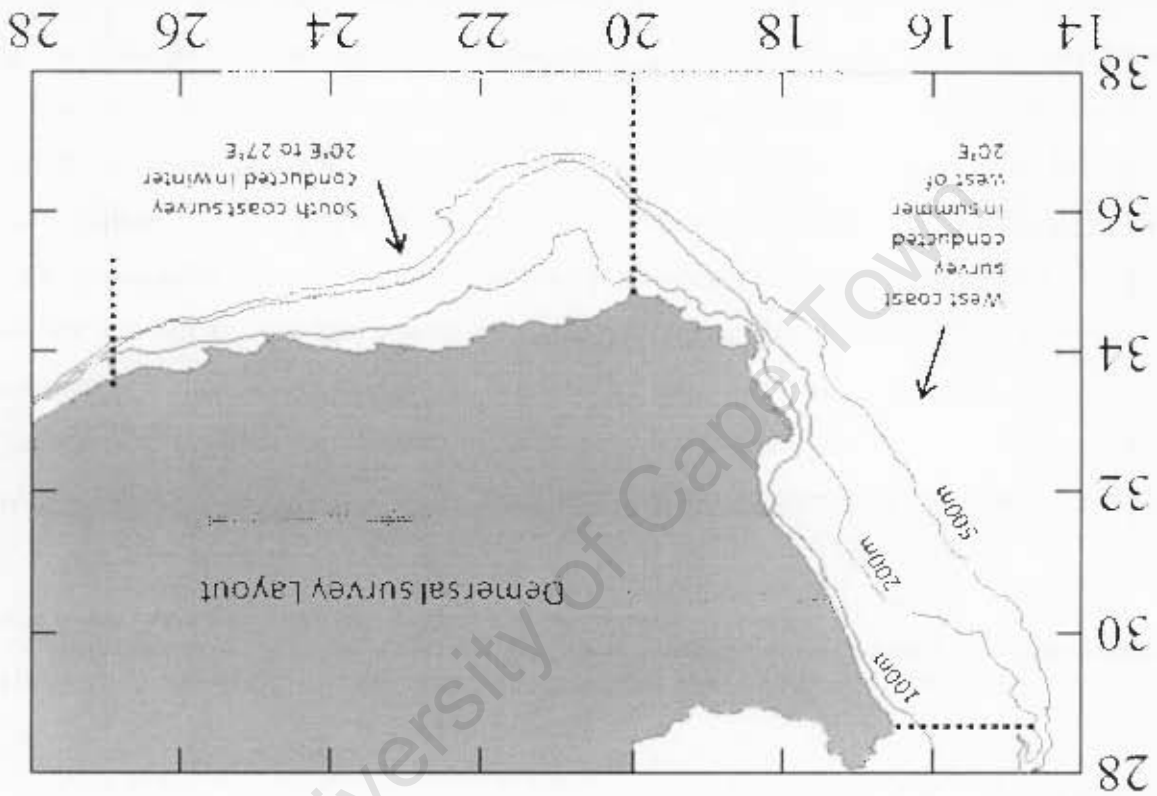


**Figure 2.3:** A map of the survey track chart for November spawner biomass surveys showing the dividing lines between strata A-F. Lines = survey tracks along which continuous acoustic sampling and directed mid-water trawling is conducted. Stratum F is not routinely surveyed.

Pelagic survey data from 1997-2010 were presented as presence per average size class, length frequency distribution per stratum per year and biomass per stratum per year. Presence per average size class was calculated by determining mean fish length per trawl which was then assigned to one of four size classes (1-9.9cm TL, 10-19.9cm TL, 20-29.9cm TL, and >30cm TL), and mapped, making the data comparable to Barange *et al.* (1998). Maps for each year (Appendices 1 and 2) and a composite map of all acoustic data extending 1997-2010 were produced. Horse mackerel length frequency distributions per stratum were plotted, and composite length frequency distributions per year were calculated by weighting strata length frequencies by stratum biomass (Appendices 3 and 4). Acoustically derived biomass estimates were used to produce mean biomass per stratum for the entire period, as well as the change in biomass per stratum per year.

Demersal surveys are conducted bi-annually (and have been since 1984) to estimate abundance and collect data on shallow-water Cape hake (*Merluccius capensis*), deep-water Cape hake (*M. paradoxus*), sole (*Austroglossus pectoralis*) and Cape horse mackerel (*T. capensis*) (Yemane *et al.* 2008, Atkinson *et al.* 2011). Each year, demersal abundance surveys are conducted on the west coast (west of 20°E) in summer (January/February) and on the

Figure 2.4: A map showing the extent of the demersal west coast and south coast survey. Survey is conducted from inshore to the 500m isobath.



south coast (20°E to 27°E) in winter (June/July) (Figure 2.4) (Yemane *et al.* 2008, Atkinson *et al.* 2011). Demersal-survey data from 1984-2011 (excluding 1998, 2000, 2001 (no west coast survey) and 1984, 1986, 2002 (no south coast survey)) were analysed. Data were in the form of abundance (number per  $\text{m}^2$ ) per length class (1-9.9cm TL, 10-19.9cm TL, 20-29.9cm TL and >30cm TL) per demersal trawl for both south and west coasts per year. The four size classes used are directly comparable to those presented by Barange *et al.* (1998). Abundances were plotted using colour contour maps per size class per year (Appendices 5 and 6) and a composite of all years was produced. All outputs were produced using Microsoft Office Excel 2010 (Microsoft Home and Business 2010) and Surfer 8 (graphic representation software, Golden Software Inc. Version 8.3.45.0).

## **Results**

Three different outputs were produced from the pelagic survey acoustic data set: (1) presence per average size class per year, (2) the length frequency distribution of the population per year and (3) biomass estimates per stratum per year. One output was produced from the demersal survey data: density and distribution of the size classes per year.

### **Distribution and abundance of horse mackerel from pelagic survey data**

#### **Presence per average size class**

Individuals <9.9cm TL were found across the shelf throughout the west coast, especially St. Helena Bay and the WAB, decreasing in prevalence eastwards to Port Elizabeth on the EAB (Figure 2.5). Individuals from this size class are numerically dominant on the west coast compared to the larger size classes (Figure 2.5). This size class has been recorded, very rarely, up to the midshelf region on the CAB and inshore on the EAB (Figure 2.5). In 2004 and 2007 small fish <9.9cm TL were recorded far east on the EAB and in 2010 this size class dominated the west coast and WAB and CAB, suggesting 2010 was a year of strong recruitment (Appendices 1 and 2).

Fish of 10-19.9cm TL were recorded on the west coast, primarily inshore in St. Helena Bay, and found from inshore to midshelf from the WAB to the EAB. They decreased in prevalence from inshore to the shelf edge on the CAB and eastwards from the CAB to the EAB (Figure 2.5). Fish of 20-29.9cm TL were virtually absent from the west coast and WAB during pelagic surveys and were found most frequently on the CAB from inshore to the mid-shelf region, particularly off Mossel Bay and Port Elizabeth, decreasing in density towards the shelf edge on the EAB (Figure 2.5). Fish >30cm TL were not commonly encountered during pelagic acoustic surveys. Those that were observed were found on the CAB, extending from inshore to the mid-shelf with a small component on the shelf edge at 22°E and on the EAB around Port Elizabeth, extending to just past Port Alfred (Figure 2.5).

The individual years when horse mackerel distribution best fits this pattern are 1998, 2000 and 2001 (Appendices 1 and 2). Years of uncharacteristic distribution included 2006 and 2010, caused by the extensive distribution of small fish <9.9cm TL across the WAB and CAB from inshore to the shelf edge (Appendices 1 and 2).

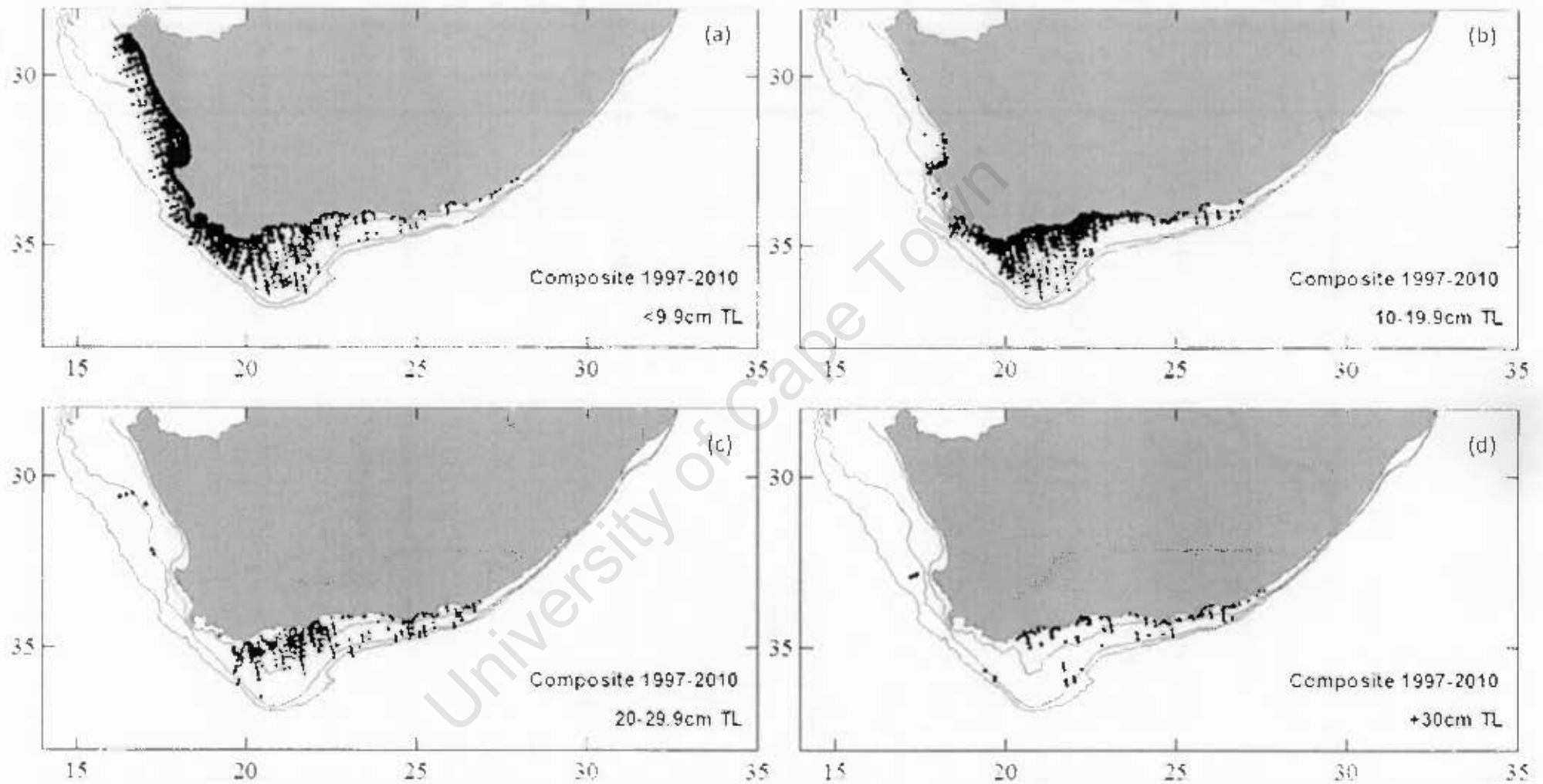


Figure 2.5: The distribution of horse mackerel along the South African coast according to average size class (a) <9.9cm TL, (b) 10-19.9cm TL, (c) 20-29.9cm TL and (d) >30cm TL from 1997-2010. Data were derived from May recruit and November spawner biomass acoustic survey data. Isobars shown represent 100m, 200m and 500m.

## **Length Frequency Distributions**

The May recruit and the November spawner biomass surveys exhibit length frequency ranges of 1-54cm TL and 1-51cm TL respectively. The 5cm TL length class of fish was the most abundant in both surveys and abundance decreased with increasing fish size, as would be expected (Figures 2.6 and 2.7). Both May and November surveys showed that the west coast consisted of fish <10cm TL, the WAB exhibited a larger size range but with most of the fish <15cm TL (Figures 2.6 and 2.7, Appendices 3 and 4). Fish of 20-29.9cm TL were mainly found on the CAB and tend to dominate this area in terms of abundance (Figures 2.6 and 2.7, Appendices 3 and 4). Moving eastwards from the CAB to the EAB, mean fish length increases from 12-24cm TL to 34-42cm TL closer to Port Elizabeth and Port Alfred (Figures 2.6 and 2.7). The largest individuals were recorded on the CAB and EAB, particularly in November 1998, 2000, 2001 and 2008 and May 2000, 2004 and 2010 (Appendices 3 and 4).

St. Helena Bay on the west coast had a larger size range of individuals compared to the other west coast strata (Appendices 3 and 4). This was the only area on the otherwise juvenile-dominated (<10cm TL) west coast where large individuals (>10cm TL) were recorded on a consistent basis. This same trend was seen in both May and November surveys (Appendices 3 and 4).

Year 2000 was a particularly uncharacteristic year because a large size range of fish (5-54cm TL) occurred across the CAB in May (strata F and G) and small fish <10cm TL were found far north on the west coast (Appendices 3 and 4). Small fish of <10cm TL were recorded in every stratum along the coast in the May survey and a total of ~1.5 billion fish of 6-7cm TL was recorded for the whole survey (Appendices 3 and 4), indicating a year of strong recruitment.

As expected, fish of <11cm TL dominated the composite length frequencies (Figures 2.6 and 2.7) and the May 2000 survey depicts this well (Appendices 3 and 4). There were several years from 2000 onwards when a large abundance of recruits was recorded, particularly in November 2010 (Table 2.1). In May 2010, large numbers of large fish (49-51cm TL) were recorded on the EAB and in November ~ 17.52 billion recruits (<10cm TL) were recorded in total. This is the maximum number of fish <10cm TL recorded in a single survey to date (Appendices 3 and 4).

Table 2.1: Total horse mackerel recruitment (#recruits <10cm TL) from 2000-2010 derived from Acoustic length frequency data from May recruit- and November spawner biomass surveys. Bold numbers represent years in which particularly large numbers of recruits were found.

Year	Survey	Recruitment (total # fish <10cm TL)	Year	Survey	Recruitment (total # fish <10cm TL)
2000	May	<b>3.93 billion</b>	2006	May	<b>1.60 billion</b>
	November	195 million		November	<b>9.12 billion</b>
2001	May	882 million	2007	May	<b>4.90 billion</b>
	November	<b>2.64 billion</b>		November	392 million
2002	May	70 million	2008	May	720 million
	November	<b>1.58 billion</b>		November	<b>1.28 billion</b>
2003	May	777 million	2009	May	350 million
	November	<b>5.00 billion</b>		November	<b>3.90 billion</b>
2004	May	<b>1.30 billion</b>	2010	May	<b>1.17 billion</b>
	November	380 million		November	<b>17.52 billion</b>
2005	May	900 million			
	November	<b>6.54 billion</b>			

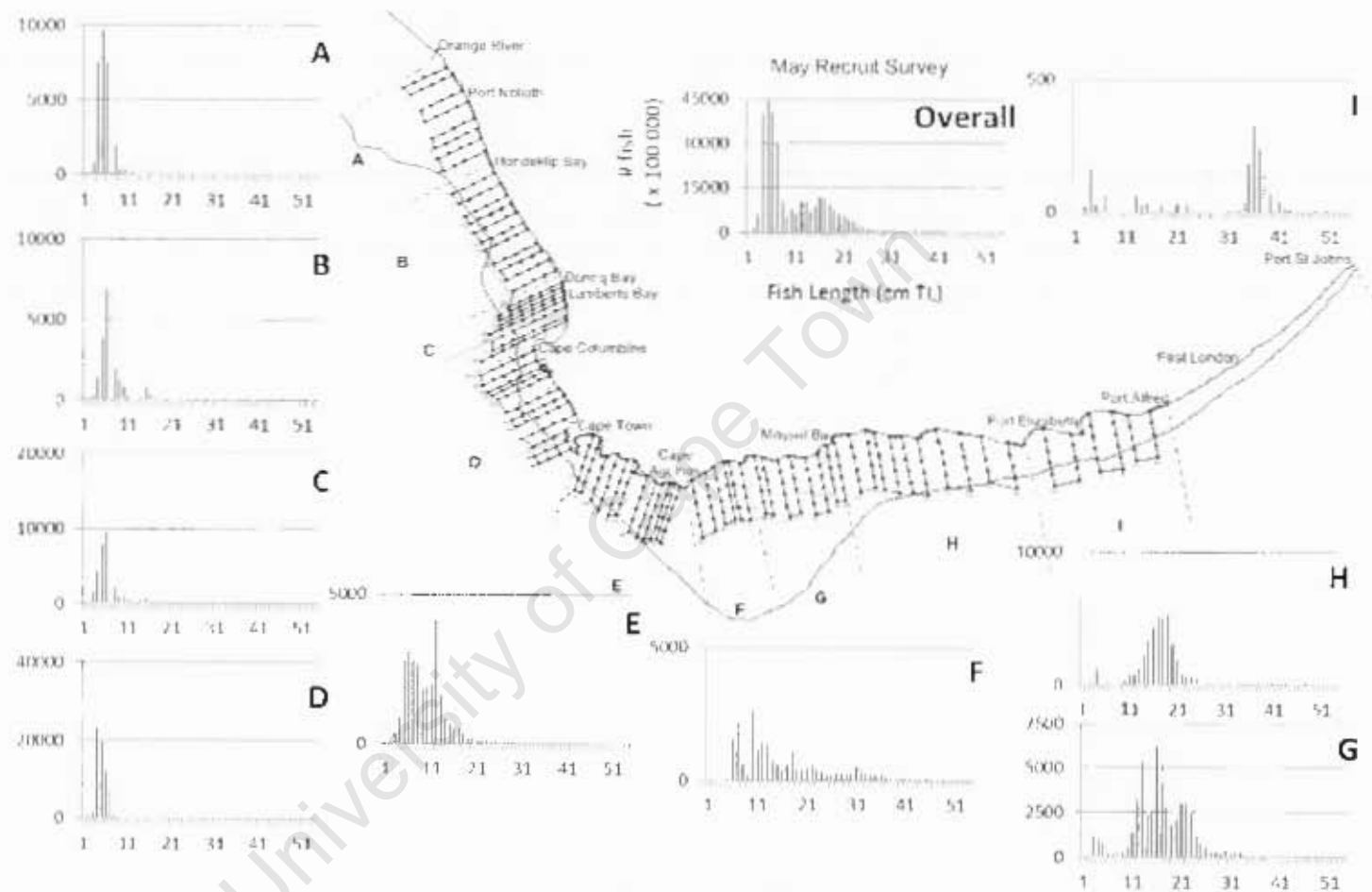


Figure 2.6: A composite length frequency distribution per stratum derived from May recruit survey data from 1997-2010. Frequencies represented as # of fish (x 100 000) and Length represented as TL (cm). Isobar shown represents 200m. Strata A-D represent the west coast, stratum E represents the WAB, strata F and G represents the CAB and strata H and I represent the EAB.

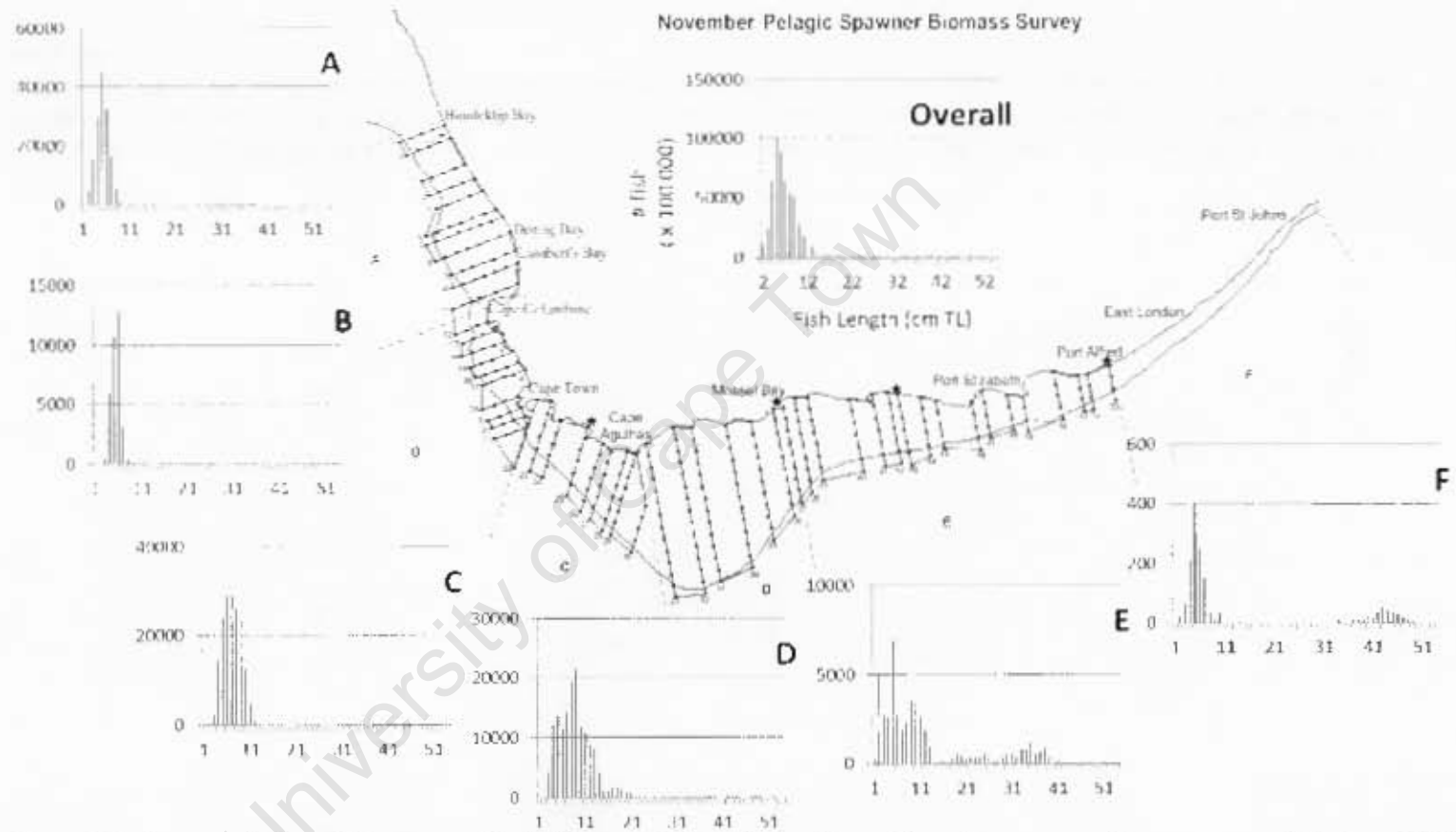


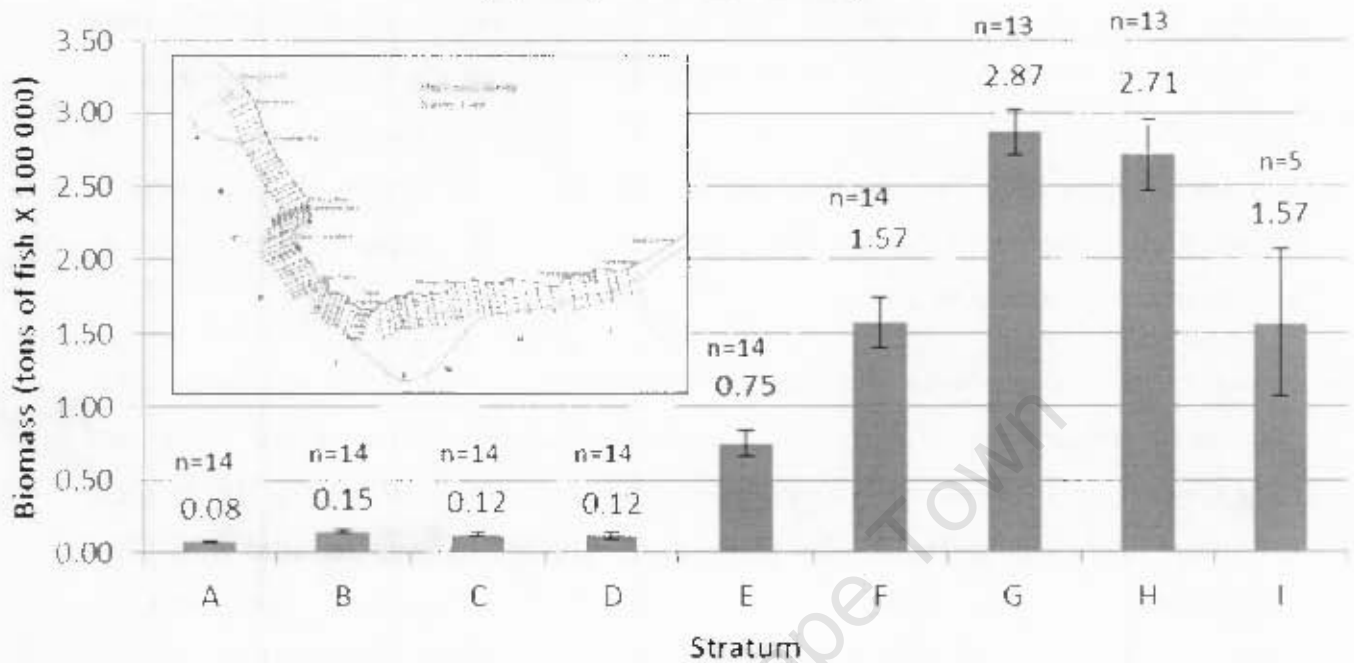
Figure 2.7: A composite length frequency distribution per stratum derived from November spawner biomass survey data from 1997-2010. Frequencies represented as # of fish (x 100 000) and Length represented as TL (cm). Isobar shown represents 200m. Strata A and B represent the west coast, stratum C represents the WAB, stratum D represents the CAB and strata E and F represent the EAR.

## **Biomass**

May recruit surveys typically show low biomass of horse mackerel from the northern west coast near the Orange River mouth to Cape Point (strata A-D) (Figures 2.8a and 2.9). Average biomass increases eastwards, from the WAB (stratum E), with the highest average biomass found on the eastern region of the CAB (stratum G) and, the western part of the EAB (stratum H) (Figure 2.8a). From this point biomass decreases eastwards onto the EAB (stratum I) (Figure 2.8a). The greatest biomass occurs from Cape Agulhas across the CAB to Mossel Bay and eastwards along the EAB (strata F- I) (Figures 2.8a and 2.9). Biomass was greatest in year 2000 (Figure 2.9).

November spawner biomass surveys also show a large horse mackerel biomass on the EAB (stratum E), similar to the May surveys, but differ in that some fish are found on the west coast (Figure 2.8b). On the west coast, biomass was higher from Hondeklip Bay to Cape Columbine, including St. Helena Bay (stratum A), than the biomass recorded from Cape Columbine to Cape point (stratum B) (Figure 2.8b). Biomass increased eastwards on the Agulhas Bank with the WAB (stratum C) having the lowest biomass and the EAB (stratum E) having the highest biomass (Figure 2.8b). On the east coast, strata E and D had the greatest biomass in 2000, with D peaking in 2004, 2006 (to a lesser extent) and 2010 (Figure 2.10).

(a) May Recruit Survey



(b) November Spawner Biomass Survey

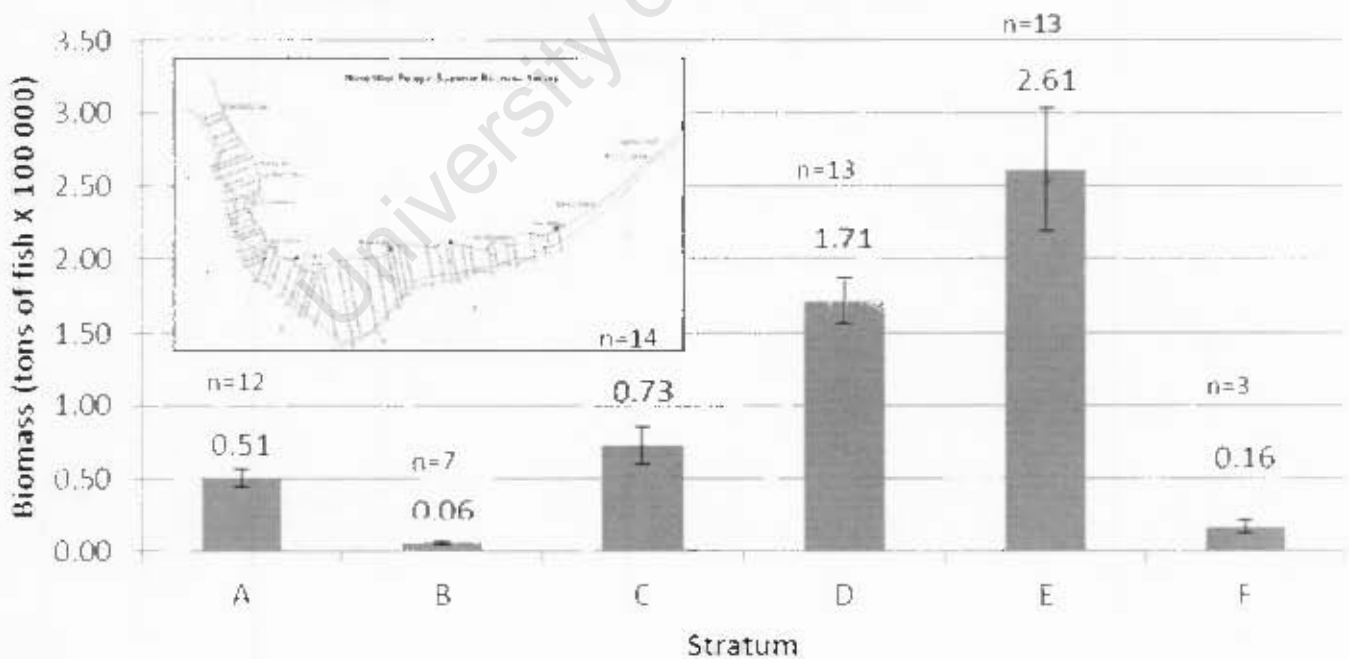


Figure 2.8: The average biomass of horse mackerel from 1997 to 2010 per stratum from the (a) May recruit and (b) November spawner biomass surveys. Biomass measured in tons of fish x 100 000. Error bars represent standard deviation. Strata layout is different for the two surveys.

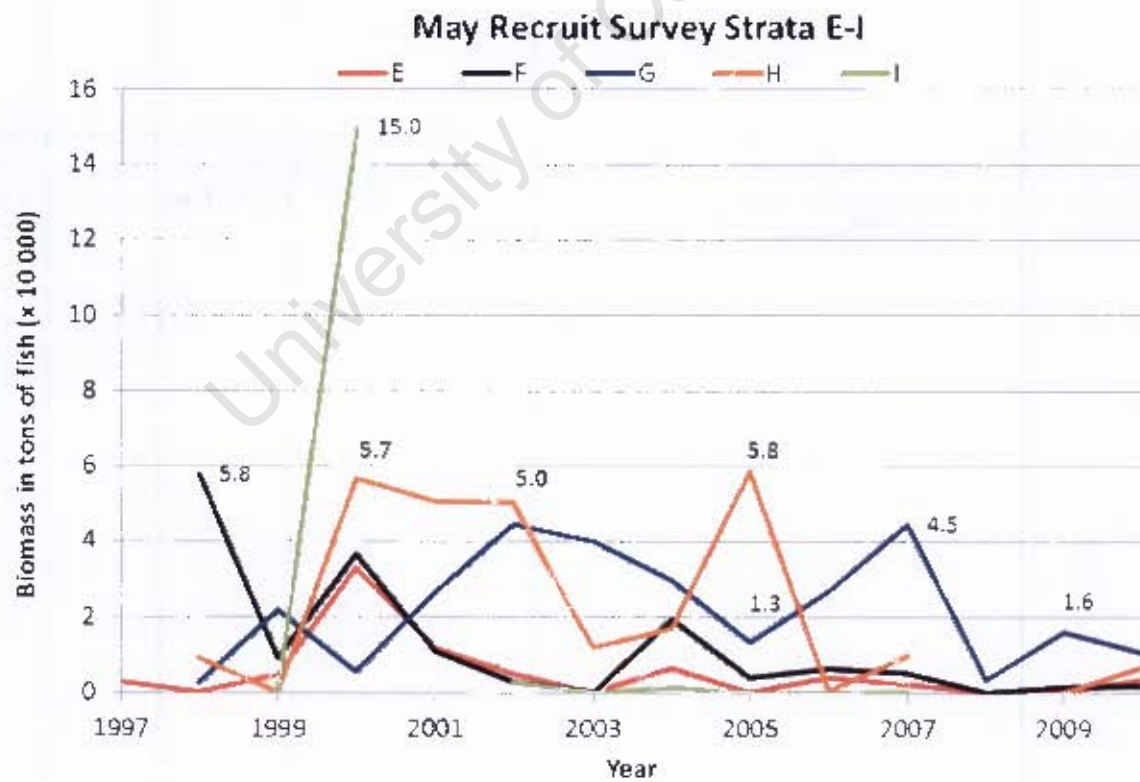
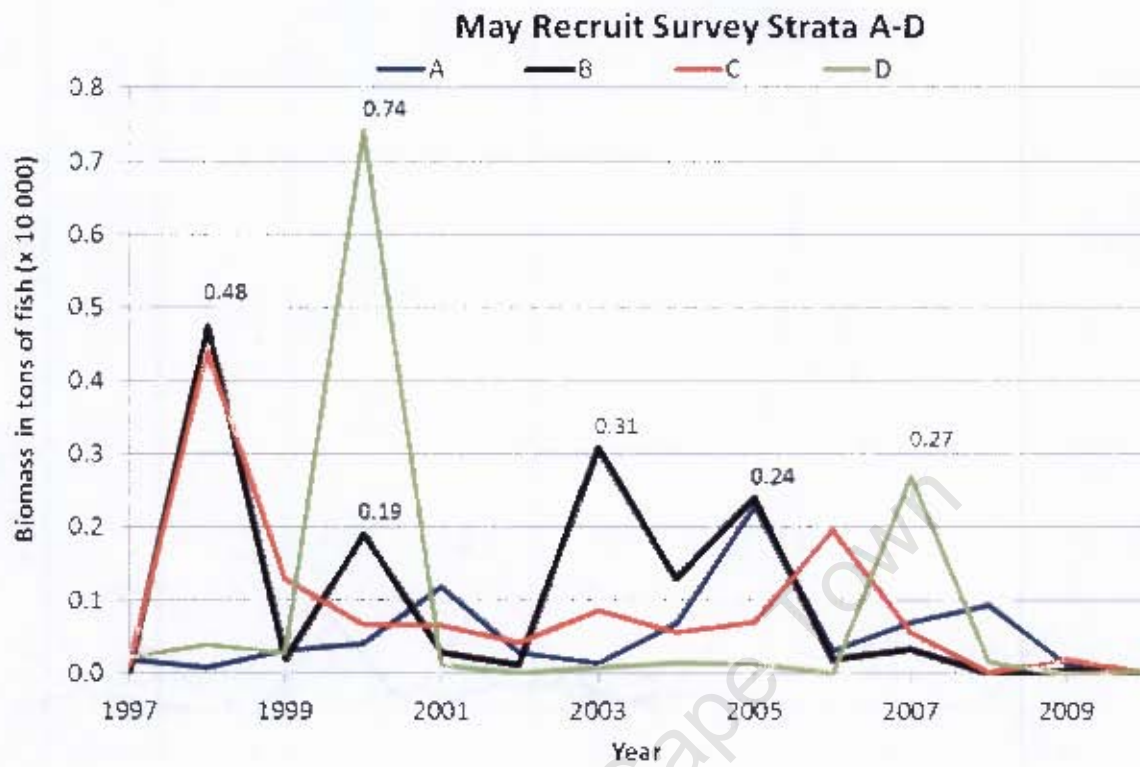


Figure 2.9: The biomass of horse mackerel from 1997 to 2010 per stratum derived from Acoustic May recruit survey data. Biomass measured in tons of fish x 10 000. West coast biomass (strata A-D) plotted separately from Agulhas Bank biomass (strata E-I). Strata layout for survey shown in Figure 2.2.

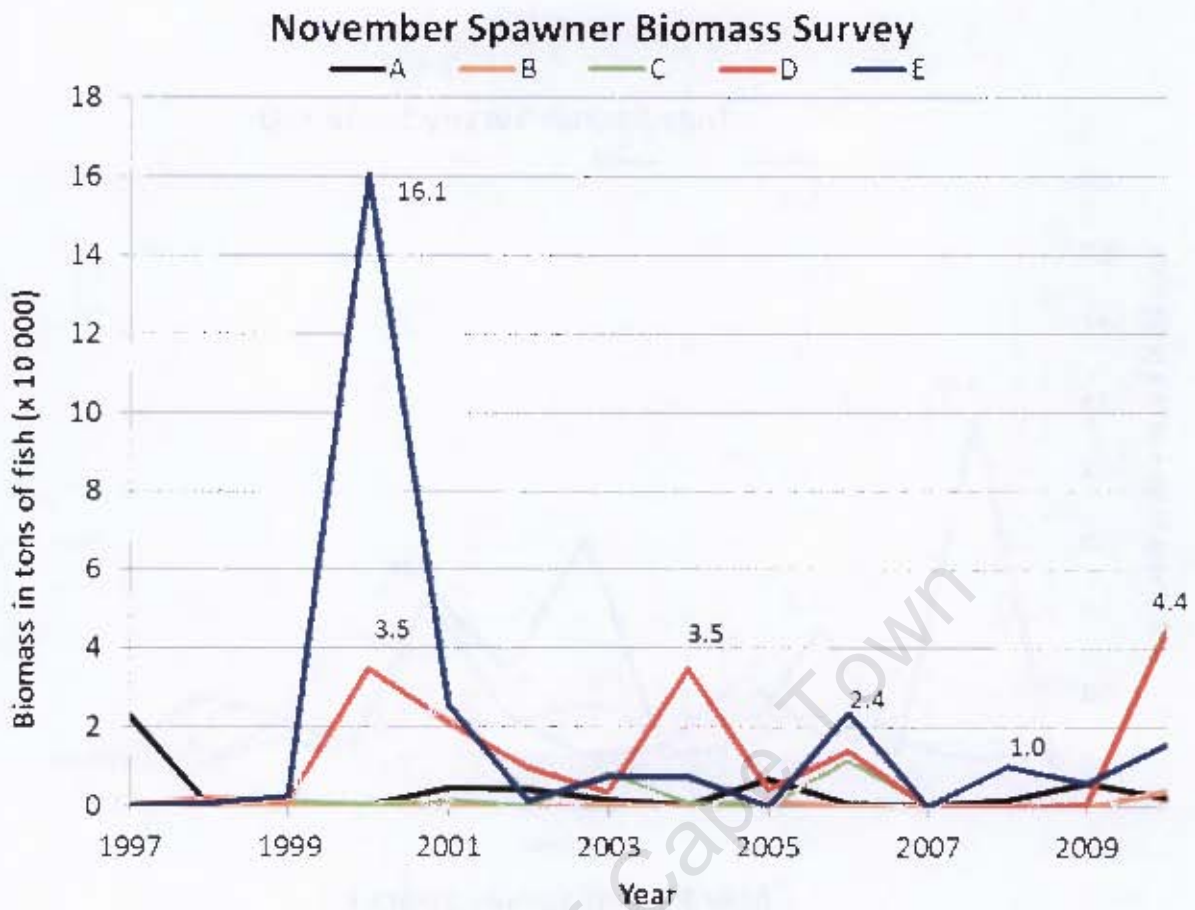


Figure 2.10: The biomass of horse mackerel from 1997 to 2010 per stratum from the November spawner biomass survey. Biomass measured in tons of fish x 10 000. Strata A and B represent the west coast whereas strata C, D and E represent the WAB, CAB and EAB respectively. Stratum F was not plotted as it is not routinely sampled. Stratum layout for survey shown in Figure 2.3.

### **Distribution and abundance of horse mackerel from demersal survey data**

Generally few fish of <10cm TL were recorded, but were found in greatest densities far north and in St. Helena Bay on the west coast, and inshore on the CAB between Cape Agulhas and Mossel Bay (Figure 2.11). Fish of 10-19.9cm TL were recorded far north and in St. Helena Bay on the west coast, inshore on the WAB and found extensively on the CAB from inshore to just past the mid-shelf region, with an additional area of high density found just off Port Elizabeth on the EAB (Figure 2.11). Fish of 20-29.9cm TL were found across the full extent of the CAB with high densities recorded on the mid-shelf and shelf edge, and lower densities found just offshore from Port Elizabeth (Figure 2.11). Fewer fish >30cm TL were recorded compared to the other three size classes. The greatest concentrations of adults were seen in St. Helena Bay, with lower densities recorded further north, inshore on the west coast (Figure 2.11). On the south coast, fish of this size class were recorded along the shelf edge of the WAB and mid-shelf on the CAB, with highest densities on the EAB from inshore to the shelf edge, particularly just offshore of Port Elizabeth. Fish of 20-29.9cm TL and fish >30cm TL exhibited the widest distribution of all size classes (Figure 2.11).

In 1994 there was a typical distribution of increasing ages towards the east and large abundances of all size classes of fish (Appendices 5 and 6). Years of uncharacteristic distribution included 1990-1992, 1995, 1997, 1999, 2004-2006, 2008 and 2010, because recruits were found on the south coast and were absent from the west coast (Appendices 5 and 6). In 2007, 2009 and 2011 there were particularly large abundances in the three smallest size classes, with record high abundances being recorded in each year.

Fish of 10-19.9cm TL have dominated in abundance compared to the other three size classes over the past several years, including 1987 and 1989 (CAB and WAB), 1990 (St. Helena Bay), 1994 (CAB and WAB), 2003 (CAB and EAB), 2004 (WAB and CAB), 2005 (CAB), 2006 (CAB), 2007 (CAB) and 2011 (St. Helena Bay) (Appendices 5 and 6).

St. Helena Bay, on the west coast, is unique in that particularly large densities of all size classes of fish were recorded there on a regular basis, including in 1988 (<10cm TL and 10-19.9cm TL), 1990 (10-19.9cm TL), 1993 (<10cm TL and 10-19.9cm TL), 1996 (all size classes except 20-29.9cm TL) and 2011 (10-19.9cm TL) (Appendices 5 and 6).

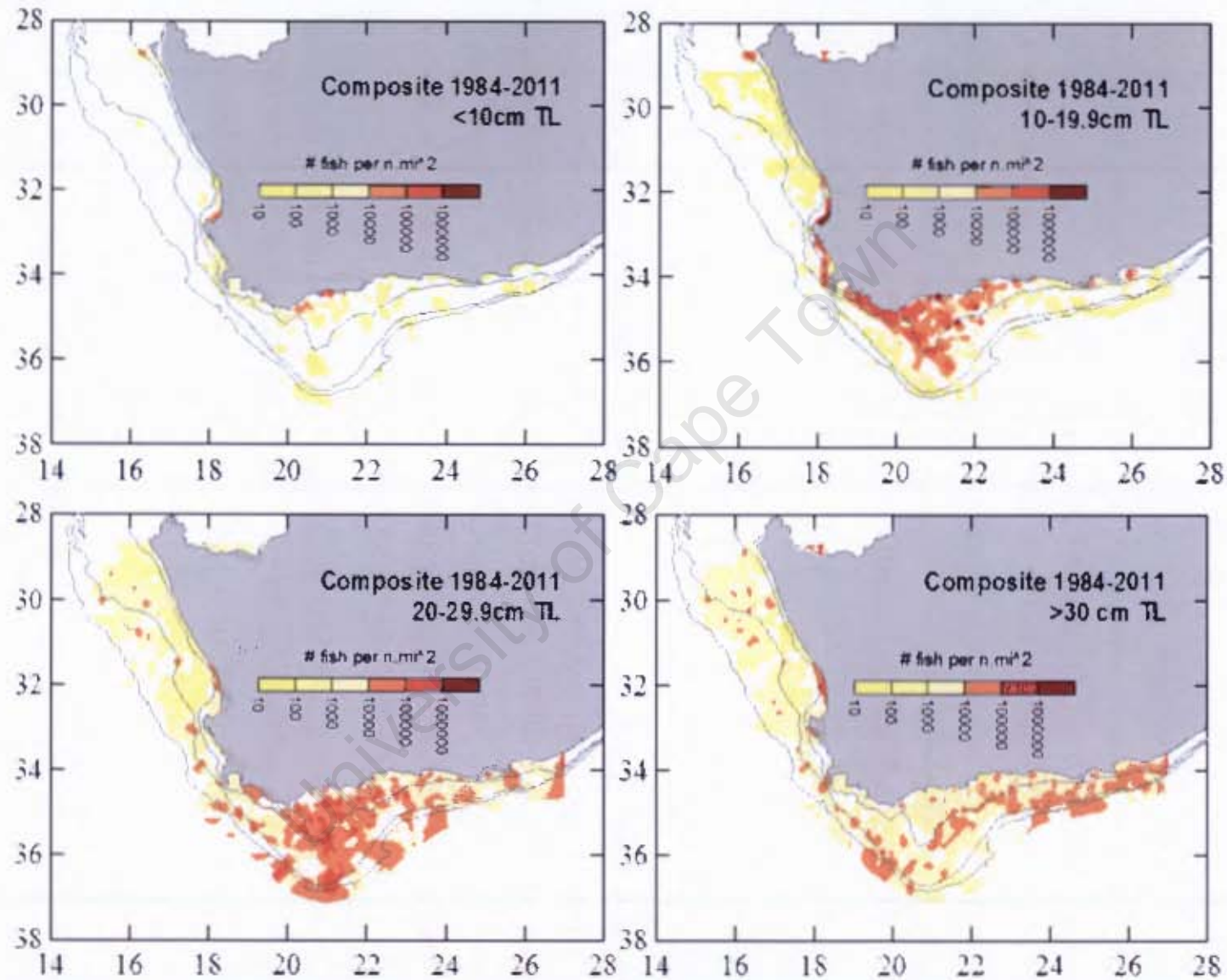


Figure 2.11: The distribution and abundance of horse mackerel along the South African coast by size class from 1984-2011 derived from demersal survey data. Units = no. of fish per  $\text{mi}^2$ . Size classes: <9.9, 10-19.9, 20-29.9 and >30cm TL. Isobars shown represent 100m, 200m and 500m.

## ***Discussion***

Pelagic survey data clearly show an eastward shift in horse mackerel distribution with size, as reported by Barange *et al.* (1998). Acoustic biomass measures did not show size-specific distribution patterns because they were measures of all size classes. Small fish <10cm TL are prevalent along the west coast and WAB, often extending onto the CAB and sometimes the EAB. Larger fish of 10-19.9cm TL and 20.29.9cm TL are common across the CAB, with the latter often found further east. Largest fish >30cm TL are found on the CAB and EAB, increasing eastwards to Port Alfred. As expected, the largest size classes had the widest distribution range because large horse mackerel can swim long distances and do so in their spawning migrations from the EAB onto the CAB and WAB.

Demersal surveys don't record small horse mackerel on the west coast, because juveniles are pelagic in distribution and demersal surveys are more successful in targeting large horse mackerel that reside on the seafloor during the day (Kerstan and Leslie 1994, Barange *et al.* 1998, Axelsen *et al.* 2003, Anon. 2010). Demersal surveys found large horse mackerel on the south coast and EAB because bottom trawling during the day was successful in detecting horse mackerel in these areas (Kerstan and Leslie 1994, Barange *et al.* 1998, Axelsen *et al.* 2003, Anon. 2010). Pelagic surveys found juveniles on the west coast because juvenile horse mackerel are known to closely shoal together in the water column and this method is accurate in detecting close shoaling fish (Barange *et al.* 1998, Axelsen *et al.* 2003). However, acoustic surveys were unreliable in detecting large horse mackerel on the south coast especially those on the EAB, because acoustics cannot accurately detect fish when they are dispersed or close to the sea floor, and large horse mackerel can easily avoid mid-water trawl gear used during acoustic surveys (Barange *et al.* 1998). Combined demersal trawl and acoustic surveys appear to be the only effective means of assessing the total abundance of horse mackerel, because abundance estimates based on a single survey method are inaccurate, and neither demersal trawl nor acoustic data can be treated as reliable independent estimates of abundance (Barange *et al.* 1998, Anon. 2010).

Areas of high abundance mentioned by Barange *et al.* (1998), such as the CAB, EAB and Port Elizabeth, also had consistently high densities in the pelagic and demersal surveys. The consistent occurrence of large horse mackerel off Port Elizabeth and often on the CAB shelf edge is thought to be a feeding aggregation around an area of localised high primary productivity as a result of shelf edge upwelling (L. Hutchings *pers comm*). These areas are

important focus areas for the mid-water trawl horse mackerel-directed fishery, as can be seen from the hours of trawl time spent fishing in these areas (Figure 1.5) (Smith *et al.* 2011).

It appears that St. Helena Bay is the most important area on the west coast for horse mackerel, and it is the only area on the otherwise juvenile-dominated west coast where all size classes of fish were recorded on a regular basis. Even though in the 1950s an adult population existed in the area, the occurrence of fish 20-29.9cm TL and >30cm TL in the bay, even in low densities, is surprising, since few or no adults were thought to exist on the west coast following heavy fishing pressure during the 1950s. The origin of these adults is uncertain but some possibilities include them recruiting in the bay as juveniles and then remaining there and not performing the typical south east migration to the Agulhas Bank. They also could be migrating adults from the Agulhas Bank, or they could represent a relic of the adult population once present in the 1950s. As fish of 20-29.9cm TL or >30cm TL have not been recorded in this area from 1984-1996 (Barange *et al.* 1998), the presence of this size class in St. Helena Bay could be consequences of improved survey techniques, analysing a longer time series or an indication of a recovery in the west coast adult population. It has been suggested that feeding circumstances in the southern Benguela have deteriorated for pelagic fish from 1970 to 1996 because of variability in food availability and changing environmental conditions (Hutchings *et al.* 1998). However there is contradictory evidence of a considerable increase in phytoplankton and copepod abundance in the St. Helena Bay area over the past four decades due to wind driven upwelling, and zooplankton concentrations, although moderate to high throughout the Benguela upwelling system, are thought to peak in St. Helena Bay (Checkley *et al.* 2009), which may account for the high concentrations of all size classes of horse mackerel in the region (Hutchings *et al.* 1998, Verheye *et al.* 1998, Hutchings *et al.* 2009).

Slight differences in size class distribution are seen when comparing the results of this study with those reported by Barange *et al.* (1998). Barange *et al.* (1998) seldom recorded fish <10cm TL further east than the WAB, apart from a few areas of recruitment on the south coast, and yet periodically this size class was recorded far east on the EAB. Fish of 10-19.9cm TL were not recorded by Barange *et al.* (1998) far offshore on the CAB or on the EAB. There was also no record of fish 20-29.9cm TL and >30cm TL on the west coast. These differences are most likely to be consequences of analysing a longer-term data set, with an additional 14 years of data, and are not necessarily sufficient evidence to suggest an

eastward shift in horse mackerel distribution, as seen in other pelagic species on the Agulhas Bank including sardine (Coetzee *et al.* 2008) and anchovy (Roy *et al.* 2007). Both these species have exhibited a significant eastward shift in biomass since the mid- to late 1990s, with that of anchovy thought to have been environmentally induced (Roy *et al.* 2007).

The year 2000 stands out in terms of acoustic data outputs (Figures 2.9 and 2.10). Unfortunately, no demersal surveys were conducted in 2000. In that year particularly high levels of recruitment and unusually large abundances of recruits on the west coast were observed (Hutchings *et al.* 2009). Anchovy recruitment in 2000 was also extremely high, and during the summer of 1999/2000 the entire South African west coast, from Hondeklip Bay to Cape Point, was influenced by two unusual, large scale oceanographic events (Roy *et al.* 2001, van der Lingen and Huggett 2003, van der Lingen *et al.* 2006, Howard *et al.* 2007, Hutchings *et al.* 2009). These events have been implicated in the high levels of successful recruitment and may also have impacted horse mackerel recruitment (Roy *et al.* 2001, van der Lingen and Huggett 2003, van der Lingen *et al.* 2006, Howard *et al.* 2007, Hutchings *et al.* 2009).

Initially, a period of warming occurred in mid-December, lasting two weeks, followed by a period of intense cooling, lasting from mid to late summer (Roy *et al.* 2001, Howard *et al.* 2007). The initial warming event was caused by a lull in the typical mid-December winds that promote upwelling events, bringing warm water close to the coast (Roy *et al.* 2001). Following this, weather conditions favouring upwelling returned, particularly oscillating pressure systems inland and offshore in the south east Atlantic, triggering the critical south easterly winds (Hutchings *et al.* 1998, Roy *et al.* 2001, van der Lingen *et al.* 2006). From November 1999 to April 2000, 12 intense upwelling events were recorded, with the initial upwelling lasting for an uninterrupted 20 days (Roy *et al.* 2001). This combination of events may have influenced phytoplankton production and pelagic fish recruitment (Roy *et al.* 2001). The lack of strong offshore currents during the warming period would have meant reduced egg and larval losses offshore and increased the number of eggs and larvae transported from the south coast spawning areas to the west coast nursery area by the jet current (Roy *et al.* 2001). The cooling period that followed, as a result of intense upwelling, would have increased food availability that would favour growth and reduce mortality of pelagic recruits (Hutchings *et al.* 1998, Roy *et al.* 2001, van der Lingen *et al.* 2006, Howard *et al.* 2007).

The highest anchovy recruitment in 16 years as well as unusually high sardine recruitment in that year was attributed to both these large scale oceanographic events (Roy *et al.* 2001, van der Lingen and Huggett 2003, van der Lingen *et al.* 2006, Howard *et al.* 2007, Hutchings *et al.* 2009). However, other factors, not only those effecting egg and larval survival, influence recruitment, because no such event has been recorded since 2000 and yet anchovy recruitment success has remained high (van der Lingen *et al.* 2006). It is possible that the particularly successful recruitment of horse mackerel in 2000 (Figures 2.9 and 2.10) is as a result of the same oceanographic events and, similarly, high recruitment has continued from 2000 to 2010 (except May 2002). This is evident from the number of recruits (<10cm TL) recorded in the acoustic length frequency data (Table 2.1) and supported by reports of a 20% increase in horse mackerel abundance over the last five years, mainly attributed to good recruitment (Furman and Butterworth 2011). It is possible that longer term environmental fluctuations may have influenced horse mackerel recruitment, such as, a slight upward trend in upwelling-favourable winds recorded on the west coast over the period 1980-2007 (Hutchings *et al.* 2009). The extensive spread of horse mackerel recruits across the Agulhas Bank in 2009 and 2010 (Appendices 1 and 2), and the continued large numbers of recruits caught as by-catch in the west coast pelagic fishery, seem to indicate the existence of strong year classes in 2010 and 2011. Following two strong year classes of horse mackerel in the 1950s, eight years of heavy fishing occurred before the stock collapsed (Geldenhuys 1973). Based on this historical evidence, horse mackerel is expected to be abundant for the next few years.

Following an analysis of various pelagic species in the southern Benguela, Branch *et al.* (1987) found that most species appear to have periodic outbreaks of successful recruitment, upon which a fishery is often based for a number of years. This appeared to happen to horse mackerel in the late 1940s and appears very likely again now in the early 2010s. Such fluctuations are common, and fish stock collapses frequently follow heavy fishing of strong year classes (Branch *et al.* 1987, Barange *et al.* 2009). Population numbers are unstable and unpredictable over time, particularly in pelagic populations in upwelling areas, and inter-annual variability in small pelagic fish biomass is characteristic of the southern Benguela and other upwelling systems (Branch *et al.* 1987, Crawford 1987, van der Lingen *et al.* 2006, Anderson and Lucas 2008, Barange *et al.* 2009, Checkley *et al.* 2009). Population fluctuations in small pelagics occurred prior to large-scale fishing. This is an indication that major fluctuations are as a result of environmental influences, and no single factor or event is

responsible for determining year class strength (Huggett *et al.* 2003). This emphasizes the complexity involved in understanding the causes of variability in small pelagic fish populations. This variability, particularly in small pelagic populations, has been recorded worldwide, is often decadal and associated with longer term and larger scale changes in environmental variability (van der Lingen *et al.* 2006, Coetzee *et al.* 2008).

Horse mackerel still show a clear eastward shift with age, as described by Barange *et al.* (1998). In addition, the current study has identified the presence of a small adult population in the St. Helena Bay area on the west coast, and shown that the extent of south coast recruitment is much greater than previously thought.

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University of Cape Town

## **Chapter 3: The reproductive ecology of horse mackerel *Trachurus capensis* in the southern Benguela**

### ***Abstract***

The reproductive ecology of horse mackerel was analysed on a temporal basis using egg and larval abundance measures from the SARP line from 1995 to 2011 and horse mackerel gonads from biological samples collected on the EAB. The gonads were analysed using two different techniques: a GSI analysis and the Walsh gonad staging maturity scale. The spawning strategy of horse mackerel is similar to that of anchovy and sardine, with spawning occurring across the Agulhas Bank and primary recruitment occurring on the west coast. The main spawning season of horse mackerel is in winter (June to August), with a secondary peak in summer (December), with simultaneous spawning occurring across the Agulhas Bank. The three techniques for determining spawning seasonality (ichthyoplankton data, GSI analyses and the Walsh scale) were evaluated in terms of accuracy and appropriateness. The ichthyoplankton data and the GSI analysis complemented each other, with similar spawning seasonality results, and the advantages and disadvantages of using each of these methods was discussed further. The Walsh scale showed different spawning seasonality results to the other two methods. It proved inappropriate and inaccurate for reproductively staging Cape horse mackerel based on the inability to macroscopically distinguish between stages during spawning and recovery. Future work should use models to investigate links between environmental conditions, spawning seasonality and recruitment strength.

## Introduction

In addition to examining spatial aspects of horse mackerel's life history strategy (such as size specific distribution patterns), temporal aspects (such as spawning seasonality) should also be assessed. The life history strategies of small pelagic species such as anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in the southern Benguela are well understood, and this will be briefly described to provide a context for horse mackerel. In these species, spawning occurs across the eastern (EAB), central (CAB) and western (WAB) Agulhas Bank near the continental shelf edge (Figure 3.1) (Hutchings *et al.* 2002, van der Lingen and Huggett 2003, Hutchings *et al.* 2009). Sardine also spawn off the west coast. The water on the south coast is more favourable for quick egg and larval development compared to the cold west coast (Huggett *et al.* 2003), and this minimises the chances of eggs and larvae falling prey to other species (Huggett *et al.* 2003). The eggs and larvae remain on the inshore edge of the main current and those caught in the current itself are swept off the continental shelf by advection and are lost to starvation or predation (Figure 3.1) (Hutchings *et al.* 1998, 2002,

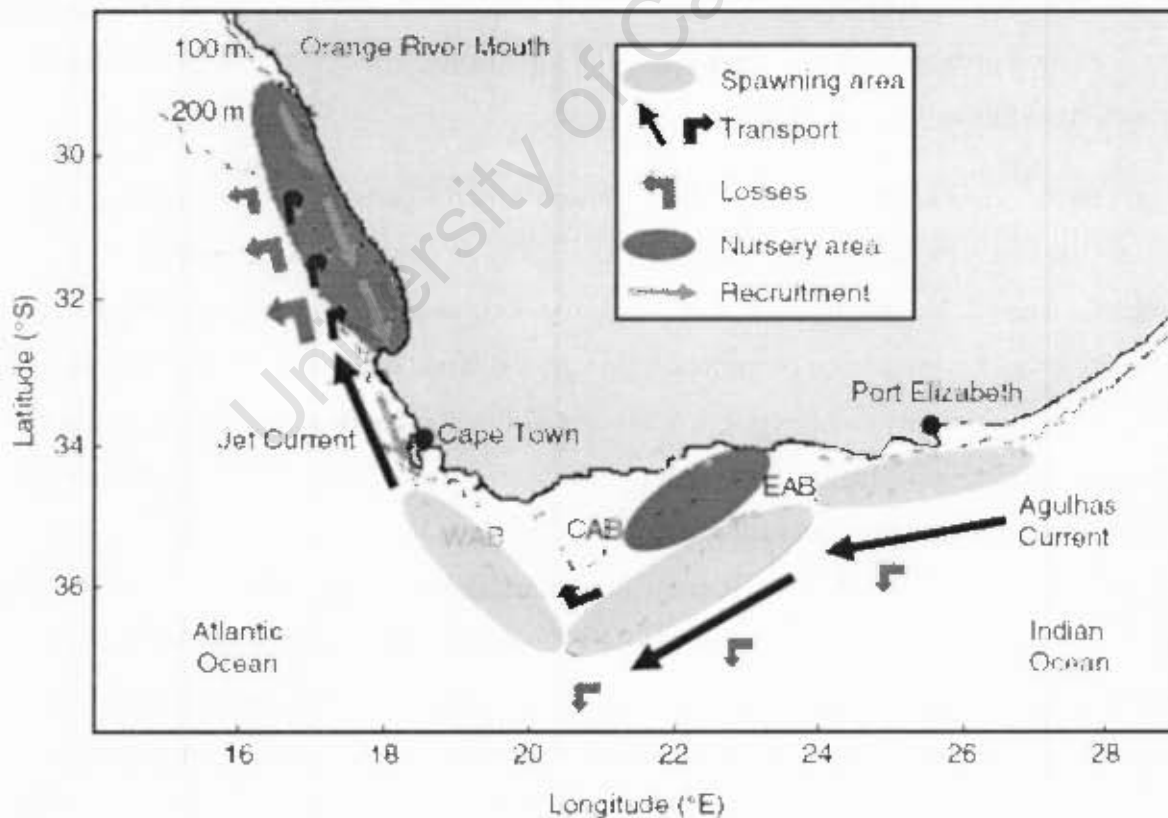


Figure 3.1: A map of the southern Benguela system showing the typical spawning and nursery grounds of anchovy and sardine and the transport processes that impact eggs and larvae. WAB, CAB & EAB=western, central & eastern Agulhas Bank respectively (adapted from Lehodey *et al.* (2006)).

2009). Eggs spawned on the CAB and EAB tend to be retained on the south coast (east of Cape Agulhas), whereas those spawned on the WAB are transported northwards to the west coast nursery area by a fast-flowing jet current (Figure 3.1) (Boyd and Nelson 1998, Huggett *et al.* 1998, 2003, Mullon *et al.* 2003, Miller *et al.* 2006). Most of the eggs remain offshore and once they have developed into larvae they swim inshore. The nursery area occurs along the food-abundant west coast from the Orange River mouth to Cape Columbine (Figure 3.1) (Hecht 1990, Naish *et al.* 1991, Hutchings *et al.* 1992, Barange *et al.* 1998, Huggett *et al.* 2003, Lehodey *et al.* 2006). Surviving larvae develop into recruits there and move inshore and southwards with age, returning to the Agulhas Bank as adult fish (Hutchings *et al.* 1992, Barange *et al.* 1998, Hutchings *et al.* 1998, Huggett *et al.* 2003). Primary recruitment occurs along the west coast. As a consequence, successful recruitment and population size of pelagic species rely on the passive transport of early life stages from the spawning grounds on the Agulhas Bank to nursery grounds on the west coast (Hutchings *et al.* 1992, Barange *et al.* 1998, Boyd and Nelson 1998, Huggett *et al.* 1998, Hutchings *et al.* 1998, Huggett *et al.* 2003, Mullon *et al.* 2003, van der Lingen and Huggett 2003, Miller *et al.* 2006). Given that horse mackerel juveniles are found primarily on the west coast (see Chapter 2, Figure 10), whereas adults are found primarily on the south coast, the life history strategy of this species appears to be similar to those of the small pelagic fish.

The jet current plays an instrumental role in transporting the early life stages of pelagic fish from the spawning to the nursery grounds, particularly in summer. As a result, a research programme known as the Sardine and Anchovy Recruitment Programme (SARP) was designed to measure within-season variations in egg and larval abundance in that current, and also to determine the factors affecting recruitment of commercially-important species in the southern Benguela, specifically sardine and anchovy (Huggett *et al.* 1998). SARP initially comprised monthly surveys conducted in spring (October–March), during which a grid of stations between Cape Agulhas and Cape Columbine was surveyed (Painting *et al.* 1998). After two years 1993/1994 (SARP I) and 1994/1995 (SARP II) of such sampling it became clear that more frequent sampling was required in order to accurately forecast recruitment, and weekly sampling of ichthyoplankton along a transect crossing the jet current (Figure 3.2) was initiated (Huggett *et al.* 1998). These surveys have improved our understanding of life history cycles of pelagic species that are reliant on the passive transport of spawning products from the spawning ground on the Agulhas Bank to the nursery ground on the west coast (van der Lingen and Huggett 2003, Miller *et al.* 2006). SARP samples collected over the period

1995 to 2003 show that a small number of horse mackerel eggs and larvae are found along the SARP line all year round, with two major spawning periods, when eggs are most abundant, from May to August and October to January, whereas larvae are most abundant from June to October (Figure 3.3) (Grote 2005).

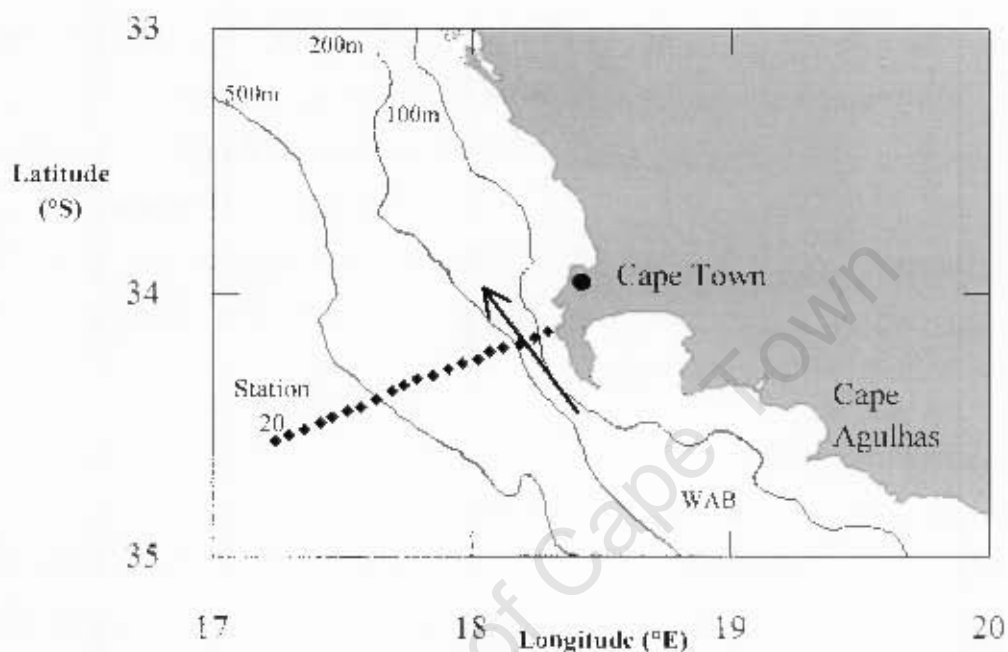


Figure 3.2: Map showing station positions along the SARP transect crossing the jet current off the South African south-west coast. Arrow = Jet current, WAB = Western Agulhas Bank.

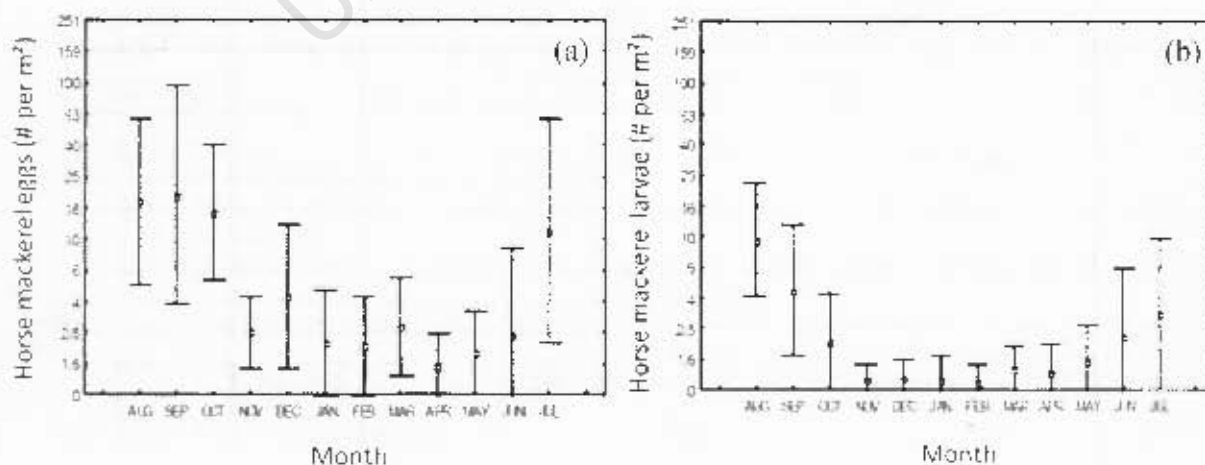
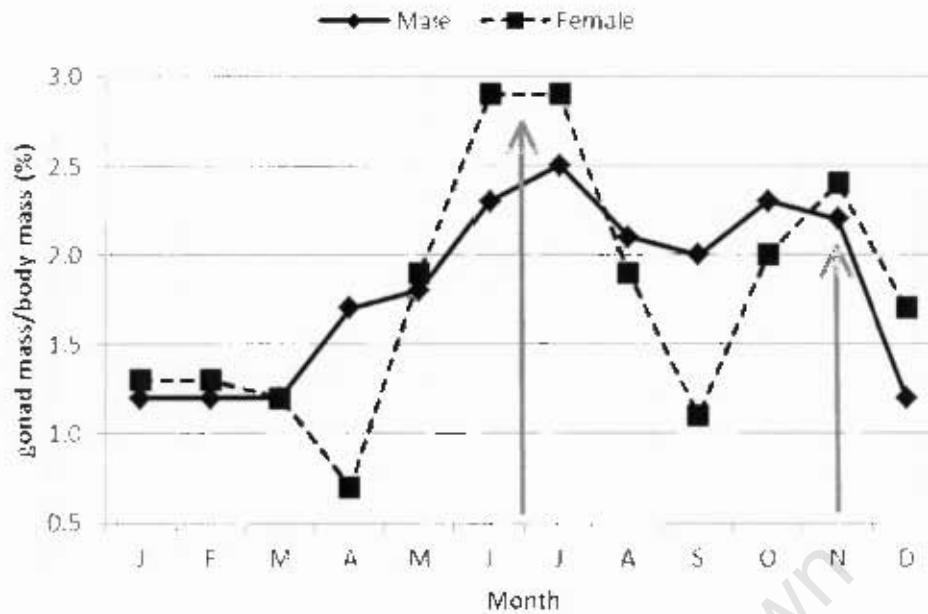


Figure 3.3: The mean number (+SD) of horse mackerel (a) eggs and (b) larvae recorded (number per m<sup>2</sup>) per month from the SARP line extending from 1995-2003 (Grote 2005).

Most horse mackerel spawning takes place offshore across the CAB and WAB, following the westwards migration of mature individuals from the EAB (Kerstan and Leslie 1994, Barange *et al.* 1998). However, spawning has also been recorded at a lower intensity on the EAB (Hecht 1990, Kerstan and Leslie 1994, Barange *et al.* 1998, Anon. 2004). Individual-based models (IBMs) coupled with a hydrodynamic model of physical ocean characteristics of the southern Benguela region, such as temperature and current direction and velocity, can be used to track the movement of particles through space and time and determine transport success of particles, representing fish eggs, from the Agulhas Bank northwards to the west coast (Parada *et al.* 2003). Studies using IBMs for anchovy and sardine show that eggs spawned to the east of Cape Agulhas have a reduced probability of being transported to the west coast (Huggert *et al.* 2003, Parada *et al.* 2003), but are retained on the south coast and develop into recruits in nursery areas there (Figure 3.1) (Hecht 1990, Barange *et al.* 1998, Hutchings *et al.* 2002, Miller *et al.* 2006).

Horse mackerel spawning not only varies spatially across the Agulhas Bank, which results in two recruitment areas, but also temporally. Although spawning occurs across the Agulhas Bank all year round, previous studies have suggested that there are temporal differences in peak spawning times between the WAB and EAB (Hecht 1990, Naish 1991, Kerstan and Leslie 1994). Peak spawning on the EAB is thought to occur in June and November (Hecht 1990), whereas on the CAB and WAB spawning occurs between August and February (Naish 1991, Kerstan and Leslie 1994).

The SARP ichthyoplankton survey data appear to be reliable indicators of spawning seasonality for species that spawn over the WAB and (to a lesser extent) the CAB, but not for those spawning further east (van der Lingen and Huggert 2003). As a result, an alternative method of determining spawning seasonality is needed for the EAB. Because this area is dominated by large, mature horse mackerel, an appropriate method of determining spawning seasonality there would be to use data on gonad maturity and/or gonad mass (Kerstan and Leslie 1994, Kerstan 1995, Anon. 2004). Monitoring the changes in gonad state and mass, in relation to body mass, over a year for male and female fish will enable identification of peak spawning periods of fish from the EAB. These data can then be compared to those of Hecht (1990) for horse mackerel caught off Port Elizabeth during the period 1967-1975 (Figure 3.4).



**Figure 3.4:** Monthly changes in gonad mass/body mass (%) for female and male horse mackerel collected from Port Elizabeth on the south east coast. Arrows indicate spawning peaks (adapted from Hecht 1990).

Previous studies of reproductive ecology of horse mackerel have shown that the sex ratio of this species is evenly distributed (1:1), and that maturation rates and mean length at age are similar in male and female fish (Geldenhuys 1973, Hecht 1990, Kerstan and Leslie 1994, Kerstan 1995). The different stages in the reproductive cycle of the Atlantic horse mackerel (*Trachurus trachurus*), from immature to the end of spawning, have recently been described using the Walsh scale. The Walsh scale, (Figure 3.5 and Table 3.1), assigns a standardised maturity stage, based on the macroscopic appearance and texture of the gonads, and gives guidelines regarding their size relating to the body cavity of the fish (ICES 2008). There are numerous macroscopic maturity scales used by different institutes for different species worldwide. The Walsh scale is a standardised maturity scale and the longest established, having been used for the last 17 years (Aukland and Ninnis 2004, ICES 2008). This scale therefore facilitates assigning a gonad maturity stage to each fish at the time of capture. The Walsh scale has six stages for males and females, each representing a stage within the reproductive cycle (Figure 3.5) (ICES 2008).

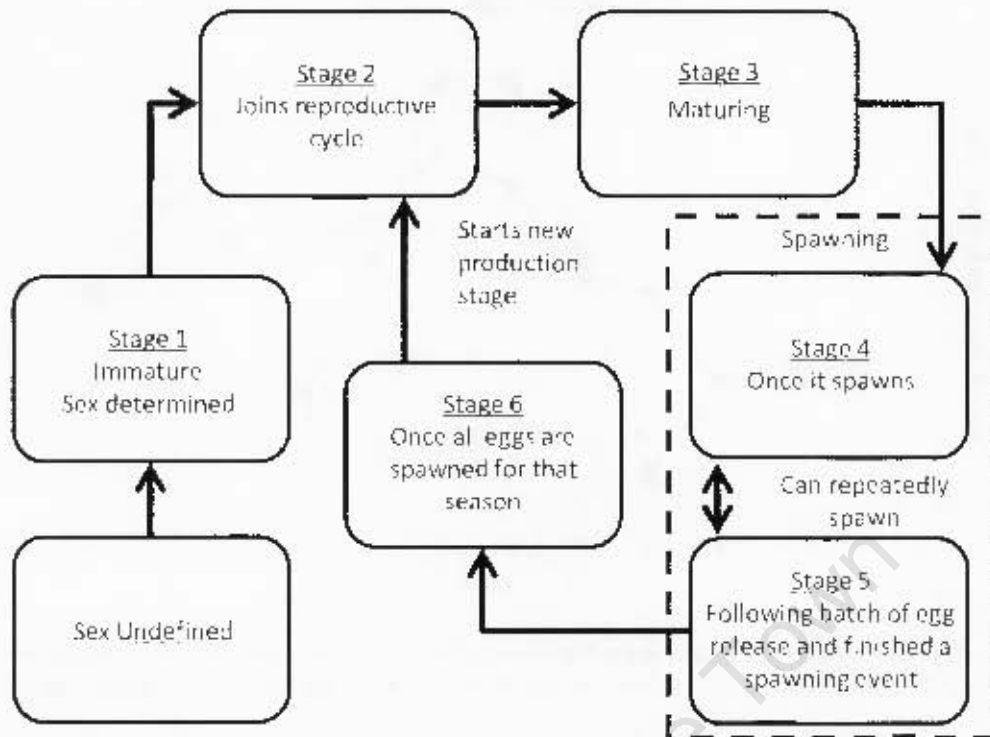


Figure 3.5: Reproductive cycle of Atlantic horse mackerel (*T. trachurus*) from immature to the end of a spawning season as described by the Walsh scale (adapted from ICES 2008).

Table 3.1: The Walsh maturity scale (adapted from ICES 2008).

Walsh Scale	Mature/ Immature	State	Female	Male
1	Immature	Immature	Gonads small. Ovaries wine red, clear, torpedo shaped.	Gonads small, pale, flattened and transparent.
2	Mature	Maturing	Gonads occupying $\frac{1}{4}$ to $\frac{1}{2}$ body cavity. Opaque eggs visible in ovaries giving pale pink to yellowish colouration, largest eggs without oil globules.	Gonads occupying $\frac{1}{4}$ to $\frac{1}{2}$ body cavity. Testes off-white, milt not running.
3	Mature	Maturing	Gonads occupying $\frac{3}{4}$ to almost filling body cavity. Ovaries yellow to orange. Largest eggs may have oil globules.	Gonads occupying $\frac{3}{4}$ to almost filling the body cavity. Testes creamy white.
4	Mature	Spawning	Ovaries characterised by externally visible hyaline eggs no matter how early the stage of hydration. Ovary size variable from full to $\frac{1}{4}$	Testes filling body cavity, milt freely running.
5	Mature	Spawning	Gonads occupying $\frac{3}{4}$ to $< \frac{1}{4}$ body cavity. Ovaries slacker than in stage 3 and often bloodshot.	Gonads occupying $\frac{3}{4}$ to $< \frac{1}{4}$ body cavity. Testes with free running milt and shrivelled at anus end.
6	Mature	Spent/ Recovery	Gonads occupying $\frac{1}{4}$ or less of body cavity. Ovaries reddish and often murky in appearance, sometimes with a scattering or patch of opaque eggs.	Gonads occupying $\frac{1}{4}$ or less of body cavity. Testes opaque with brownish tint and no trace of milt.

When the sex of a young fish is determined but its gonads are undeveloped it is considered immature (Stage 1, Figure 3.5). It remains classified as immature until it develops its gonads to join the reproductive cycle for the first time, at which point it is considered mature (Stage 2 and 3, Figure 3.5) (ICES 2008). Upon spawning, an individual releases a batch of eggs or sperm (Stage 4, Figure 3.5). Because horse mackerel are indeterminate spawners, they spawn several times during the reproductive season (Abaunza *et al.* 2003) and switch between Stages 4 and 5 (Figure 3.5). When all batches of eggs or sperm have been spawned in a particular season (Stage 6, Figure 3.5), the fish will start a new production cycle where the gonads go through a recovery process in preparation for the next spawning season (Stage 2, Figure 3.5) (ICES 2008). Once an individual has matured and spawned it will never return to an immature state (Stage 1, Figure 3.5) (ICES 2008).

The aim of this chapter was to examine the temporal patterns in spawning of horse mackerel on the Agulhas Bank in recent years and to compare the results to previous findings. Differences in spawning seasonality were analysed by comparing the WAB and EAB. Spawning seasonality of horse mackerel on the WAB was assessed using recent SARP data and was compared to previous SARP data analyses from 1995 to 2003 (Grote 2005). On the EAB spawning seasonality was assessed using gonad stage and gonad mass data collected during 2011, and those were compared to past analyses conducted by Hecht (1990). The macroscopic horse mackerel Walsh maturity gonad staging index for Atlantic horse mackerel (*T. trachurus*) was used to test the appropriateness of using this scale for Cape horse mackerel. The different methods of determining spawning seasonality (eggs, mass and staging) are compared and discussed in order to determine whether horse mackerel spawning seasonality has changed. Spatial and temporal changes in spawning strategy have been recorded in other pelagic species such as anchovy and sardine in the past (van der Lingen *et al.* 2006), therefore a similar change in spawning seasonality might be expected for horse mackerel.

## **Methods**

Data on the abundance of eggs and larvae of Cape horse mackerel in ichthyoplankton samples collected along the SARP monitoring line were used to determine spawning seasonality of this species on the WAB. Samples have been collected at a series of stations along a transect of the north-westerly flowing southern Benguela jet current (Figure 3.2) (Huggett *et al.* 1998, Grote 2005). The transect consisted of 20 stations, each 3nmiles apart, beginning with station 1 closest to shore off Slangkop Point and extending 58nmiles offshore to station 20 (Figure 3.2) (Huggett *et al.* 1998, Grote 2005). Stations 1-14 were routinely sampled whereas stations 15-20 were only occasionally sampled. At times, sampling at certain stations was not carried out because of bad weather conditions (Huggett *et al.* 1998, Grote 2005). One sampling year extended from August to July the following year. Samples were collected by various vessels including: F.R.S. *Africana*, F.R.S. *Algoa*, R.S. *Sardinops*, M.F.V. *Osprey*, R.V. *Ecklonia* and R.V. *Dr. Fridtjof Nansen*. Samples were collected using a mini-bongo net (200-300 $\mu$ m mesh, 0.025m<sup>2</sup> mouth area) that was lowered into the water to sampling depth (70m at station 1,  $\pm$ 90m for all other stations), and then retrieved at a speed of 1-2m per second, while the vessel steamed at 2 knots (Grote 2005). A flow meter attached to the bongo net was used to determine the amount of water filtered. Samples were preserved in a 5% formaldehyde solution buffered with seawater and fish eggs and larvae were identified and counted under the light microscope. Data were standardised to a mean number of eggs and larvae per m<sup>2</sup> of sea surface per month. A previous assessment of horse mackerel egg abundance along the SARP line for the period 1995 to 2003 was conducted by Grote (2005), and the results presented here use data collected over the period from 2004 to June 2011.

Spawning seasonality of horse mackerel on the EAB was assessed by collecting biological data from fish sampled from commercial catches. A total of 2289 fish from 27 trawls was collected and analysed (Figure 3.6). Most (75%) of the samples were obtained from the *F.V. Desert Diamond*, and the remaining samples were obtained from other vessels, including *Sister's Viking*, the *Marretjie* and the *St. Blaize*. Samples were collected approximately every three days during fishing trips and over the period from June to December 2011. Fish were frozen on board following capture and thawed just prior to analysis, which usually took place 2 weeks to 1 month later. Analysis included measurements of total length (TL mm) (the length from tip of the snout to the tip of the longer lobe of the caudal fin), fork length (FL mm) (the length from the tip of the snout to the end of the middle caudal fin rays), wet body mass (WBM g) (measured to the nearest 0.1g), sex, gonad mass (g) (measured to the nearest

0.01g) and gonad stage, from 1 to 6 determined using the Walsh scale (Table 3.1). Length and mass measurements were used to calculate the overall length-mass relationship separately for males and females, represented by the exponential equation  $W = a.L^b$ , (where  $W$  = WBM of fish (g),  $L$  = TL of fish (mm),  $a = 12.846 \text{ g.mm}^{-b}$  and  $b = 0.0093$ ,  $R^2 = 0.9494$ ) (Appendix 7). Gonad mass and WBM data were used to calculate the gonadosomatic index or GSI ( $GSI = [\text{gonad mass (g)} / (\text{WBM (g)})]$ ). Monthly GSI values were arcsine transformed to normalise the residuals and the level of variation within each month was represented as standard error. Although calculation of GSI usually incorporates a stomach mass term ( $GSI = [\text{gonad mass (g)} / (\text{WBM (g)} - \text{stomach mass (g)})]$ ), as was used by Hecht (1990), this was not possible in this study because of time constraints.

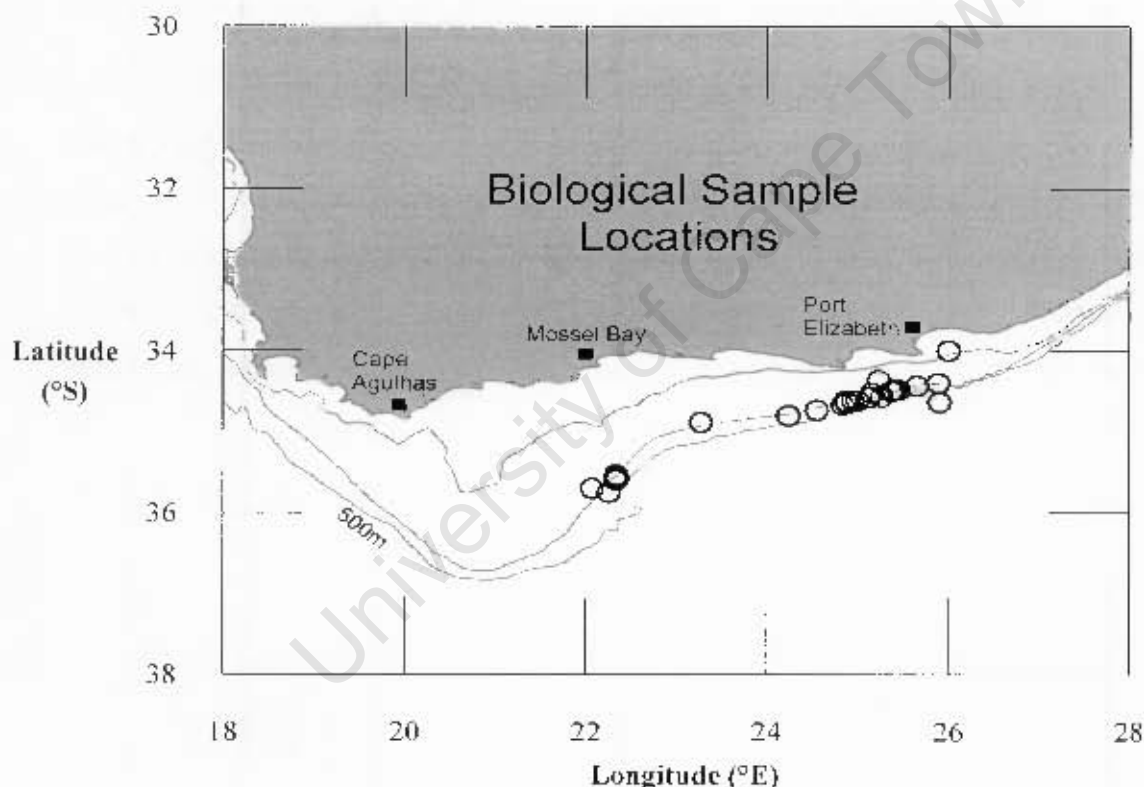


Figure 3.6: A map of the South African south coast showing the locations of trawls from which horse mackerel were taken for biological analyses collected on the eastern and central Agulhas Bank from June to December 2011.

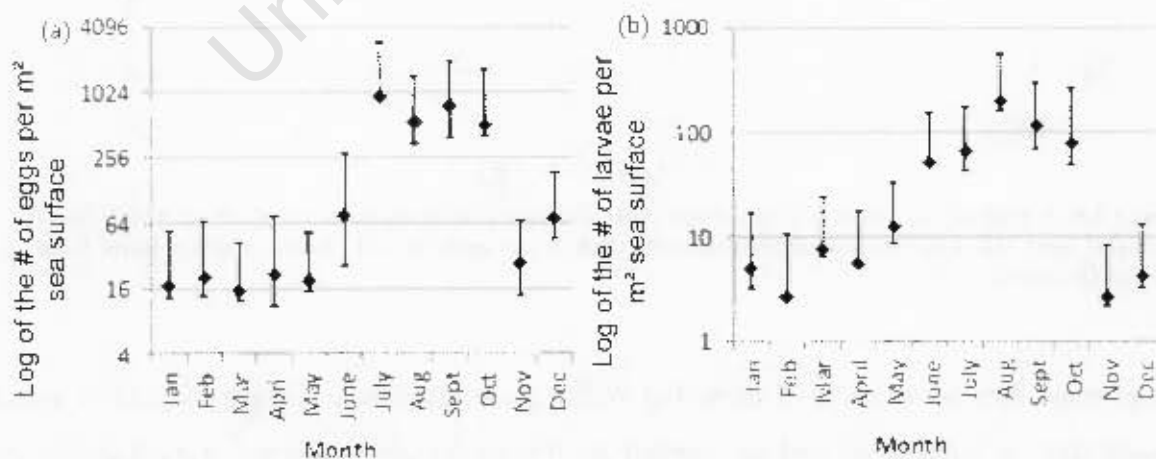
Gonad stage data were gathered using the Walsh scale. This macroscopic method of gonad classification is subjective, and as a result its objectivity and accuracy were assessed by calculating the average percentage error (APE) between independent readers (either 3 or 4) on selected samples every month from July to November (Test 1-5). This was done to

determine whether certain gonad stages were commonly over- or under-estimated. Biological data were collected with the help of DAFF staff.

## Results

Cape horse mackerel eggs were recorded along the SARP line all year round. Mean monthly egg abundance was between 15 and 22 eggs per m<sup>2</sup> of sea surface from January to May (Figure 3.7a), and this increased slightly in June and peaked in July with an average of 943 eggs per m<sup>2</sup> being recorded. Eggs remained abundant in August, September and October, followed by a sudden drop during November. The mean monthly egg abundance appears to increase again in December, with 70 eggs per m<sup>2</sup> of sea surface (Figure 3.7a). From these data it appears that horse mackerel spawn in autumn and winter, particularly July to October, with an apparent short and less intense spawning peak occurring in summer (December) (Figure 3.7a).

Fewer larvae compared to eggs were recorded, but they too were present all year round (Figure 3.7b). Average monthly abundances of 3-12 larvae per m<sup>2</sup> of sea surface were observed from November to May (Figure 3.7b), and larval abundance peaked from June to October, with the highest abundances being recorded in August. November and February appear to have the lowest average number of larvae of all the months (2 larvae per m<sup>2</sup> sea surface) (Figure 3.7b).



**Figure 3.7: The average ( $\pm$ SD) number of horse mackerel (a) eggs and (b) larvae recorded per m<sup>2</sup> of sea surface per month from SARP data over the period 1995 to June 2011. Number of eggs and larvae plotted on log scales.**

The fish sampled for biological analyses ranged from 206mm to 479mm TL, and the majority of these were 260-340mm TL (Appendix 8) and weighed between 97g and 1 121g. Of the 2 289 fish sampled, 2 211 could be assigned a sex based on the state of the gonads. Of these, 1 166 were female and 1045 were male resulting in a sex ratio of females to males of 1:1.12 ( $X^2 = 12.59$ ,  $df = 1$ ,  $p > 0.05$ ).

The average monthly GSI of males and females followed a similar pattern (Figure 3.8), with highest GSI values recorded in June 2011, with an average proportion ( $\pm$ SE) of 0.15 (0.001) and 0.17 (0.005) for females and males respectively (Figure 3.8). GSI decreased in July, increasing again slightly in August before steadily decreasing monthly to a minimum in October for females and November for males (Figure 3.8). In December GSI values increase once more (Figure 3.8). It is difficult to determine differences in monthly GSI values because of the large degree of variability (Figure 3.8) (males ( $F = 47.40$ ,  $df_1 = 6$ ,  $df_2 = 1038$ ,  $p < 0.01$ ) and females ( $F = 16.14$ ,  $df_1 = 6$ ,  $df_2 = 1159$ ,  $p < 0.01$ ).

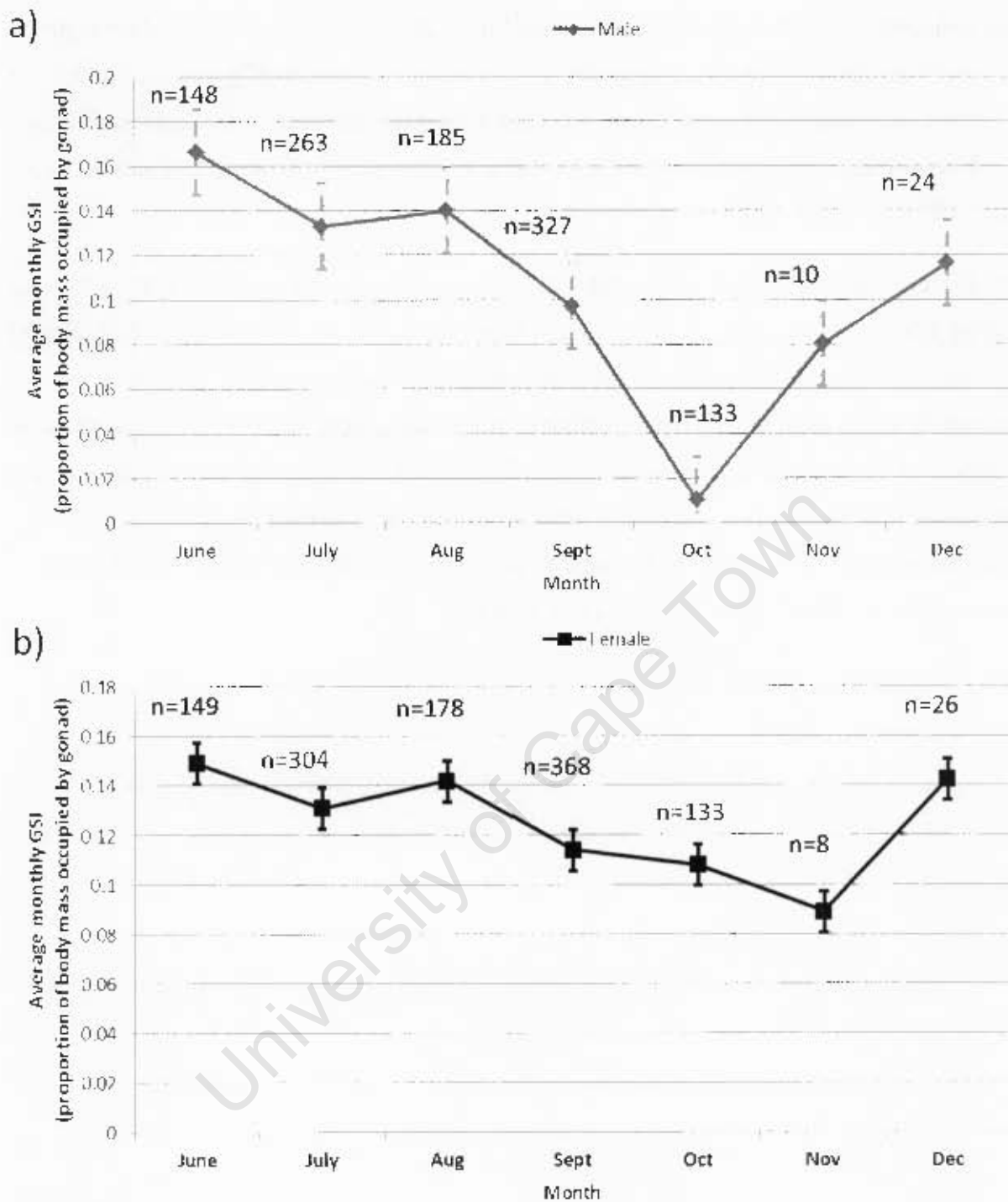


Figure 3.8: The spawning seasonality of (a) male and (b) female horse mackerel according to the overall monthly average ( $\pm$ SE) GSI index (proportion of body mass occupied by the gonad) from biological samples collected from the eastern Agulhas Bank from June to December 2011. GSI values have been arcsine transformed. n values represent the number of gonads analysed per month.

Median monthly gonad stages showed a similar pattern for male and female fish (Figure 3.9), remaining at stage 2 throughout the year for both sexes apart from female fish in December (Figure 3.9). In October the 25% quartile indicates a lower gonad stage (Q1=1) than the previous months (Q1=2) followed by a higher gonad stage indicated by the 75% quartile for November (Q3=2.75) and December (Q3=3) for males (Figure 3.9a). For females, from July to October a low 25% quartile was recorded (Q1=1) followed by an increase in the 75% quartile (Q3=3) and a marked increase in the median gonad stage in December (Figure 3.9b).

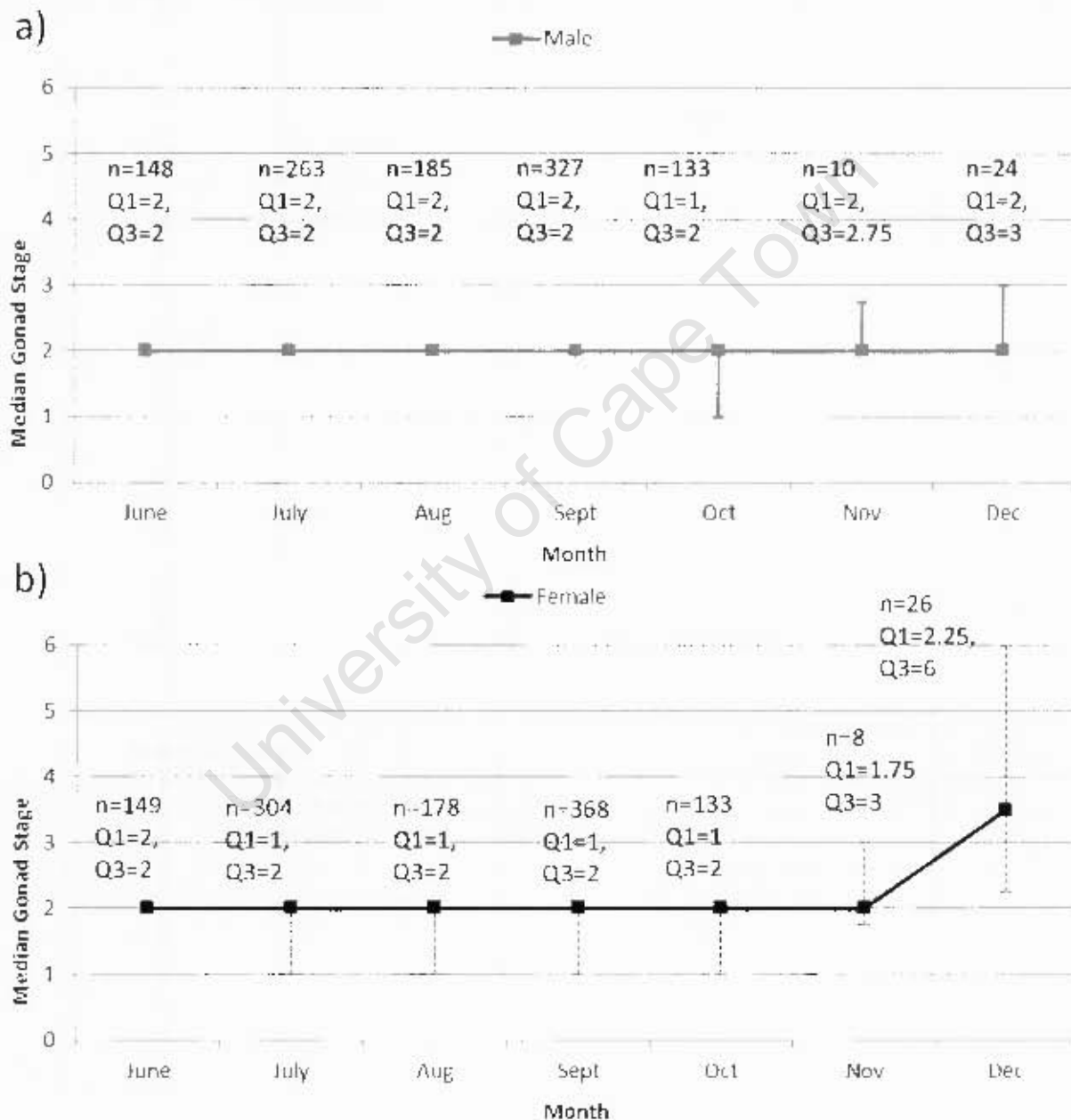


Figure 3.9: The median monthly gonad stage ( $\pm 25\%$  (Q1) and  $75\%$  (Q3) quartile values) of (a) male and (b) female horse mackerel according to the Walsh scale (Table 3.1) (ICES 2008) from fish collected on the eastern Agulhas Bank from June to December 2011. n represents the number of gonads staged per month.

The average observer percentage error per gonad stage from APE tests was also plotted (Figure 3.10). The APE ranged between 3 and 15% (Figure 3.10). There appears to be an increasing percentage error associated with an increase in the average gonad stage, with lowest error tending to be found on the lowest gonad stage (Figure 3.10). Test 5 had the lowest percentage error (3%) and the greatest number of observers (n=4) (Figure 3.10). This suggests that increasing the number of observers may reduce the overall percentage error in staging of gonads.

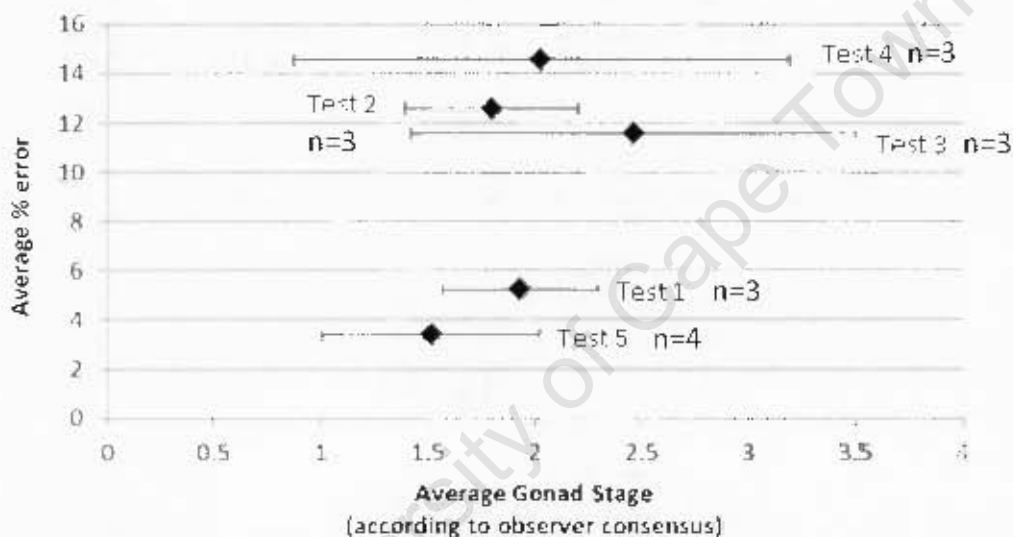


Figure 3.10: The average (±SD) percentage error of observers from five APE tests per average gonad stage from the Walsh scale (Table 3.1) (ICFS 2008) of both male and female horse mackerel combined from samples collected on the eastern Agulhas Bank from June to December 2011. Tests 1 and 2 were conducted in July, and tests 3, 4 and 5 were conducted in August, September and October respectively. The letter n represents the number of observers present for each test.

## ***Discussion***

The spawning seasonality derived from SARP data collected between 1995 and 2011 (Figure 3.7) has not changed from that derived from data collected between 1995 to 2003 (Figure 3.3) (Grote 2005). Peak spawning occurs primarily in winter (June to October), followed by a secondary peak in late spring-early summer (December). The indeterminate batch spawning strategy exhibited by horse mackerel accounted for the presence of eggs and larvae along the SARP line all year round (Figure 3.7) (Hecht 1990, Kerstan and Leslie 1994, Barange *et al.* 1998). These results differ slightly from previous studies, which identified main spawning seasons from May to August and October to January (Figure 3.7) (Hecht 1990, Naish 1991, Kerstan and Leslie 1994). This difference may be a reflection of recent changes in spawning seasonality, however there is no strong evidence to suggest this. Instead the difference is most likely as a result of better assessment of the process as the data extended 16 years, whereas previous studies only extended one year (Hecht 1990), seven non-consecutive months (Naish 1991).

The GSI values of fish from the EAB from June to December 2011 (Figure 3.8) were largest from June to August, followed by a decrease in October and November and an increase in December. These high GSI values are similar to those derived from GSI analyses performed by Hecht (1990) (Figure 3.4), which showed highest GSI values in June-July and again in November for fish caught in the vicinity of Port Elizabeth on the EAB. Comparing the ichthyoplankton and GSI data shows that peak spawning appears to occur simultaneously across the WAB, and EAB. This contradicts some previous studies, which suggested temporal differences in spawning across the Agulhas Bank, with peak spawning on the WAB and EAB respectively occurring in February and August and June and November (Kerstan and Leslie 1994).

Spawning seasonality from the Walsh gonad maturity scale shows little indication of spawning during winter, from June to August, but an increasing trend in gonad stage in November and December (Figure 3.9). During this time, on average, females had matured sufficiently to reach the spawning stage (Stage 4), whereas males were still in the gonad maturation stages (Stages 2 and 3) (Figure 3.9). Because of the subjectivity of this technique, one might expect an improvement over time in the observer's ability to detect differences between gonad stages as defined by the Walsh scale. This is a possible explanation for the consistently similar gonad stages observed from June to October, and the increase in average

gonad stage towards the end of the assessment in late spring and summer during November and December (Figure 3.9). However, APE tests reveal no difference in the average gonad stage according to observers between the five tests (Figure 3.10). Instead the APE associated with each of those tests ranged between 3.4% and 14.5%, with no particular order of decreasing percentage error with increasing number of tests, as one might expect (Figure 3.10). APE results from mesenteric fat staging of anchovy and sardine in the southern Benguela respectively ranged between 5.1% and 23.5% and 9.4% and 22.8% (van der Lingen and Hutchings 2005). Even with these APE values, the fat-staging technique was considered accurate (van der Lingen and Hutchings 2005). The APE values from fat-staging of anchovy and sardine are much larger than those from gonad staging in this study, so the Walsh scale could be regarded as an accurate. However, the maturity scale does not match the GSI data at the beginning of the assessment (June to October), and only provides similar results towards the end (November and December).

Macroscopic evaluations of gonad maturity are advantageous because they are quick, inexpensive and, can easily be performed in the field. This is unlike histological methods which are used to determine fish maturity by counting the number of eggs and sperm ready to be released from the gonad. Although potentially more accurate, histological methods are much more limited in their application as they take much longer to process a sample, must be conducted on fresh gonads or those preserved in 4% buffered formalin solution, and cannot be conducted on frozen samples (ICES 2008, Costa 2009). A detailed comparison of macroscopic and microscopic staging of gonads of Atlantic horse mackerel (*T. trachurus*) can be found in Costa (2009). The GSI method appears to be more accurate than the Walsh scale, possibly because GSI values are continuous rather than discrete values (Stages 1-6), as in the Walsh scale. However, the GSI technique is limited in that it is a relative measure of maturity that is fairly meaningless in isolation and, as a result, requires information on the maturity of other individuals in the population on an annual scale in order to provide perspective (Costa 2009). Consequently, there are benefits to using a macroscopic maturity scale that can provide meaningful results almost instantly. However, as macroscopic maturity staging is less accurate than the preferred histological method, it would be ideal to incorporate a certain level of histology for validation purposes (Costa 2009, ICES 2008). This was not done in this study.

Because of the need to validate the gonad staging, the same gonads used in the GSI analyses were staged using the Walsh scale. Consequently the same trends in spawning seasonality

between the GSI output and the Walsh scale output were expected. However, the Walsh scale results (Figure 3.9) were mostly different from the GSI (Figure 3.8) and SARP data (Figure 3.7) results. The latter data sets complemented each other and the results were similar to previous reports of spawning seasonality (Hecht 1990, Naish 1991, Kerstan and Leslie 1994, Grote 2005). It is possible that, because horse mackerel are indeterminate batch spawners, macroscopic analysis is unable to identify gonad stages accurately and, as a result, maturity stages are incorrectly assigned because of the subjectivity of the measure (ICES 2008, Costa 2009).

It is also possible that the Walsh scale proved inaccurate not because of an inherent flaw in the measure itself, but rather because of the loss of quality and difficulty associated with correctly staging thawed gonads. It is likely that, with fresh material and more experienced observers the accuracy of the method could improve, although the results of the APE tests do not show that percentage error decreases with observer experience (Figure 3.10). A previous study on horse mackerel (*T. trachurus*) from Portugal, where gonads were preserved in 4% buffered formalin solution prior to being staged, showed that the Walsh maturity scale is inappropriate for correctly assigning maturity stages (ICES 2008, Costa 2009). In that study (Costa 2009), macroscopic results were compared to histological analyses, which showed that the highest percentage of errors in macroscopic identification was between late ripening (underestimated stage 3) and partly spent stages (over-estimated stage 5) in fish >30cm TL. More than 50% of horse mackerel >30cm TL were incorrectly assigned to maturity stages, but fish <15cm TL were all correctly assigned to a gonad stage (Costa 2009). Based on these results and the fact that no fish <15cm TL were analysed in this study, it can be assumed that about half of the gonads in this analysis were staged incorrectly. For this reason the Walsh scale is not recommended and is considered inappropriate and inaccurate in determining gonad maturity and spawning seasonality of Cape horse mackerel, particularly considering the method was validated using two other reliable methods of determining spawning seasonality.

In contrast, data from the SARP programme appear to be reliable for determining spawning seasonality for species that utilise the jet current to transport their eggs from the spawning to the nursery areas. Therefore, it is a good technique for sampling eggs spawned on the WAB, but not those spawned on the CAB and EAB, as eggs spawned in these areas are retained on the south coast (Hecht 1990, Huggett *et al.* 2003). The mini-bongo net is effective at catching eggs and small larvae but not large ones, which are strong swimmers and are able to avoid the

net (Huggett *et al.* 2003). In the past, SARP data have shown promise as potential predictors of anchovy recruitment (van der Lingen and Huggett 2003), and although the SARP programme is costly to run on a consistent basis, it is beneficial in providing data on all pelagic species, including commercially-important sardine, anchovy and red eye, which rely on passive transport of their early life stages to nursery areas on the west coast (Huggett *et al.* 2003). Consequently, data from the SARP line remain the best means of determining spawning seasonality of pelagic fish that spawn on the WAB.

Samples along the SARP line are collected from 70m-depth to the surface at station 1 and from  $\pm$  90m to the surface at all other stations (Huggett *et al.* 2003). The appropriateness of the sampling depth for accurate sampling of horse mackerel eggs is debatable as it is possible that eggs are found deeper than this, as adult fish are known to occur down to 400m (Barange *et al.* 1998, Anon. 2004). However, adults tend to become pelagic and move onshore to shallow water prior to spawning (Barange *et al.* 1998). Studies on the vertical distribution patterns of eggs of small pelagic species (anchovy, sardine and red-eye) on the WAB indicate that these eggs are mainly distributed between the surface and 80m-depth (Dopolo *et al.* 2005). Little is known about the vertical distribution of horse mackerel eggs and larvae in the southern Benguela. Studies in the northern Benguela have shown that, whereas eggs can be found down to 200m depth, their abundance declines rapidly below 60m-depth (Ekau and Verheye 2005). Similarly, whereas eggs of Atlantic horse mackerel (*T. trachurus*) can be found down to 200m, they are found predominantly in the upper 50m (Coombs *et al.* 2001). Hence, sampling along the SARP line is probably appropriate for horse mackerel eggs, as has been shown for hake (*Merluccius spp*), which are deeply distributed but most of their eggs are in the upper 90m (Grote *et al.* 2007).

Previous studies have shown that spawning season, spawning area and environmental factors have a major impact on spawning success, transport and mortality of the early life stages of pelagic species, such as anchovy and sardine (Huggett *et al.* 2003, Mullon *et al.* 2003, Miller *et al.* 2006, Coetzee *et al.* 2008), and this likely applies to horse mackerel. Cape horse mackerel appears to be a robust species within the southern Benguela, mainly as a result of an expansive temporal and spatial spawning strategy and adaptation to the environmental conditions and circulation patterns in the region (Hutchings *et al.* 1998, 2002, Huggett *et al.* 2003). Prolonged and recurrent spawning periods have made early life stages of horse mackerel more resilient to characteristic variability in south-easterly winds in mid-summer that increase upwelling (Hutchings *et al.* 1998, Huggett *et al.* 2003, Miller *et al.* 2006). Peak

spawning times, from June to August and December, occur when upwelling intensity and offshore Ekman drift is at a minimum, decreasing offshore losses by advection and optimising transport of spawning products to the west coast. During the periods of intense upwelling from late spring (September to November) to early autumn (March to May), young horse mackerel would have the ability to vertically migrate to avoid being forced offshore by water in the Ekman layer (Mullon *et al.* 2003, van der Lingen and Huggett 2003).

The ability to compensate for variability in the transport of eggs from spawning to nursery grounds, mainly through high fecundity and a protracted spawning season, is considered to be among the primary determinants of anchovy recruitment success (Hutchings *et al.* 1998, Mullon *et al.* 2003). This is also likely to apply to horse mackerel, which have a similar spawning strategy. Having two differently-located nursery areas, on the west and south coast, optimizes reproductive potential of horse mackerel and enables it to withstand the unpredictable conditions characteristic of the southern Benguela (Miller *et al.* 2006, Coetzee *et al.* 2008). The separation of recruitment areas from areas where adults normally reside is also likely to considerably reduce cannibalism of early life stages by adults (Hutchings *et al.* 1998). Predation of eggs and larvae by adult pelagic fish on the Agulhas Bank during summer is believed to be substantial (Hutchings *et al.* 2009), and the high predation on the Agulhas Bank will be a contributing factor to the reduced number of recruits on the south coast in comparison to the west coast (Hutchings *et al.* 2009).

Shifts in the main spawning areas have occurred in other species in the past, such as anchovy and sardine (Roy *et al.* 2007, Coetzee *et al.* 2008), and it is possible that horse mackerel also may have shown a shift in their spatial spawning pattern. Although this study did not examine spatial patterns of egg distribution, no temporal shift in spawning season of this species has been observed since 1995, according to results from the SARP data. There is no difference in spawning seasonality inferred from GSI data between the late 1960s and early 1970s (Hecht 1990) and the data from this study (June to December 2011), with major peaks occurring from June to August and December across the full extent of the Agulhas Bank. However, the GSI time series collected in this study is short (seven months) and does not cover a full year. Consequently, this sampling should be continued for the next few years.

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## Chapter 4: Conclusions

The information resulting from this study has improved our understanding of horse mackerel life history strategy, particularly with regard to distribution patterns by size. It is clear that the size-specific distribution proposed by Barange *et al.* (1998), holds in general, but with two important differences. Of particular interest is the evidence of an adult population on the west coast in St. Helena Bay, which was previously thought to no longer exist following heavy fishing pressure in the 1950s. Also not emphasized by Barange *et al.* (1998) was the extent of south coast recruitment. Although the west coast remains the primary nursery area, this study showed an increasing occurrence of south coast recruits, which implies that recruitment on the south coast may not be as insignificant as once thought or has possibly increased in recent years.

Spawning occurs across the Agulhas Bank primarily in winter, (June to August), with a secondary peak in summer (December). Similarly Barange *et al.* (1998) proposed spawning periods from May to August and October to January. Eggs spawned on the WAB and, possibly, some from the CAB are transported to the primary nursery area on the west coast by the jet current. The results suggest that the eggs spawned on the CAB and EAB are presumably retained on the south coast, whereas, Barange *et al.* (1998) assumed that eggs spawned on the CAB would end up on the west coast, however there is no strong evidence for either hypothesis. Recruits, whether from the south coast or west coast, join older fish offshore on the Agulhas Bank.

The hypothesised life history strategy proposed by Barange *et al.* (1998) (Figure 1.3) and the new information resulting from this study have been synthesised into a new model of the life history strategy of horse mackerel in the Southern Benguela (Figure 4.1). There is evidence of an adult population in St. Helena Bay on the west coast, implying that not all recruits from the west coast return to the Agulhas Bank. Large fish (>10cm TL) are common across the Agulhas Bank, with the larger size classes (>20cm TL) often found further east, emphasizing the eastward shift with age (Figure 4.1).

A longer term data set of gonad maturity stage and GSI would have been beneficial in the analysis of spawning seasonality. Trying to determine spawning seasonality from only seven months of GSI data is difficult, even though the two spawning peaks previously reported fell within the six month period of this analysis. In addition, otoliths should be collected during biological sampling, because this enables age determination and estimation of age-at-maturity

and size-at-maturity (Kirchner *et al.* 2010). This would not only provide valuable information on age of fish but also allow for the calculation of a growth curve, as done in previous studies (Hecht 1990, Naish *et al.* 1991). The growth curve can be calculated without age data but requires a sample to be representative of all length classes of the fish. As only large individuals from the EAB were collected in this study, a growth curve could not be calculated.

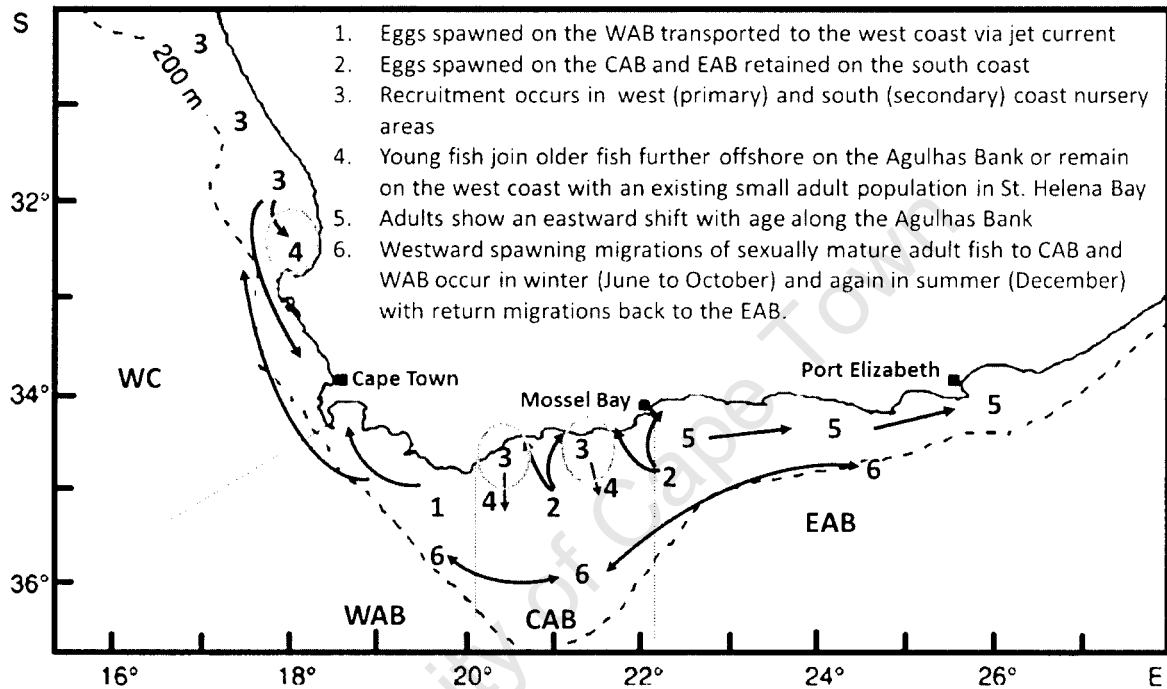


Figure 4.1: A simplified model of the life history strategy of horse mackerel *T. capensis* in the southern Benguela updated and adapted from Barange *et al.* (1998). WAB, CAB and EAB = western, central and eastern Agulhas Bank respectively and WC = west coast (separated by lines). Main changes from life history proposed by Barange *et al.* (1998) emphasized in red circles.

Ideally, histological analyses should also have been done on the fish gonads to better validate gonad staging using the Walsh scale. Unfortunately, time constraints hindered this. Histology would have required fresh samples, which were not obtainable because most samples were obtained from fishing vessels whose normal procedure involves prompt freezing of catch to maintain the quality of the fish. It is likely that the quality of the biological samples was a contributing factor to the poor results obtained for spawning seasonality from the Walsh scale method. However, similar problems have been reported when using this scale on non-frozen gonads (ICES 2008). In future a comparison should be made to determine the difference in spawning seasonality outcomes from staging of frozen samples vs. fresh ones using the Walsh scale. This would be a good indication of whether the scale is generally inappropriate

for use on Cape horse mackerel or whether it's efficacy depends on whether the sample is frozen or not.

Spawning seasonality and maturation data (such as GSI analyses) and data from ichthyoplankton surveys (such as the SARP line) are used in fishery stock assessments, egg production methods and to gain insight into the maturation cycles of certain species (ICES 2008, Costa 2009). However, forecasting recruitment from spawning seasonality and maturation measurements is particularly difficult, and relationships between recruitment success and environmental variables are notoriously unreliable (Huggett *et al.* 2003). This emphasizes the need for supplementary tools, such as IBMs coupled with hydrodynamic models of the region, to explore and determine the processes affecting horse mackerel recruitment, as has been done for other small pelagic fish species, such as sardine and anchovy (Huggett *et al.* 2003, Mullon *et al.* 2003, Parada *et al.* 2003, van der Lingen and Huggett 2003, Miller *et al.* 2006). Future research should also focus on horizontal egg distributions, using data from CUFES and CalVET net samples collected during the annual November spawner biomass surveys, as performed by Kuntz (2011), and vertically in the water column, as done for anchovy and sardine by Dopolo *et al.* (2005).

It is particularly uncommon, for a pelagic species, like the horse mackerel currently being caught as both adults and juveniles by three different fishing industries, to be so abundant. Following two strong year classes of horse mackerel in the 1950s, eight years of heavy fishing followed. During this period, most of the adult population on the west coast were thought to have been fished out, after which the stock collapsed. Based on these past observations, and the occurrence of two strong year classes in 2010 and 2011 (Chapter 2), it is hypothesized that horse mackerel are likely to be abundant for the next few years. Increased abundance has already caused problems within the fishing industry and will need improved understanding to manage appropriately. The presence of large fish on the west coast is a positive sign that the adult population was not completely fished out of this area in the past. High juvenile abundance on the west coast means potentially high by-catch by the pelagic fishery there. Horse mackerel bycatch should be kept to a minimum to enable the population on the south coast, targeted by the mid-water trawl fishery, to develop.

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## Appendix

**Appendix 1:** The annual distribution of horse mackerel along the South African coast according to size class from 1997-2010. Data derived from May recruit and November spawner biomass acoustic survey data. Size classes: <9.9cm, 10-19.9cm, 20-29.9cm and >30cm TL.

**Appendix 2:** An interpretation of the annual distributions of horse mackerel along the South African coast according to size class from 1997-2010 shown in Appendix 1. Data derived from May recruit and November spawner biomass acoustic survey data.

**Appendix 3:** The annual length frequency distributions of horse mackerel from the May Recruit and November spawner biomass surveys from 1997-2010.

**Appendix 4:** An interpretation of the annual length frequency distribution of horse mackerel from the May Recruit and November spawner biomass surveys from 1997-2010 shown in Appendix 3.

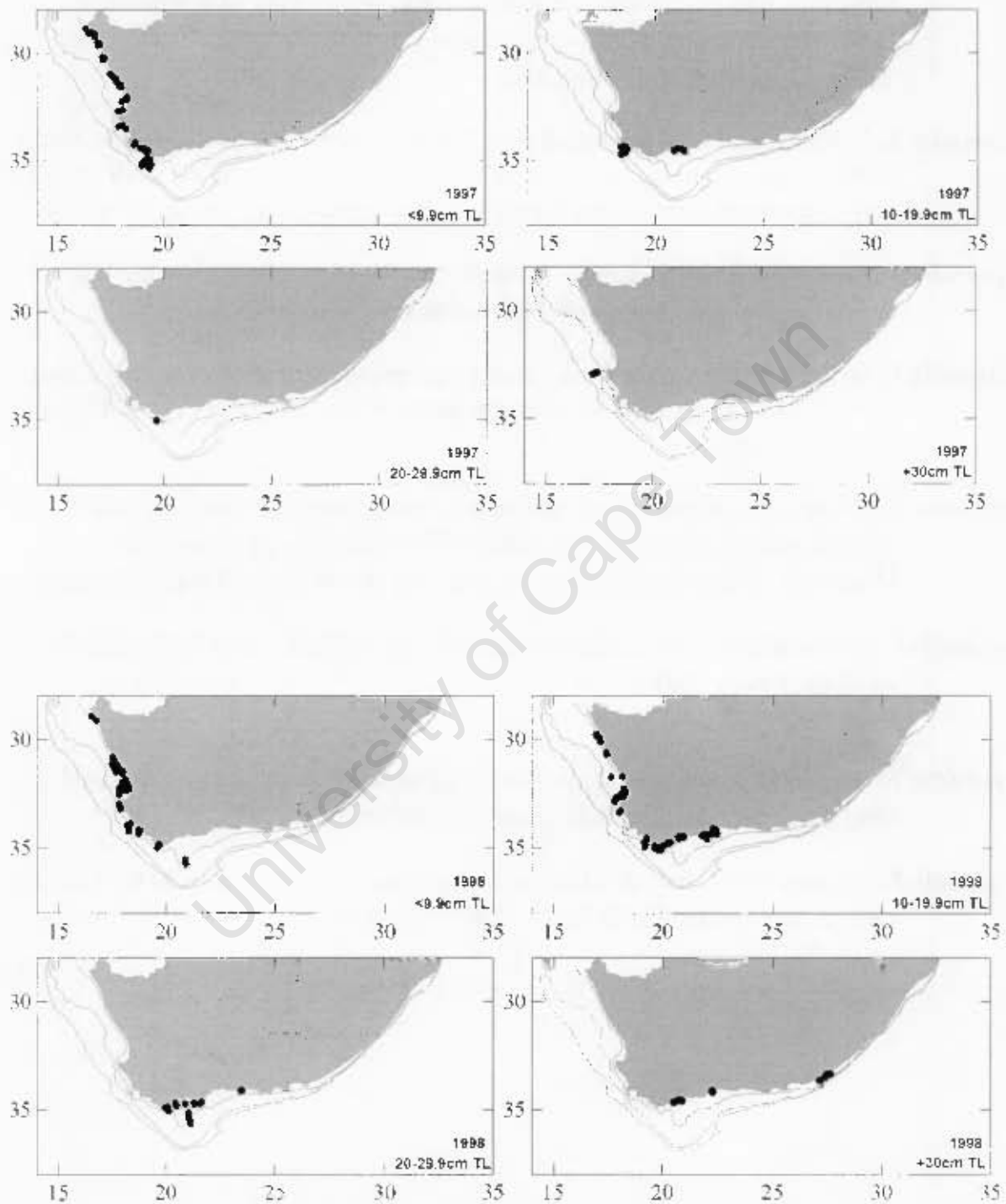
**Appendix 5:** The annual distribution and abundance of horse mackerel along the South African coast by size class from 1984-2011 according to Demersal survey data. Units – no. of fish per nmi<sup>2</sup>. Size classes: <9.9, 10-19.9, 20-29.9 and >30cm TL.

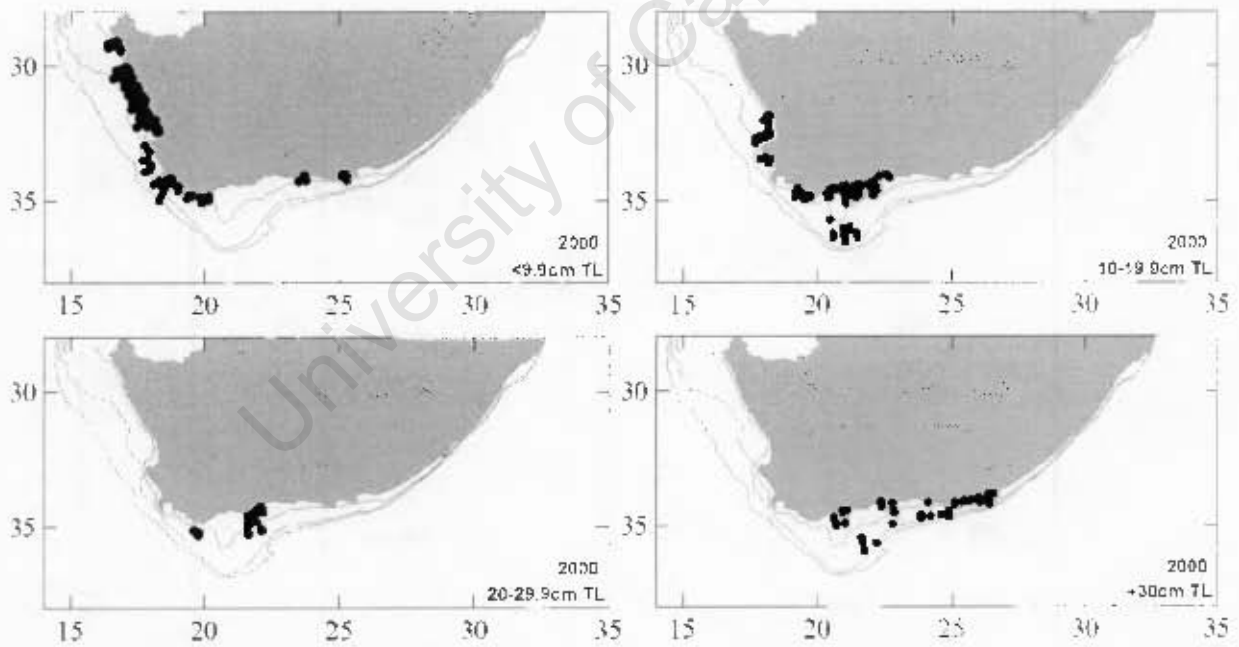
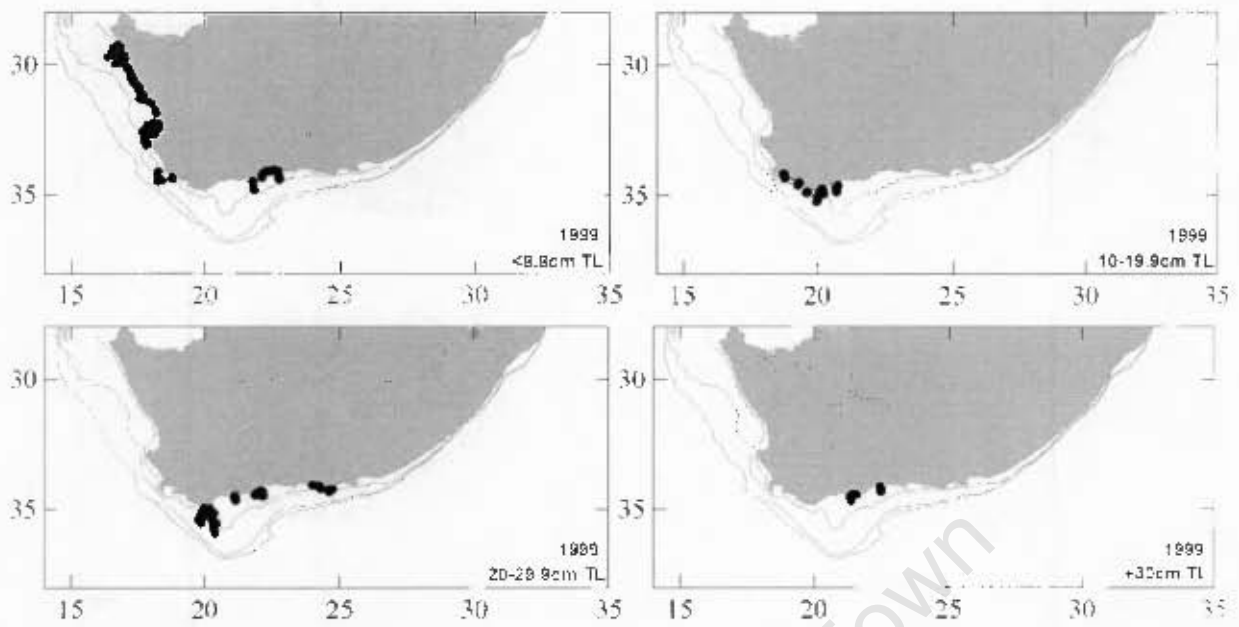
**Appendix 6:** An interpretation of the annual distribution and abundance of horse mackerel along the South African coast by size class from 1984-2011 according to Demersal survey data shown in Appendix 5.

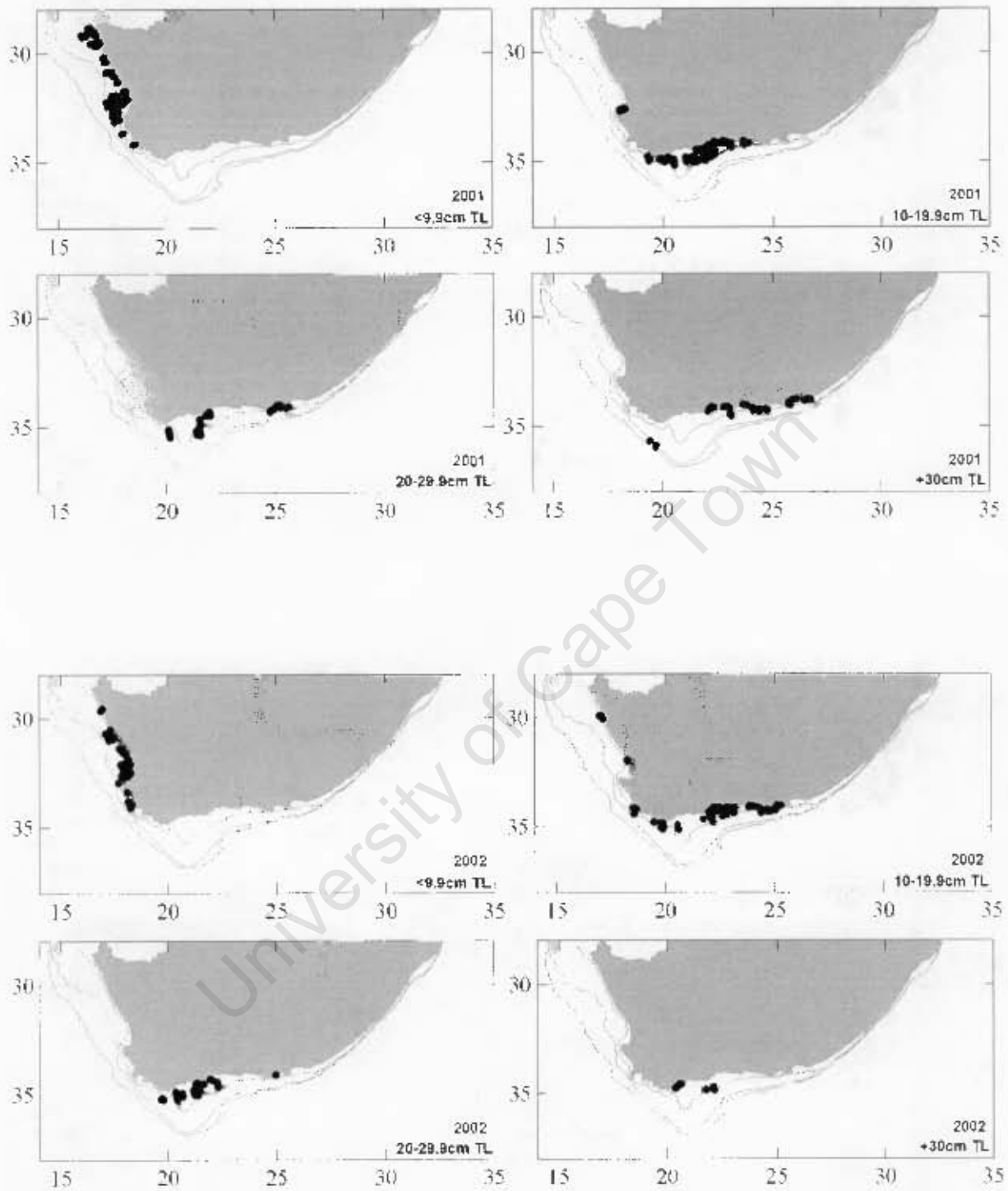
**Appendix 7:** The overall length weight relationship of horse mackerel samples collected from the eastern Agulhas Bank from June to December 2011.

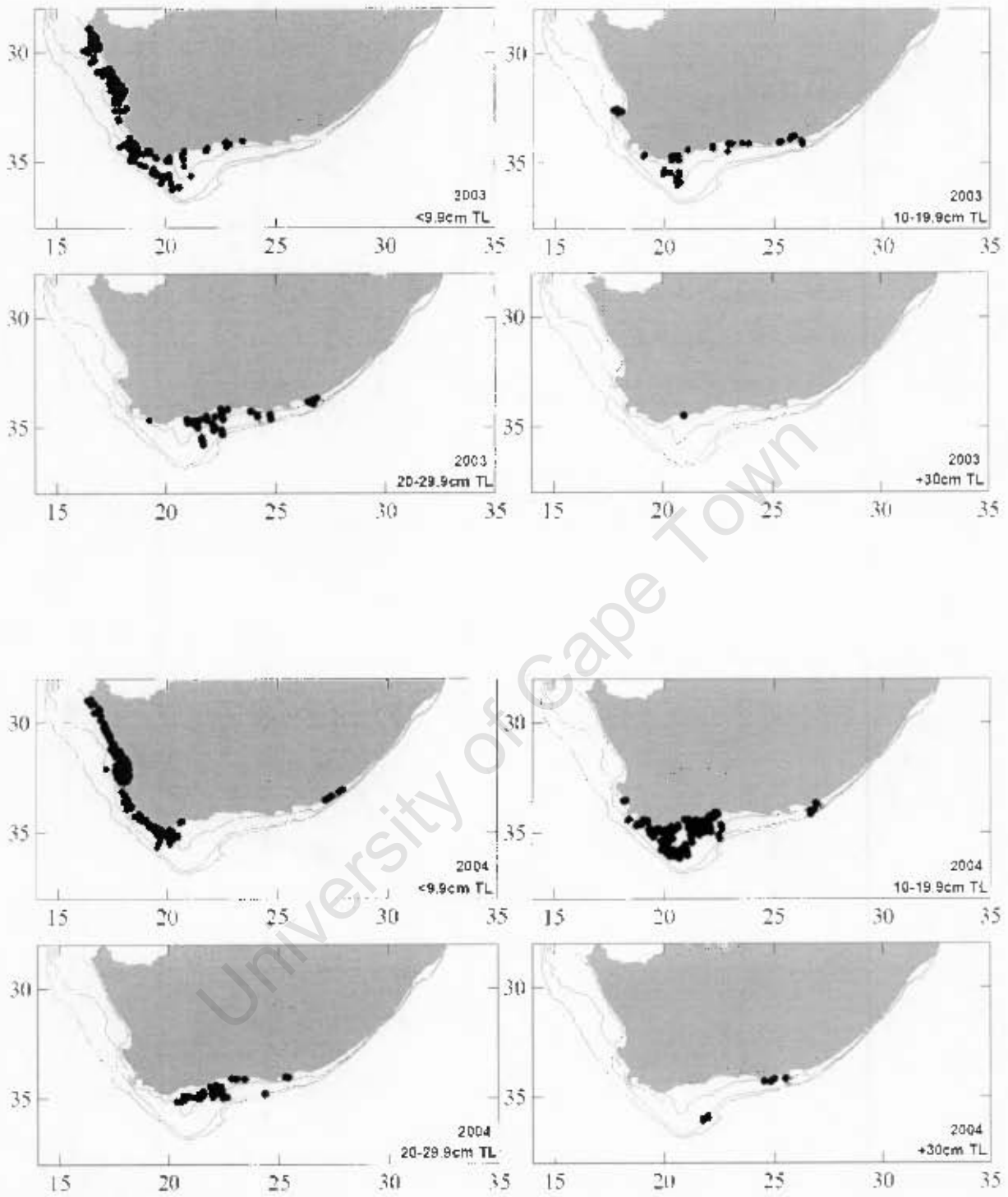
**Appendix 8:** The length frequency distribution of horse mackerel samples collected from the eastern Agulhas Bank from June to December 2011.

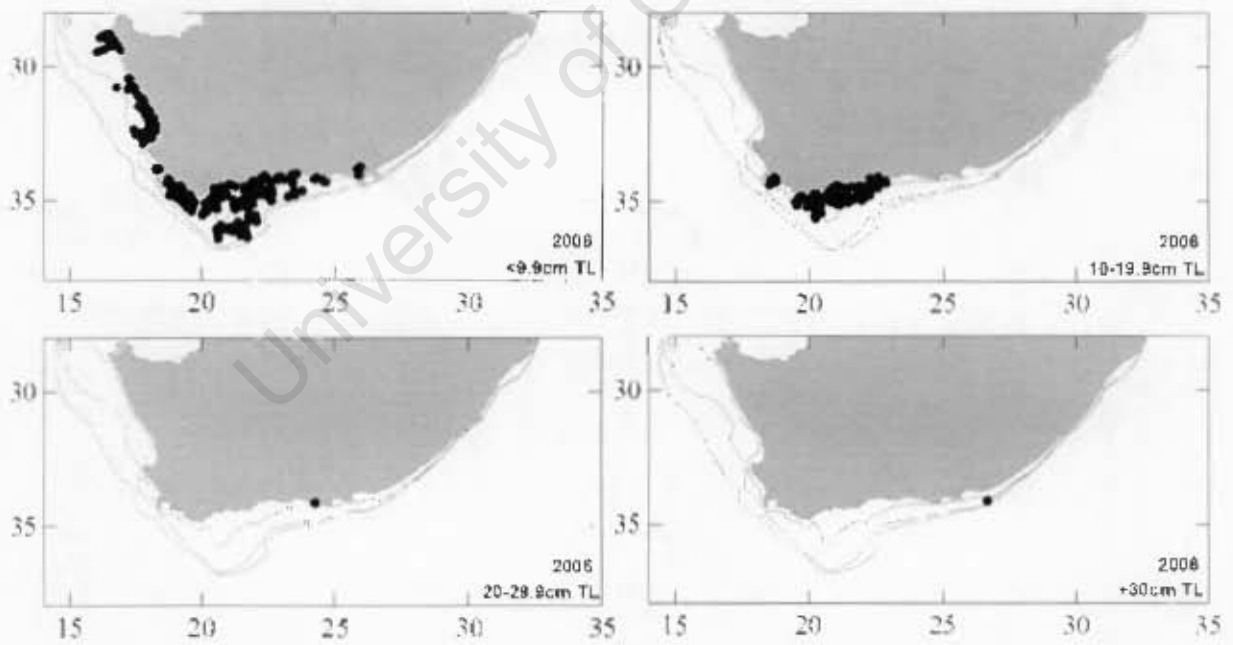
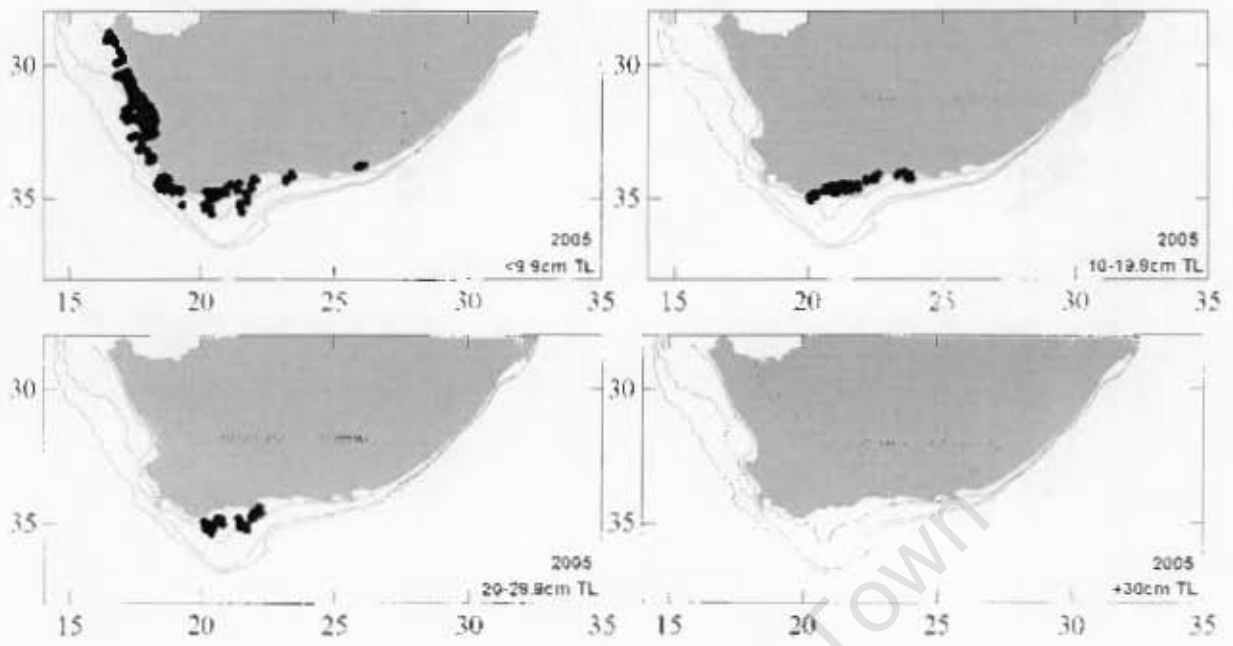
Appendix 1: The annual distribution of horse mackerel along the South African coast according to size class from 1997-2010. Data derived from May recruit and November spawner biomass acoustic survey data. Size classes: <9.9cm, 10-19.9cm, 20-29.9cm and +30cm TL.

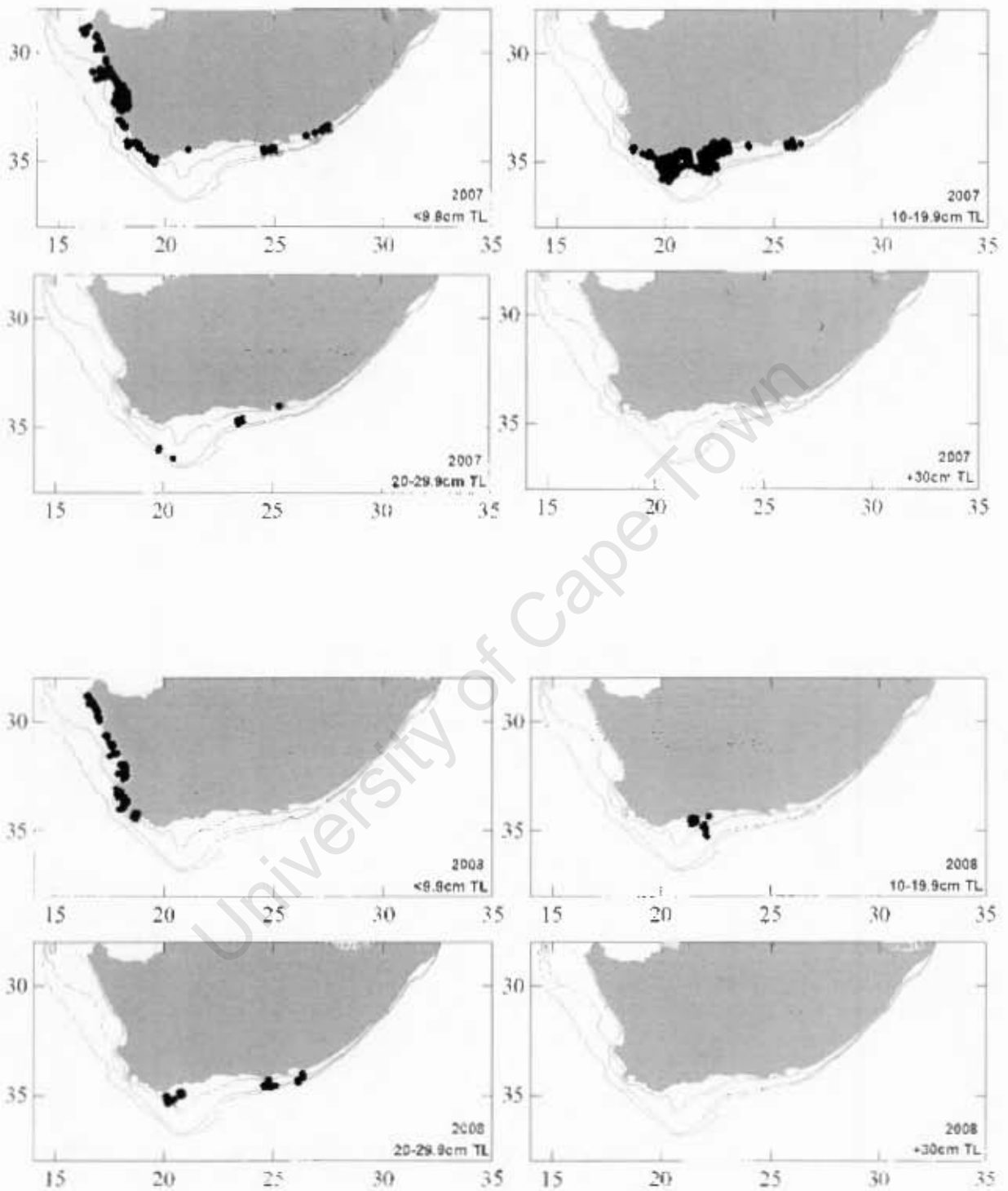


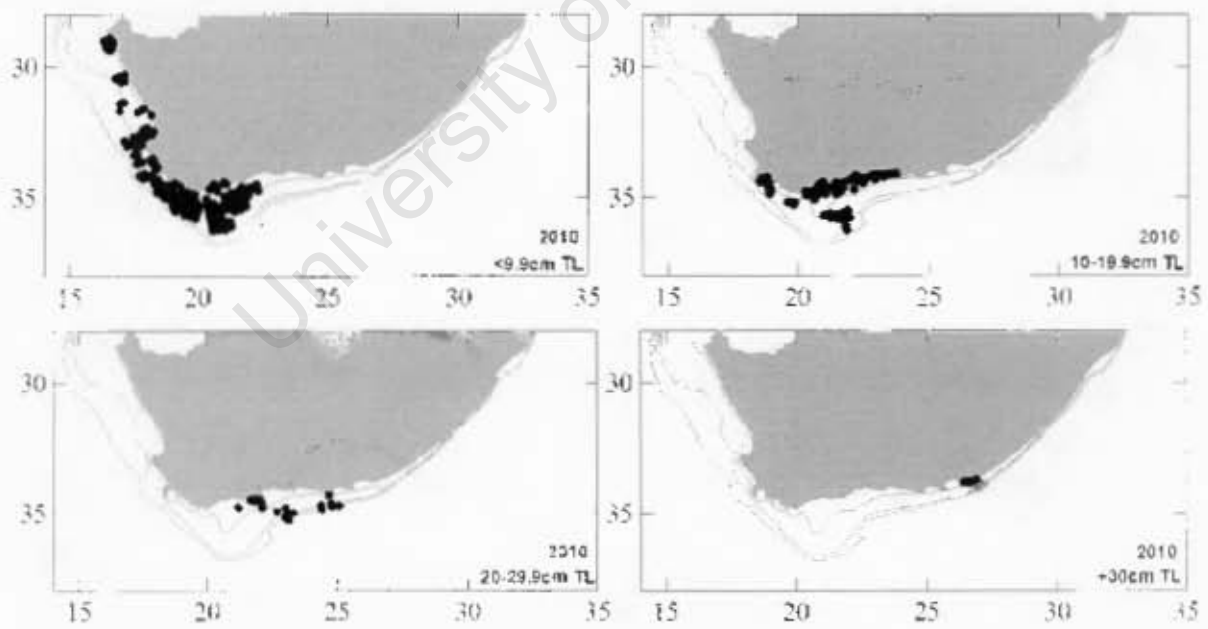
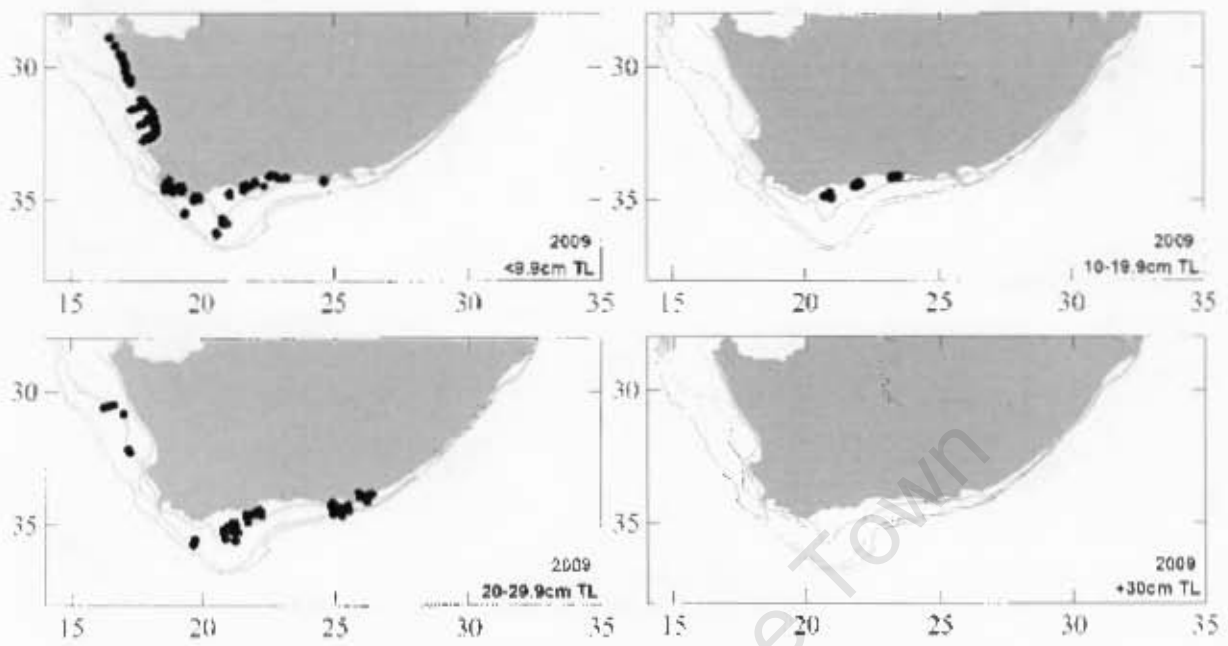












Appendix 2: An interpretation of the annual distributions of horse mackerel along the South African coast according to size class from 1997-2010 shown in Appendix 1. Data derived from May recruit and November spawner biomass acoustic survey data.

1997

Output based on 78 trawls (45 from the May recruit survey and 33 from the November spawner biomass survey). Fish in the <9.9cm TL size class dominated the mean length of fish caught with very few data points for fish from the 20-29.9cm TL and >30cm TL size classes. Larger fish located unexpectedly on the west coast just offshore of St. Helena Bay.

1998

Output based on 140 trawls (101 from the May recruit survey and 39 from the November spawner biomass survey). Fish in the <9.9cm TL size class dominated the mean length of fish caught. High density occurrences of fish from size classes <9.9cm TL and 10-19.9cm TL were found within and just offshore of St. Helena Bay on the west coast. With 20-29.9cm TL fish occurring on the CAB and fish of >30cm TL occurring on the CAB as well as further east this distribution is close to what is typically expected.

1999

Output based on 169 trawls (113 from the May recruit survey and 56 from the November spawner biomass survey). Fish in the <9.9cm TL size class dominated the mean length of fish caught and the occurrence of this size class were found throughout the west coast as well as some areas inshore on the south coast. This could be seen as evidence that some bays on the south coast were important nursery areas for horse mackerel recruits in 1999. Individuals of size class 20-29.9cm TL were found across the Agulhas and larger individuals further east offshore near Port Elizabeth as expected.

2000

Output based on 314 trawls (198 from the May recruit survey and 116 from the November spawner biomass survey). More extensive sampling was performed this year than all previous years and a more even spread of size class occurrences were recorded apart from fish of 20-29.9cm TL. This output represents what is typically expected of the horse mackerel distribution. There are extensive nursery areas for fish <9.9cm TL on the west coast and some to a lesser extent on the south coast. Individuals of 10-19.9cm TL were found to extend further offshore to the shelf edge, much further offshore than what is typically expected of this size class. Larger individuals of >30cm TL dominated the EAB.

2001

Output based on 220 trawls (142 from the May recruit survey and 78 from the November spawner biomass survey). This year shows a distribution that is typically expected. There were large concentrations of individuals <9.9cm TL and 10-19.9cm TL just off St. Helena Bay. Larger individuals dominated the EAB.

2002

Output based on 165 trawls (123 from the May recruit survey and 42 from the November spawner biomass survey). Fish in the <9.9cm TL size class dominated the mean length of fish caught on the west coast. Individuals of 10-19.9cm TL were found extensively on the south

coast and to a lesser extent on the west coast. Individuals of 20-29.9cm TL were only found on the CAB with very few larger fish being recorded.

#### 2003

Output based on 248 trawls (124 from the May recruit survey and 124 from the November spawner biomass survey). Fish <9.9cm TL dominated the west coast and WAB. Fish from 10-19.9cm TL and 20-29.9cm TL occurred on the CAB and EAB. As with 2002 very few larger fish were recorded.

#### 2004

Output based on 327 trawls (199 from the May recruit survey and 128 from the November spawner biomass survey). Fish <9.9cm TL dominated the mean length of fish caught on the west coast with unexpectedly some occurring high on the EAB. Fish 10-19.9cm TL dominate the WAB and CAB also with a small component occurring high on the EAB. Individuals 20-29.9cm TL mainly occurs on the CAB with larger individuals mainly on the EAB and on the shelf edge of the CAB.

#### 2005

Output based on 238 trawls (177 from the May recruit survey and 82 from the November spawner biomass survey). Fish <9.9cm TL dominate down the west coast as expected but extend much further east than expected onto WAB and CAB and further to Mossel Bay and Port Elizabeth. On the CAB individuals of 10-19.9cm TL were found inshore whereas 20-29.9cm TL fish were situated offshore. Fish >30cm TL were not recorded as a mean length at any of the sample stations.

#### 2006

Output based on 330 trawls (177 from the May recruit survey and 153 from the November spawner biomass survey). Fish <9.9cm TL dominate the entire coastline on both the west and south coast diminishing in occurrence on the EAB. These smaller individuals were also found to occur on the shelf edge of the CAB. They have not been recorded in this area prior to this year within the range of the Acoustic surveys from 1997. Very few larger individuals of 20-29.9cm TL and >30cm TL were recorded.

#### 2007

Output based on 273 trawls (227 from the May recruit survey and 46 from the November spawner biomass survey). Fish of <9.9cm TL dominate the west coast and occur on WAB and EAB as far as Port Elizabeth and Port Alfred. Fish of 10-19cm TL were found to dominate the inshore areas of the WAB and CAB and also occurred off Port Elizabeth. No large individuals were found but some of 20-29.9cm TL occurred offshore on the EAB and on the shelf edge of the WAB and CAB.

#### 2008

Output based on 107 trawls (32 from the May recruit survey and 75 from the November spawner biomass survey). Very few occurrences of horse mackerel compared to previous years, however this may not be an indication of population decline but simply due to reduced sampling intensity. Fish of <9.9cm TL dominate the west coast while there were a few

occurrences of fish of 10-19.9cm TL offshore on the CAB. Fish of 20-29.9cm TL were found offshore on the CAB, and around Port Elizabeth on the EAB. Fish >30cm TL were not recorded as a mean length at any of the sample stations.

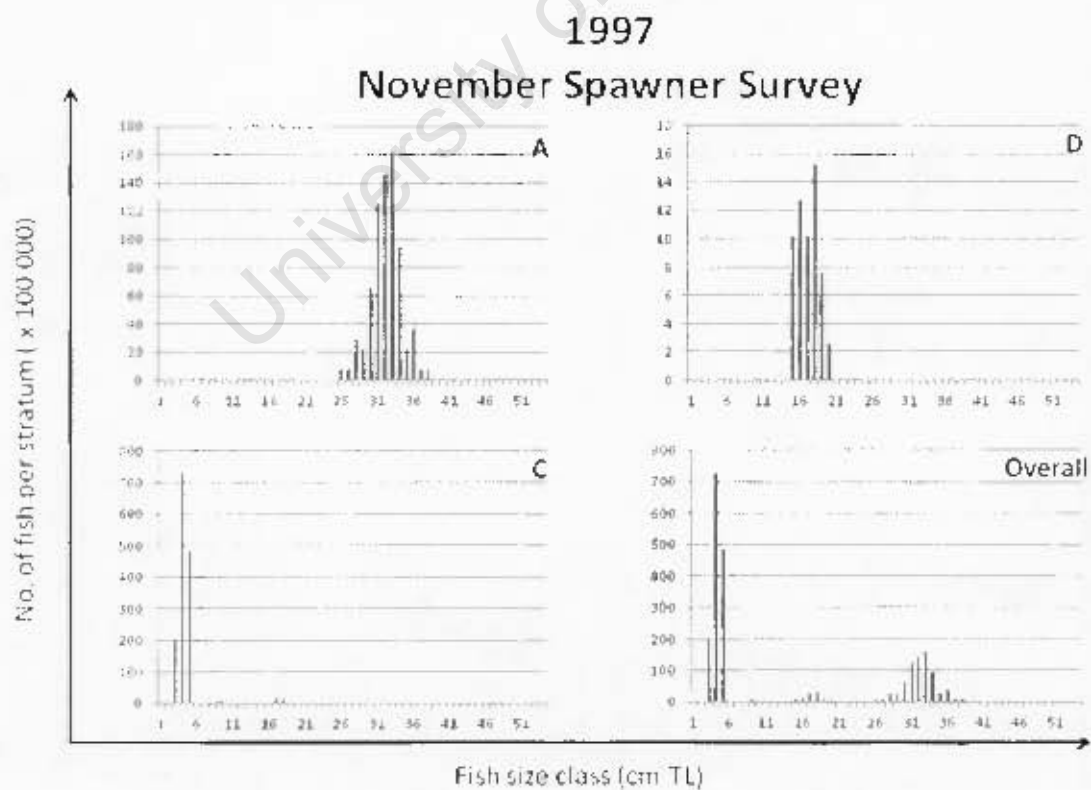
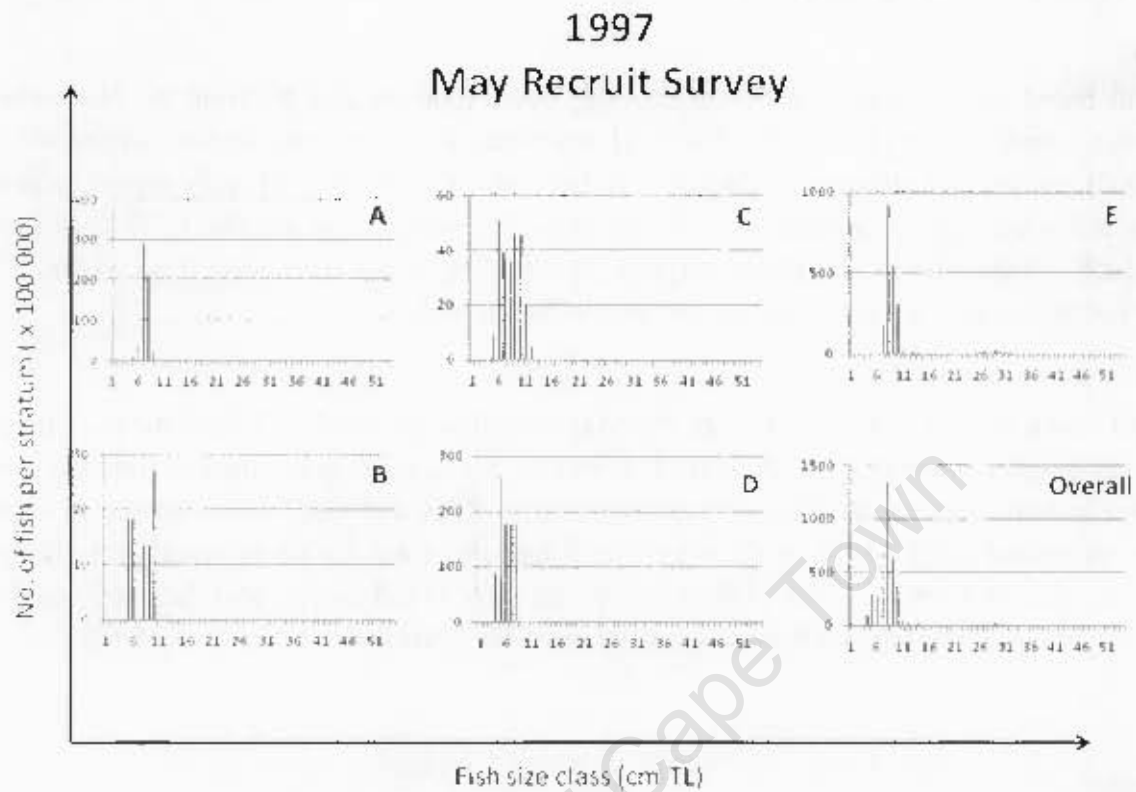
#### 2009

Output based on 170 trawls (89 from the May recruit survey and 81 from the November spawner biomass survey). Fish of <9.9cm TL dominate the west coast, inshore on the WAB and both inshore and offshore on the CAB. Individuals of 10-19.9cm TL only appear inshore along the south coast. Individuals of 20-29.9cm TL were found on the EAB near Port Elizabeth, offshore on the CAB and surprisingly offshore on the west coast. Fish >30cm TL were not recorded as a mean length at any of the sample stations.

#### 2010

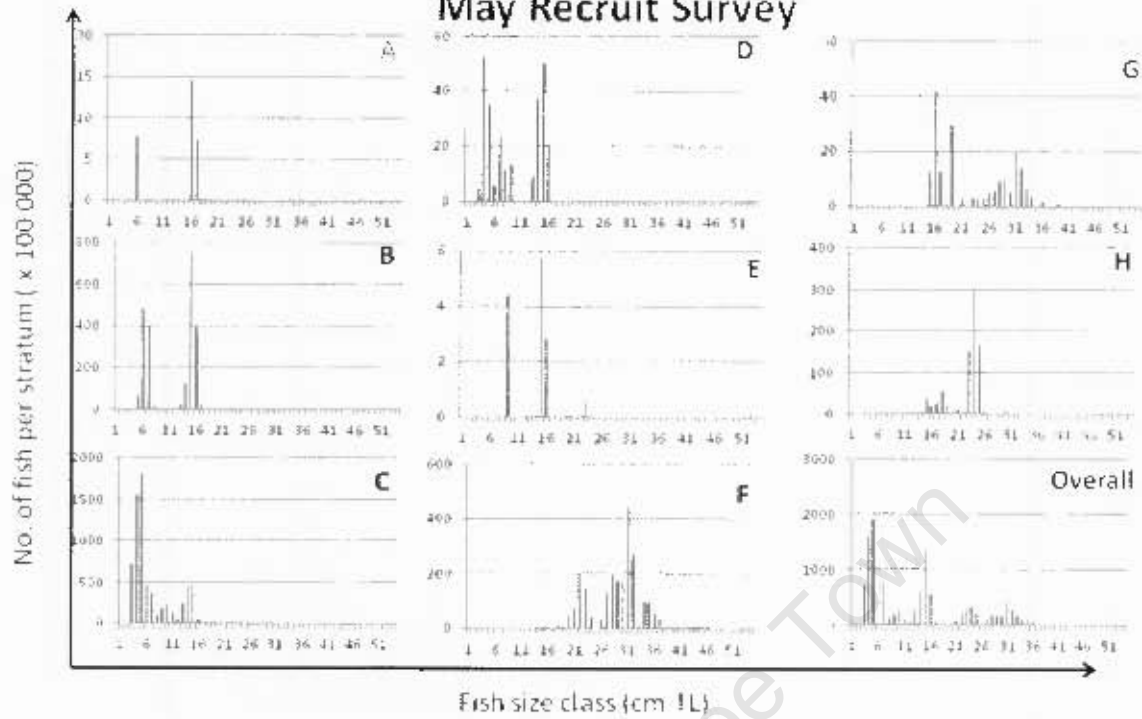
Output based on 313 trawls (121 from the May recruit survey and 193 from the November spawner biomass survey). Fish <9.9cm TL dominate the west coast but their occurrence here is more patchy than usual while they dominate the WAB and CAB from inshore to shelf edge. Individuals of 10-19.9cm TL were found inshore along the south coast with a large grouping mid-shelf on the CAB. Fish of 20-29.9cm were found inshore and shelf edge on the EAB while larger individuals were found inshore on the EAB inshore near Port Alfred.

Appendix 3: The annual length frequency distributions of horse mackerel from the May Recruit and November spawner biomass surveys from 1997-2010.



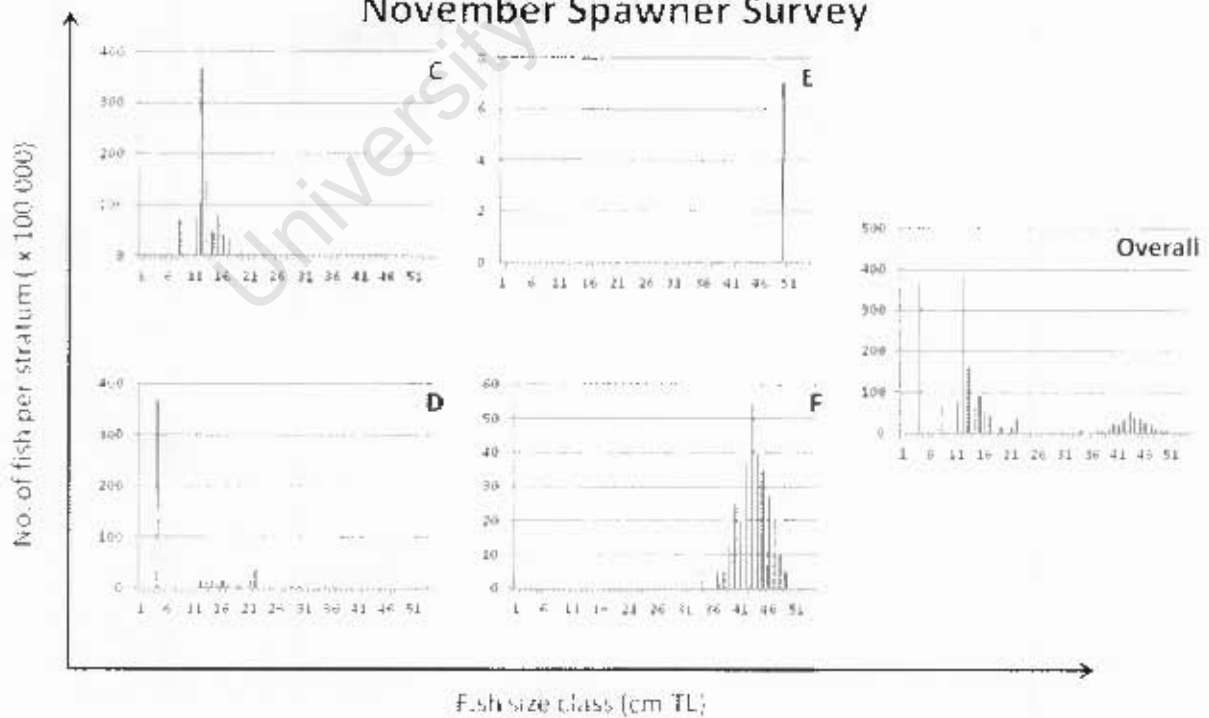
1998

May Recruit Survey



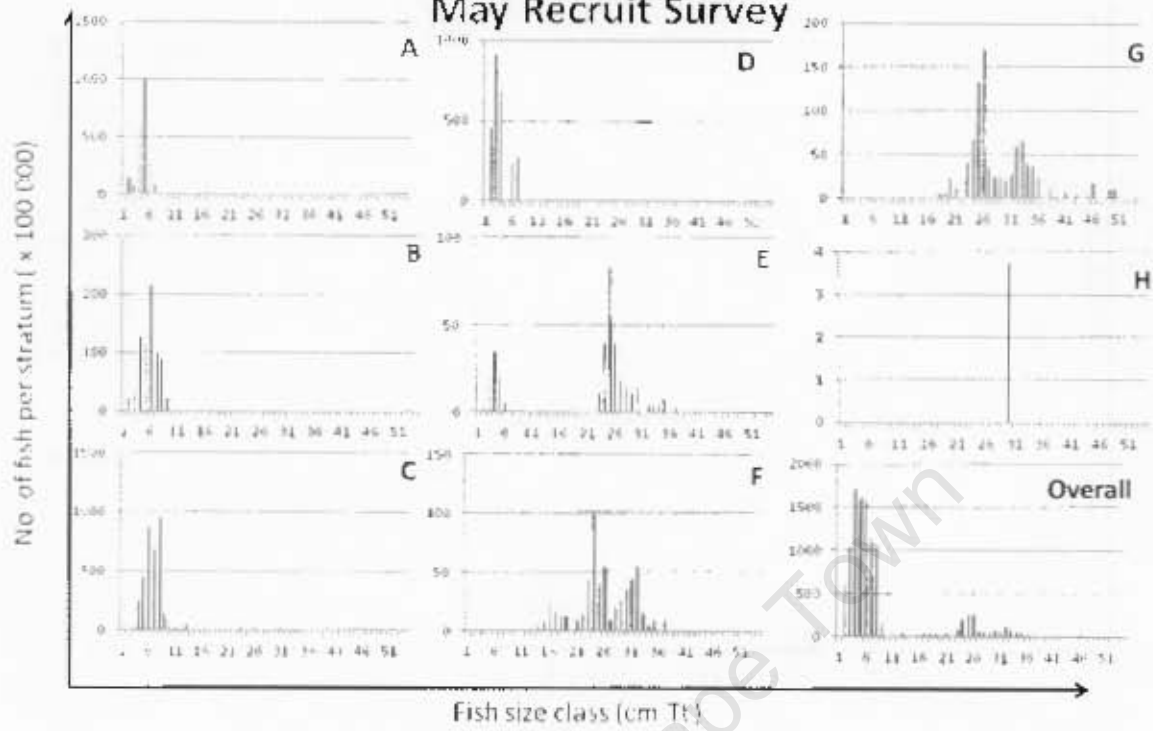
1998

November Spawner Survey



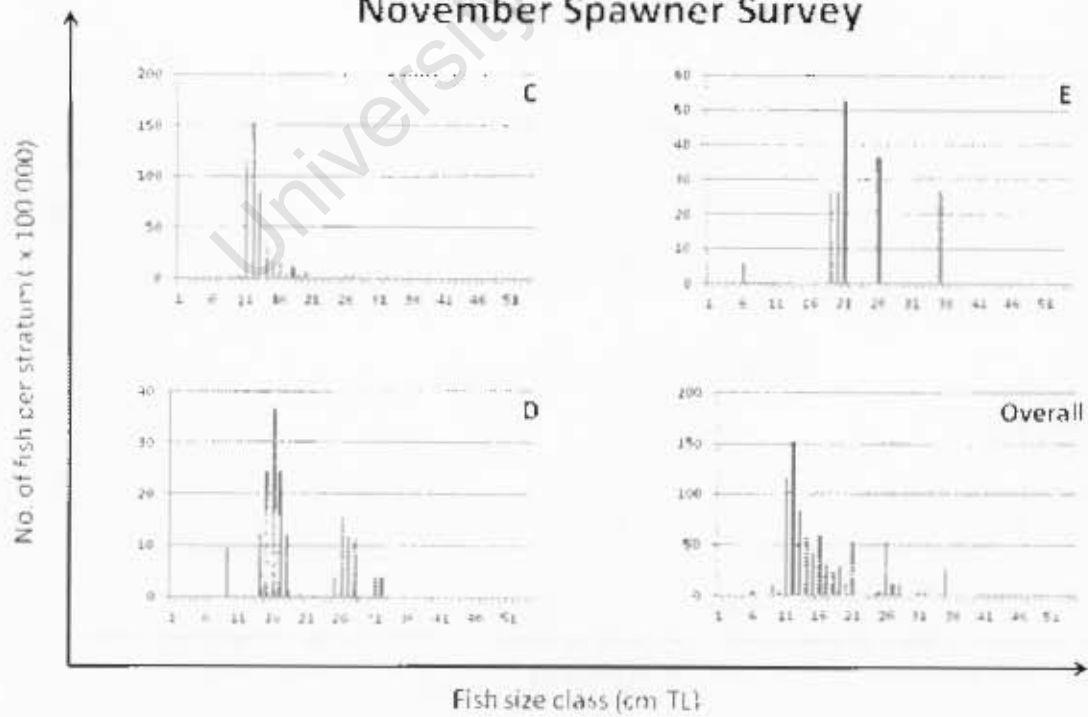
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May Recruit Survey

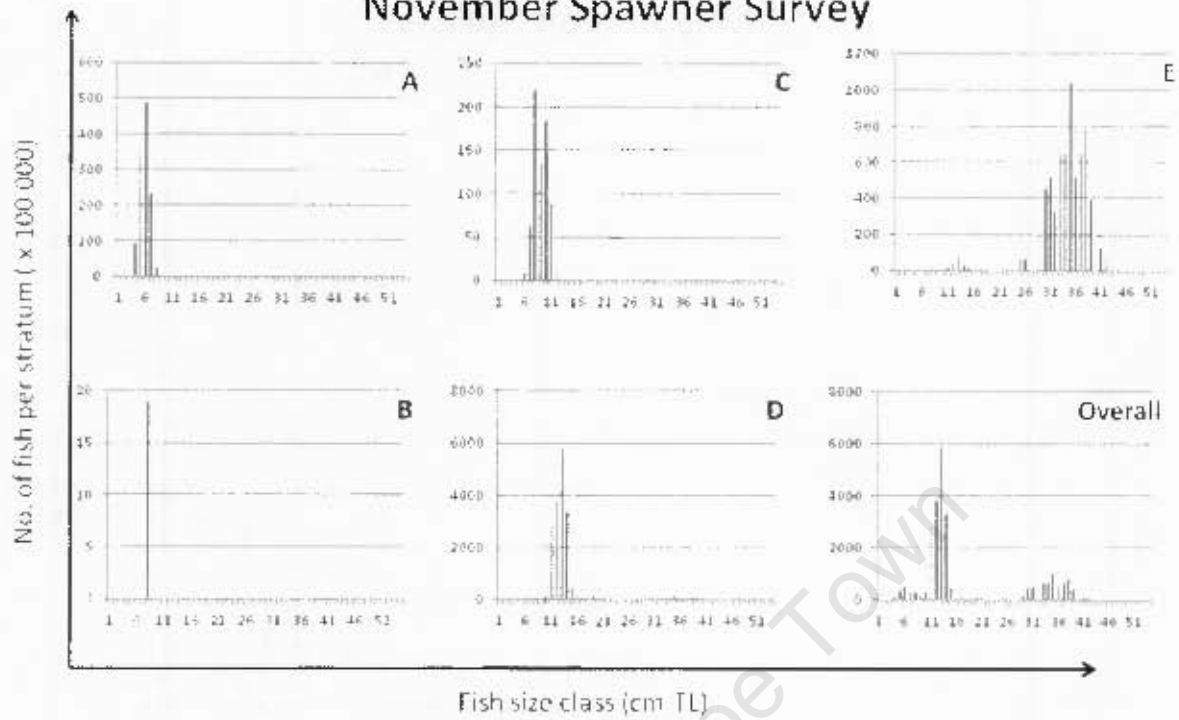


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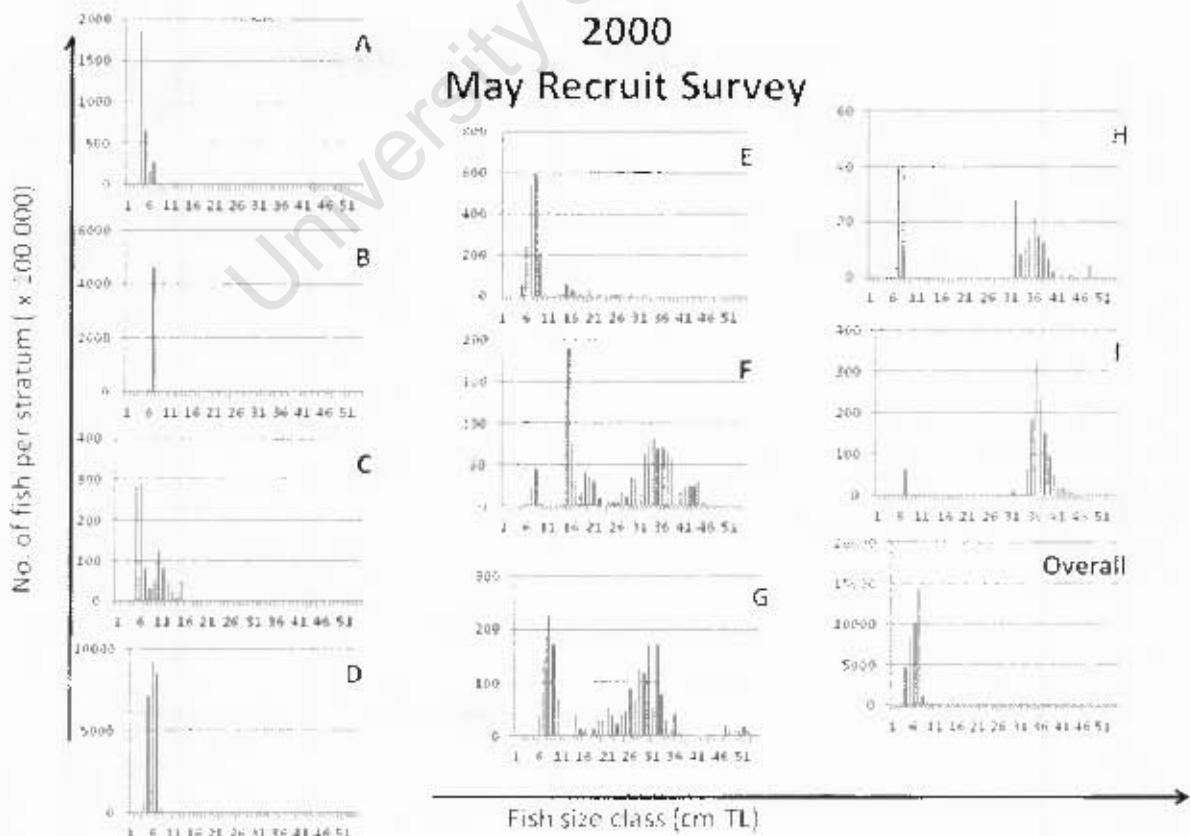
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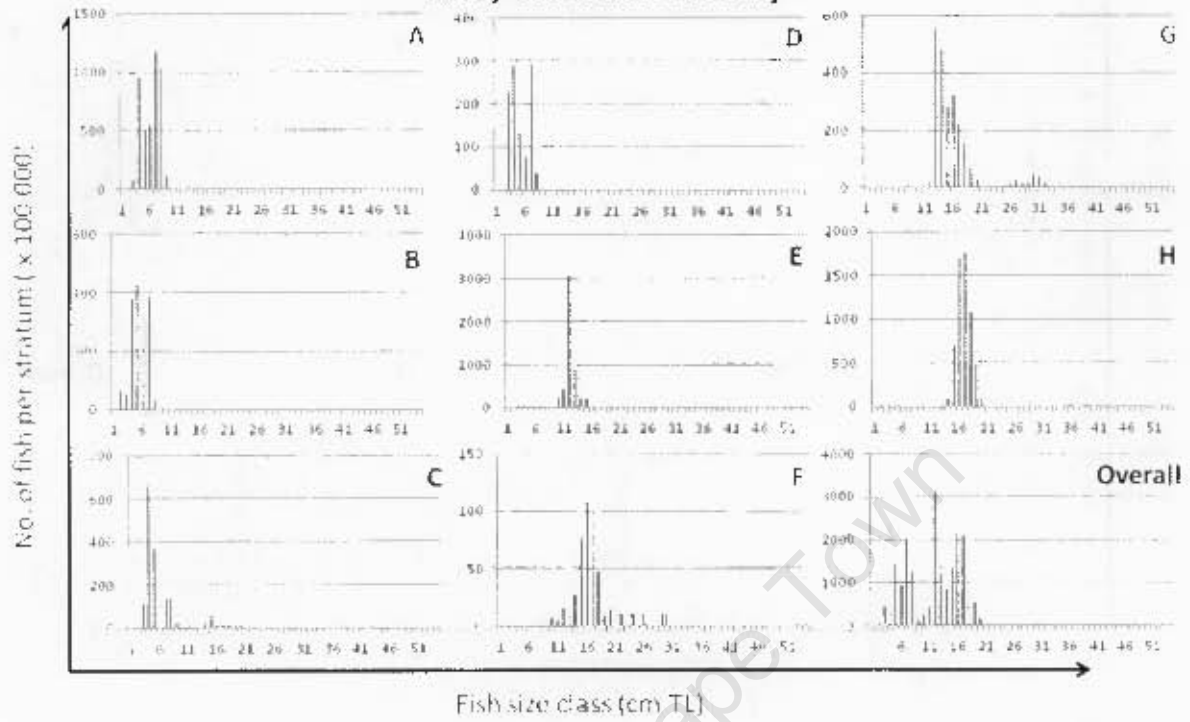
2000  
November Spawner Survey



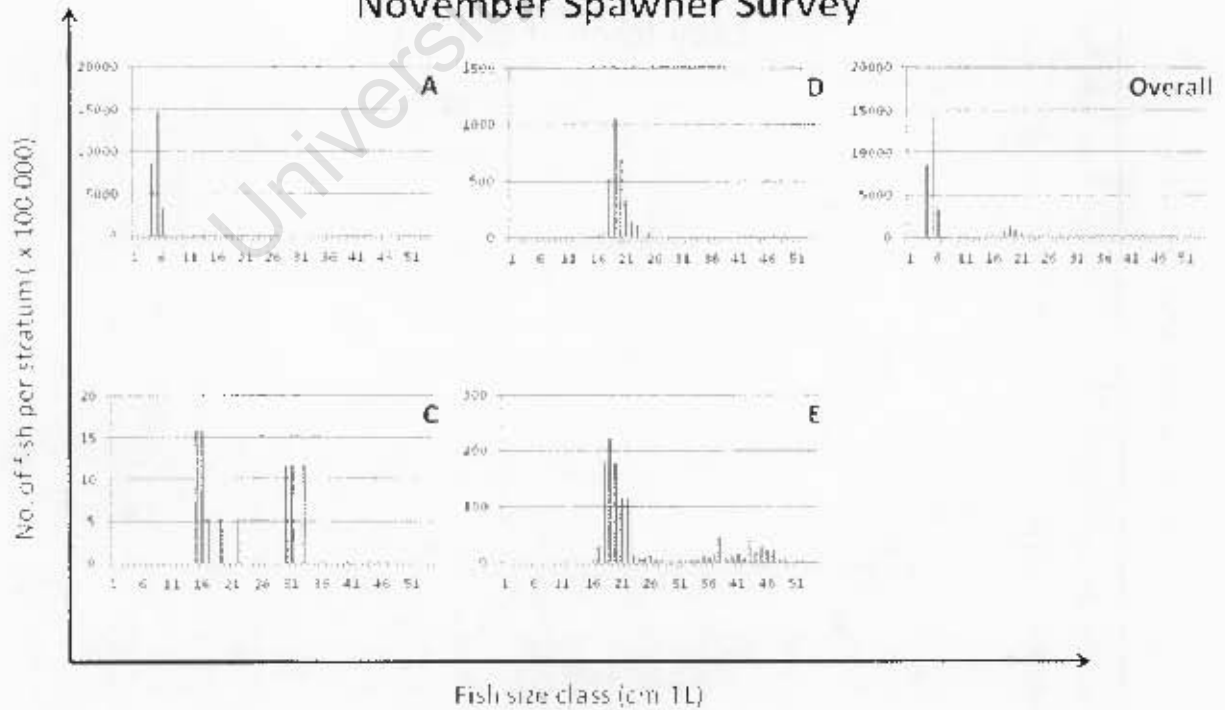
2000  
May Recruit Survey

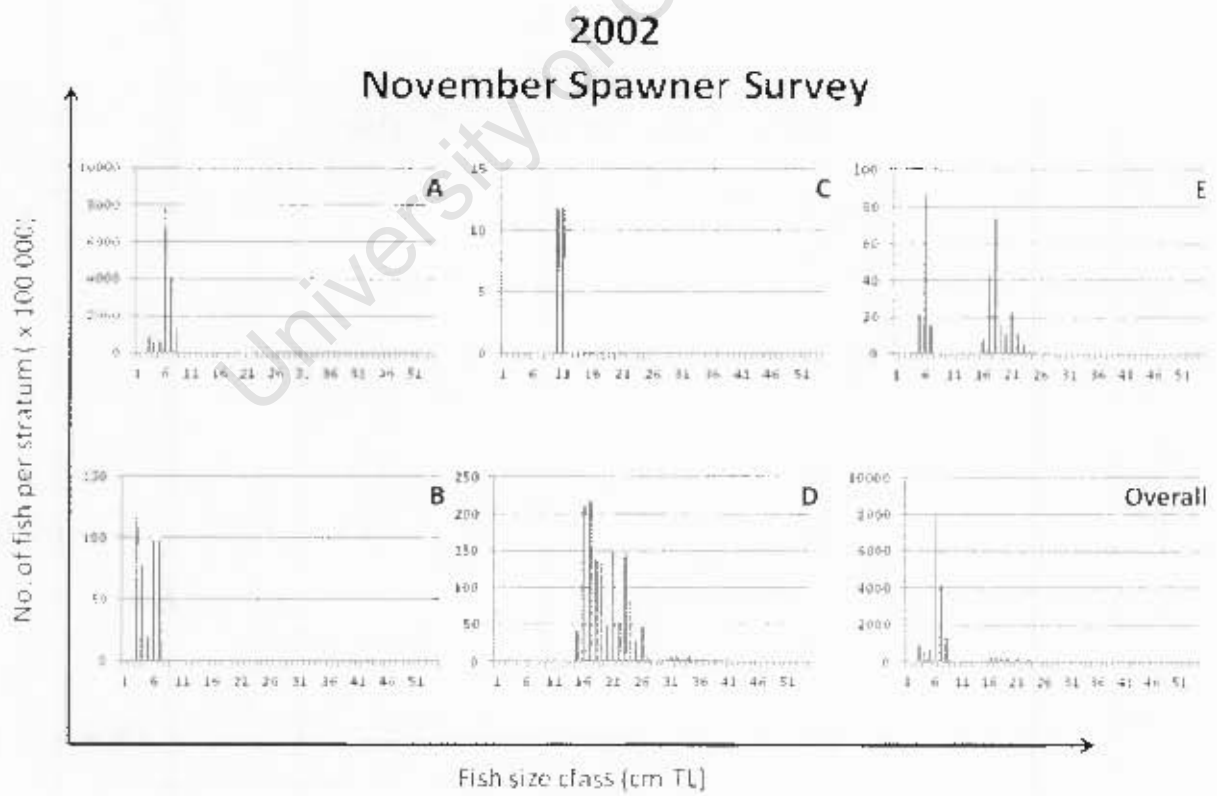
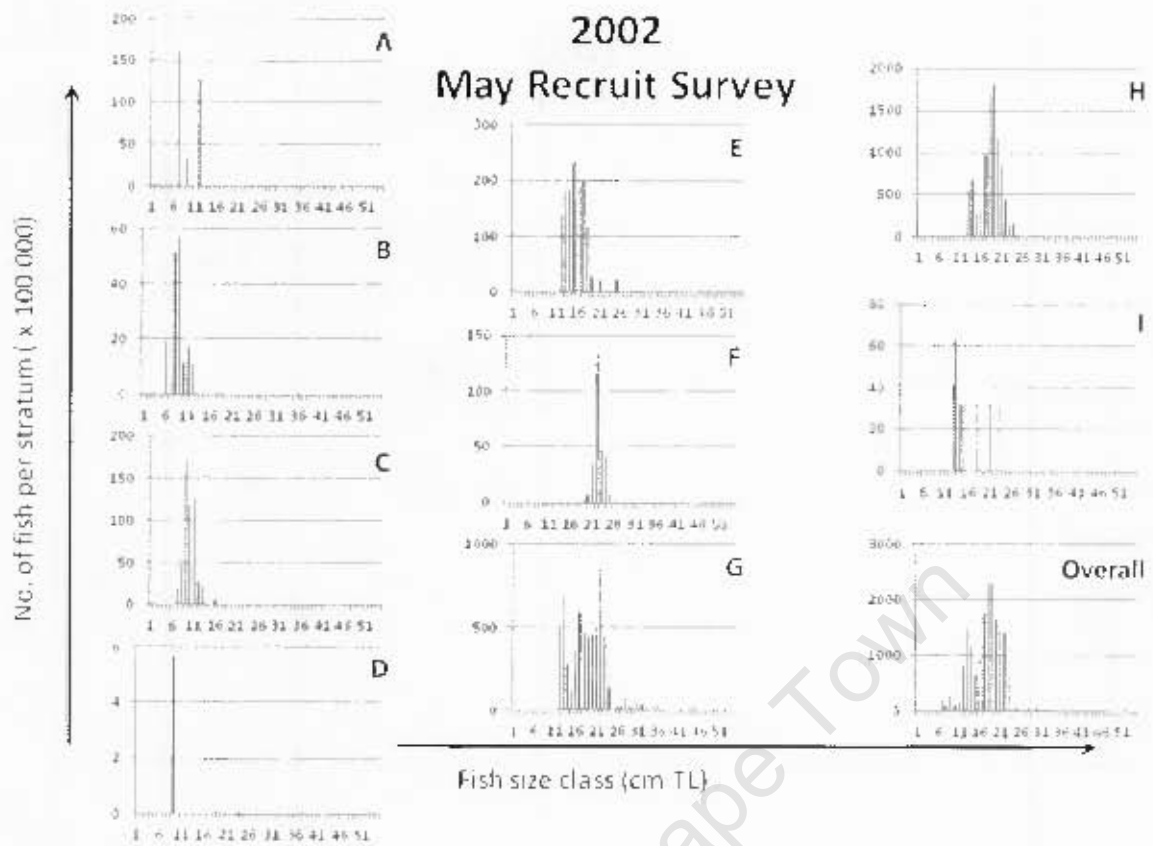


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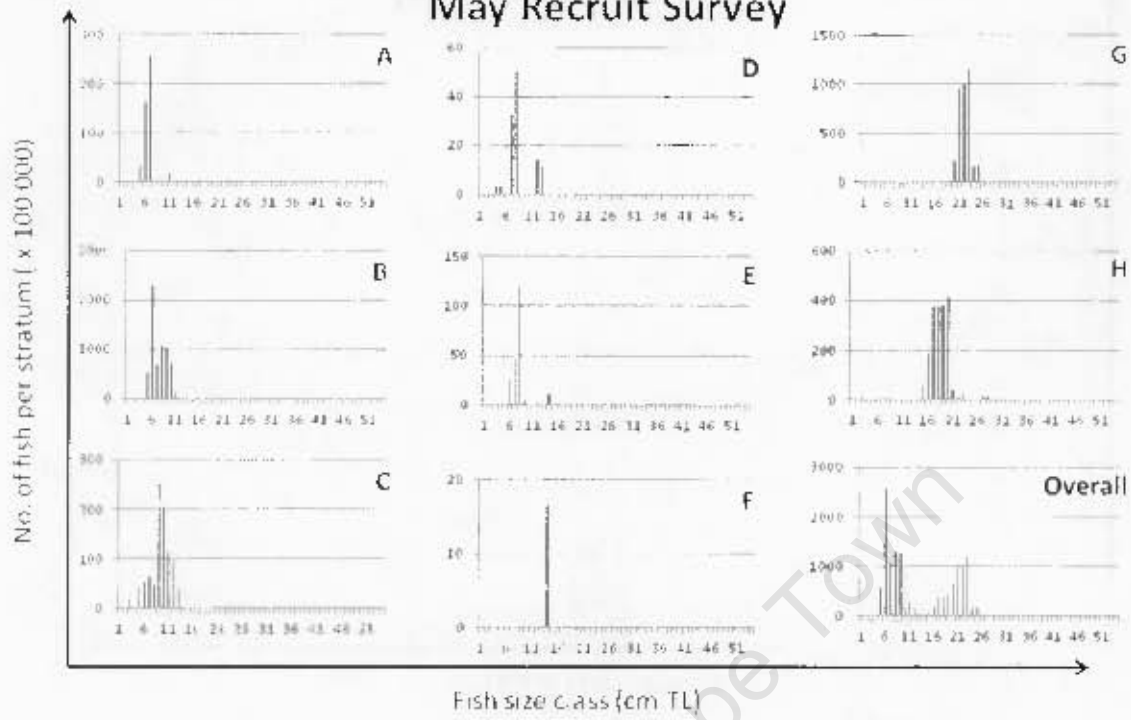


## 2001 November Spawner Survey

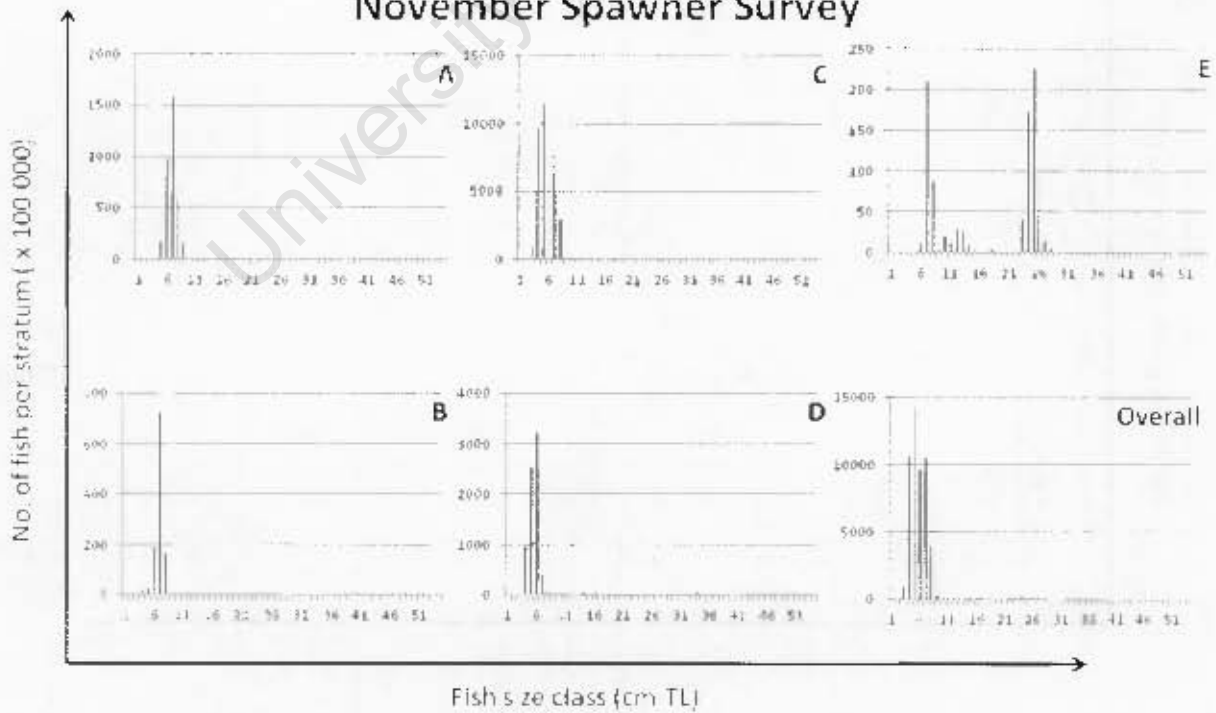


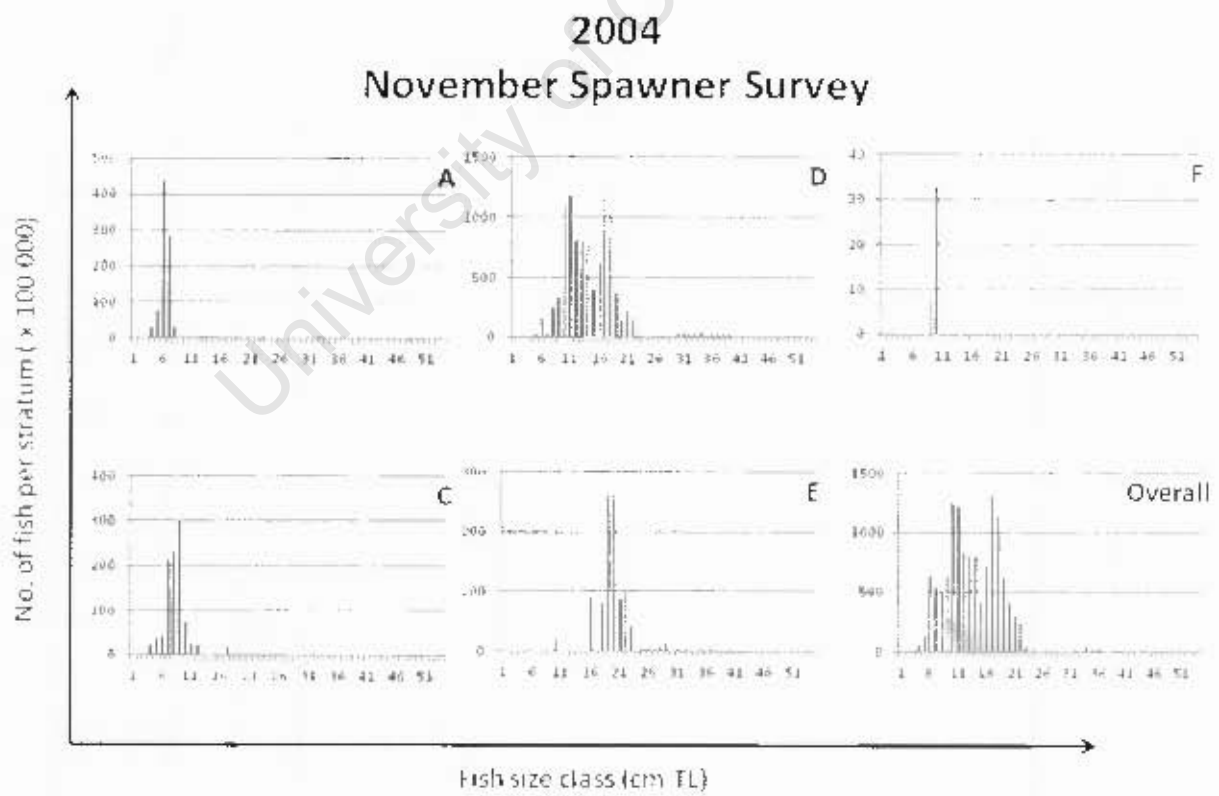
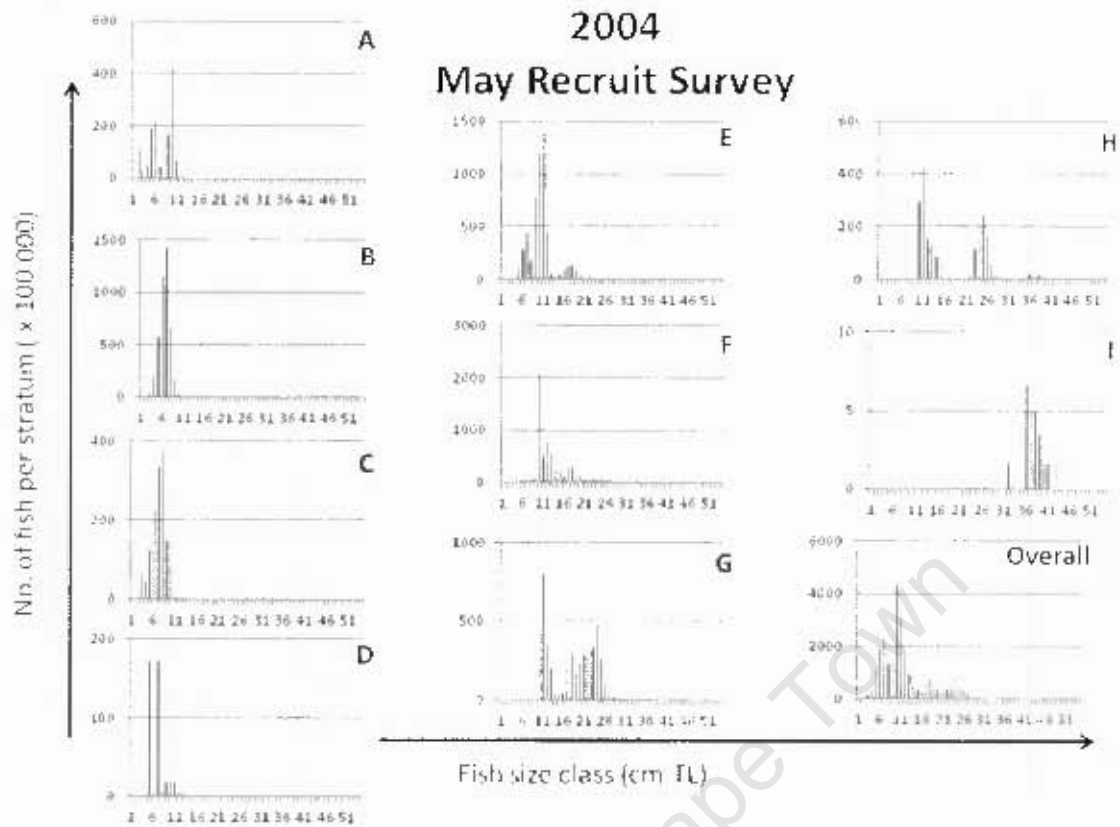


2003  
May Recruit Survey



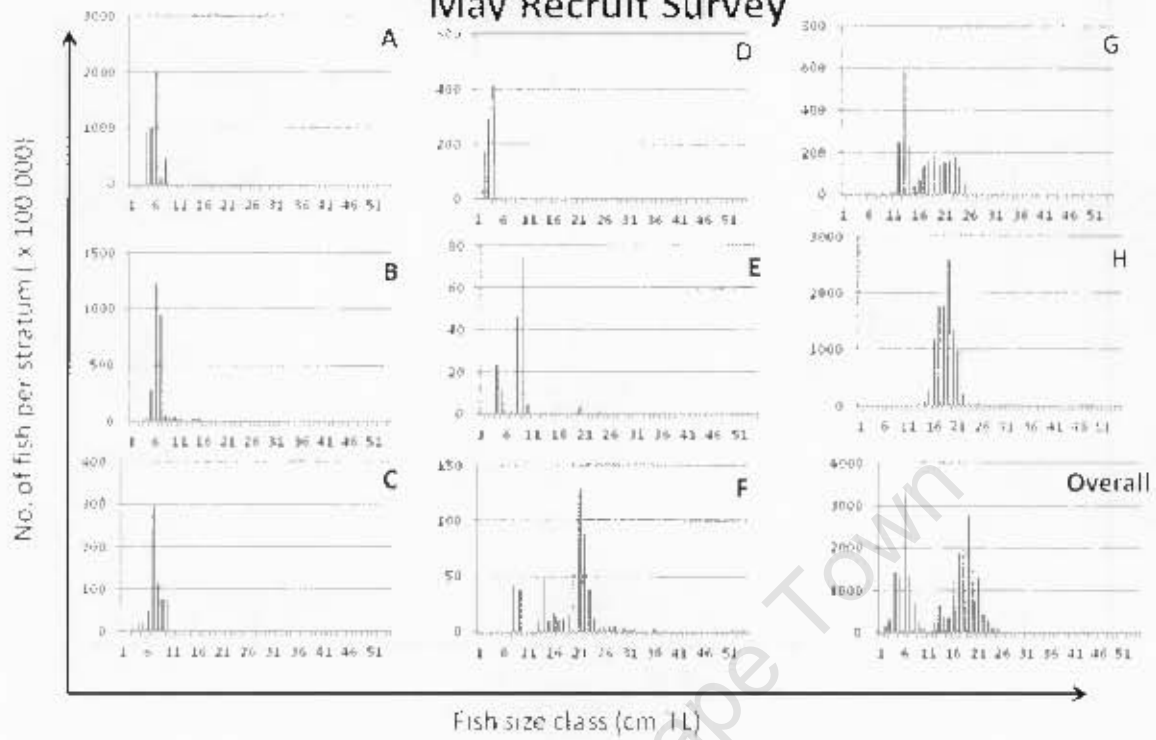
2003  
November Spawner Survey





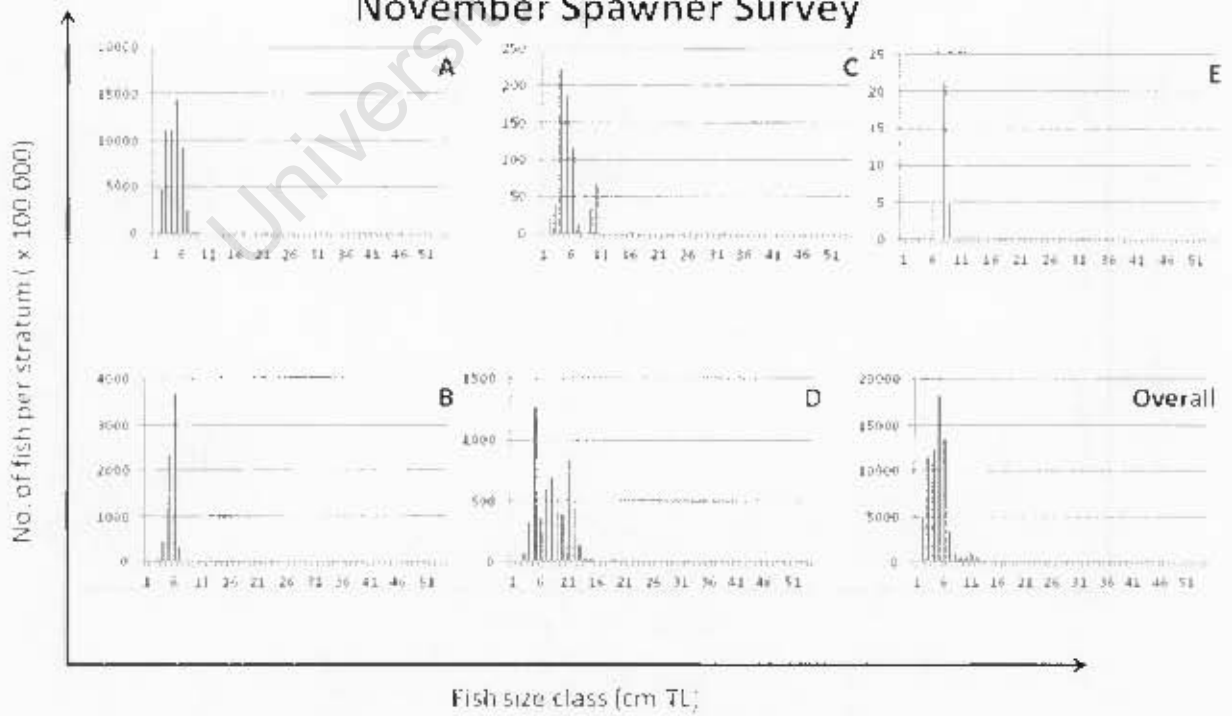
2005

May Recruit Survey



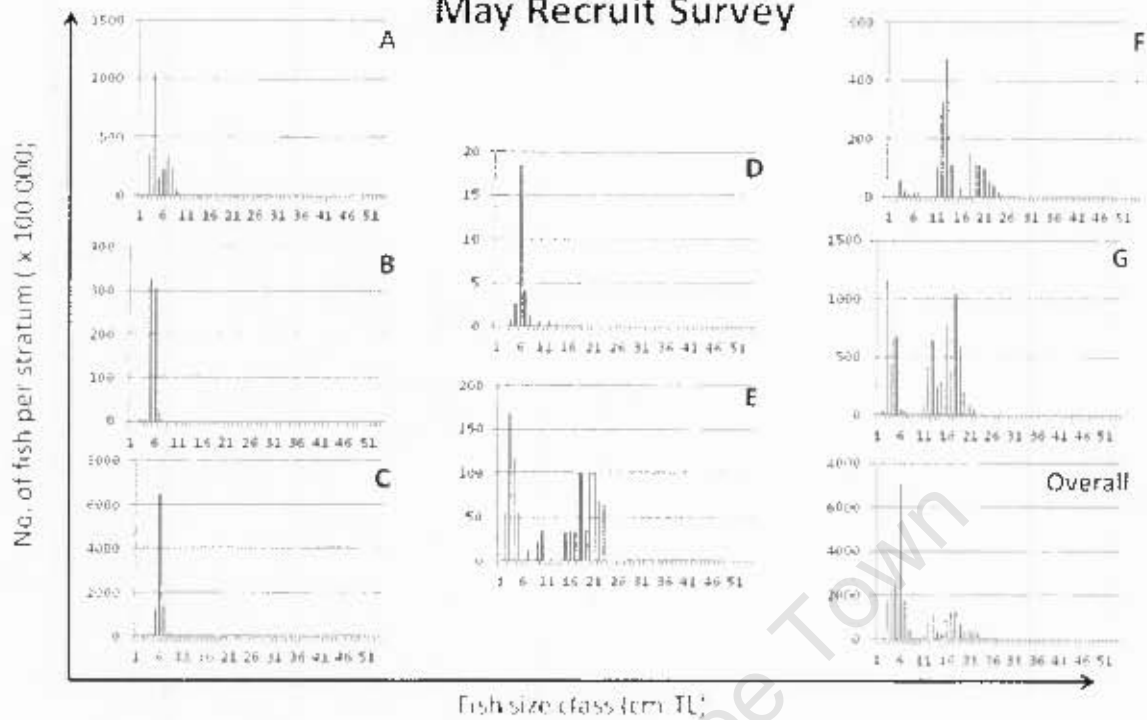
2005

November Spawner Survey



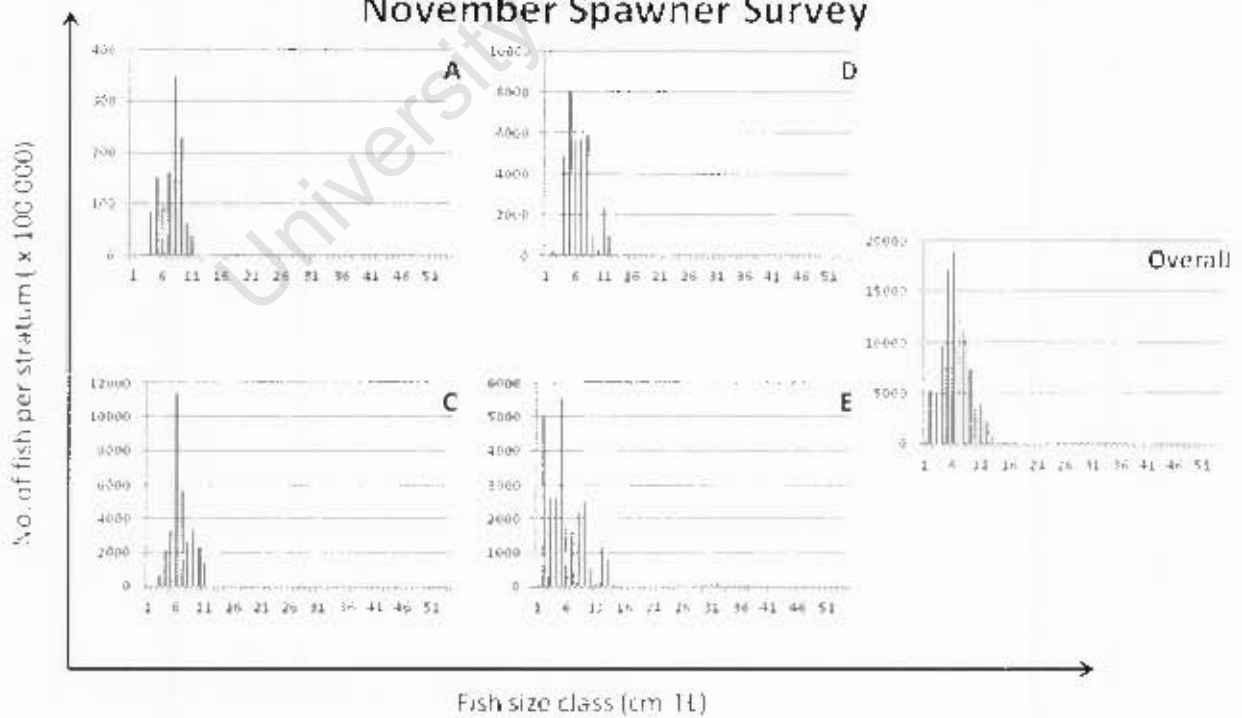
2006

May Recruit Survey

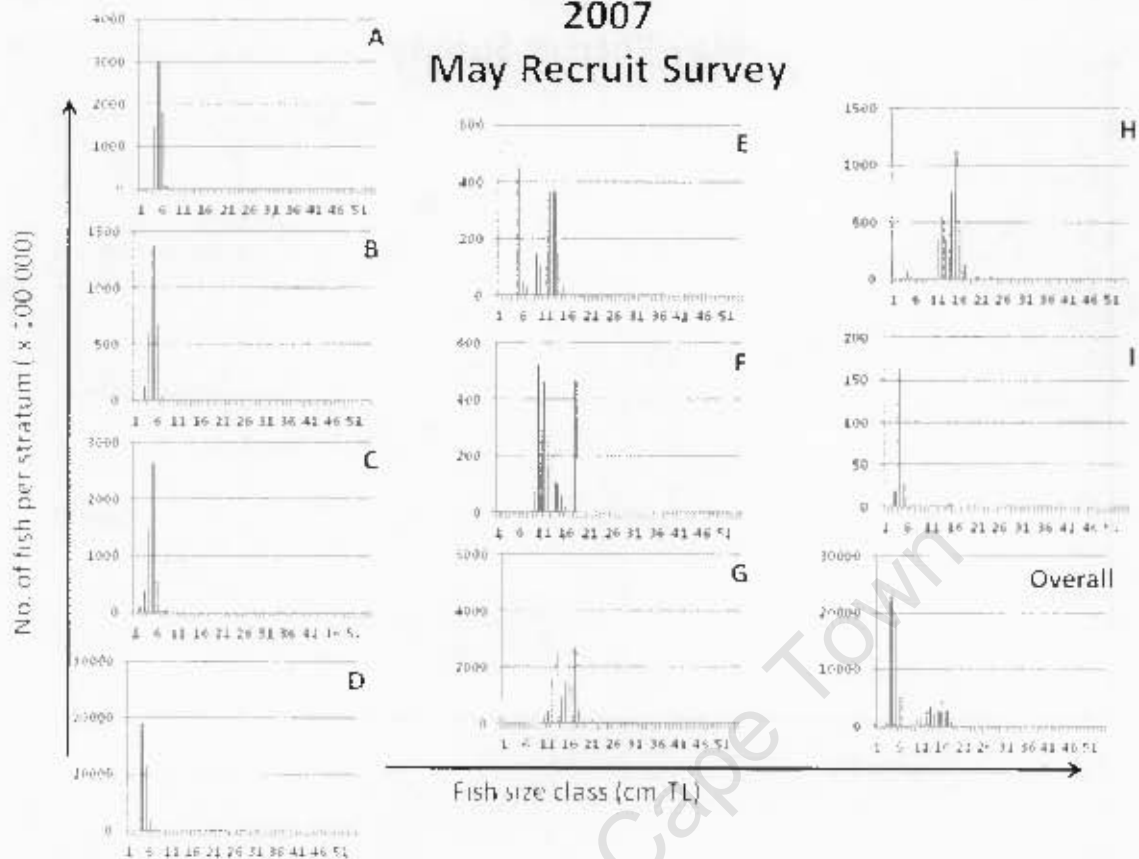


2006

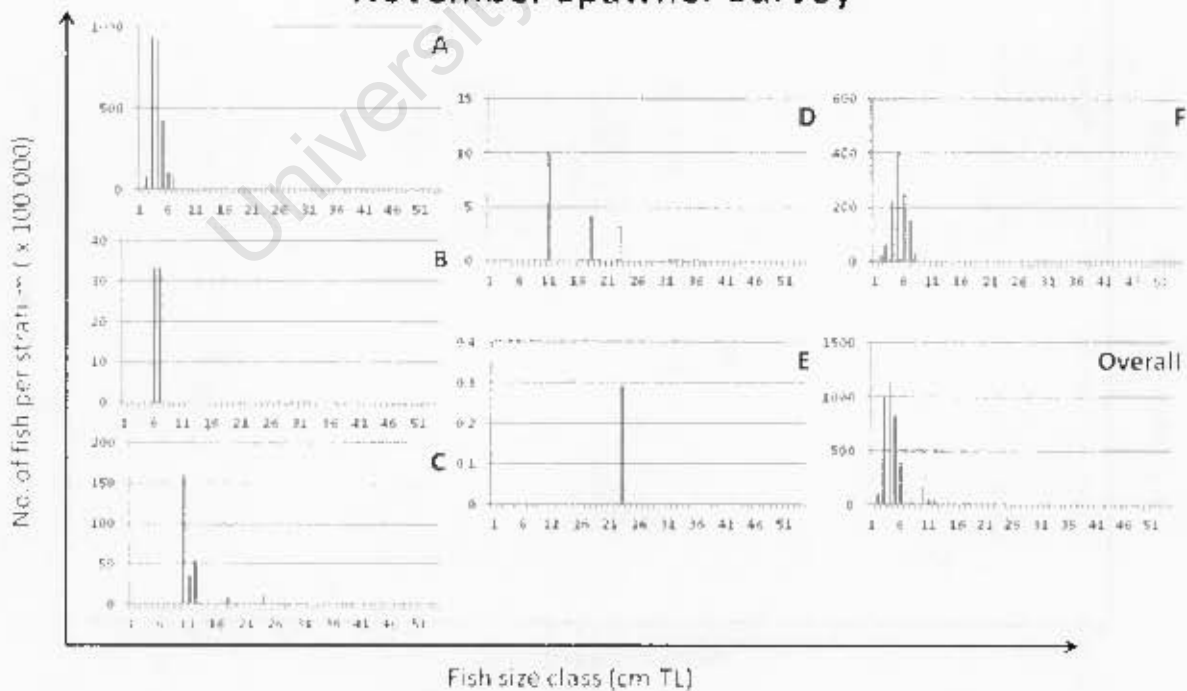
November Spawner Survey

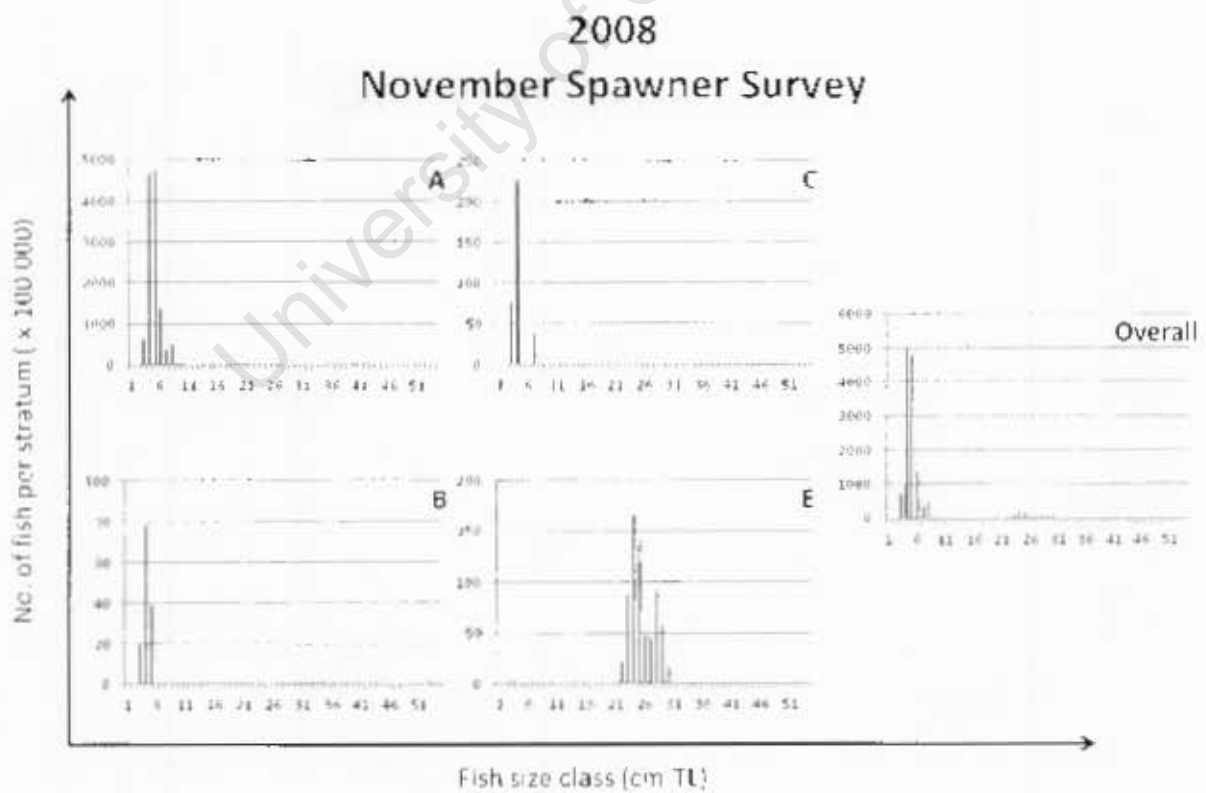
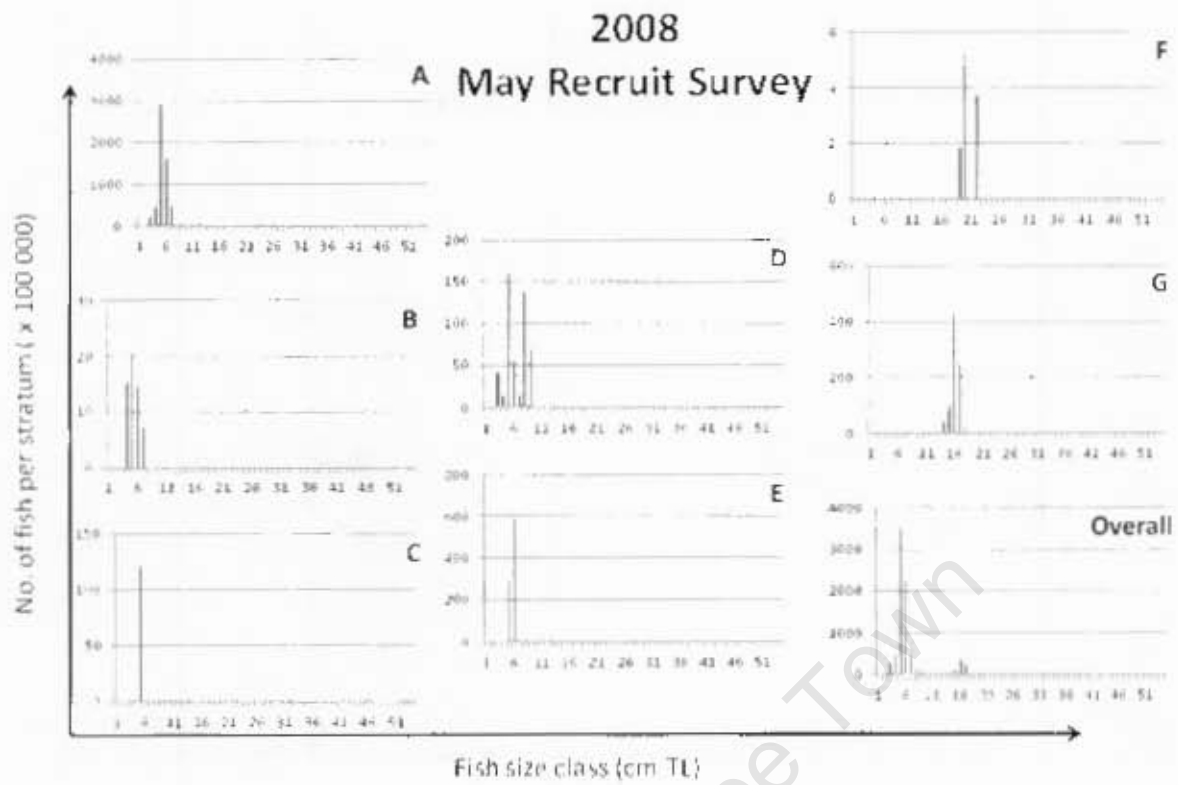


## 2007 May Recruit Survey

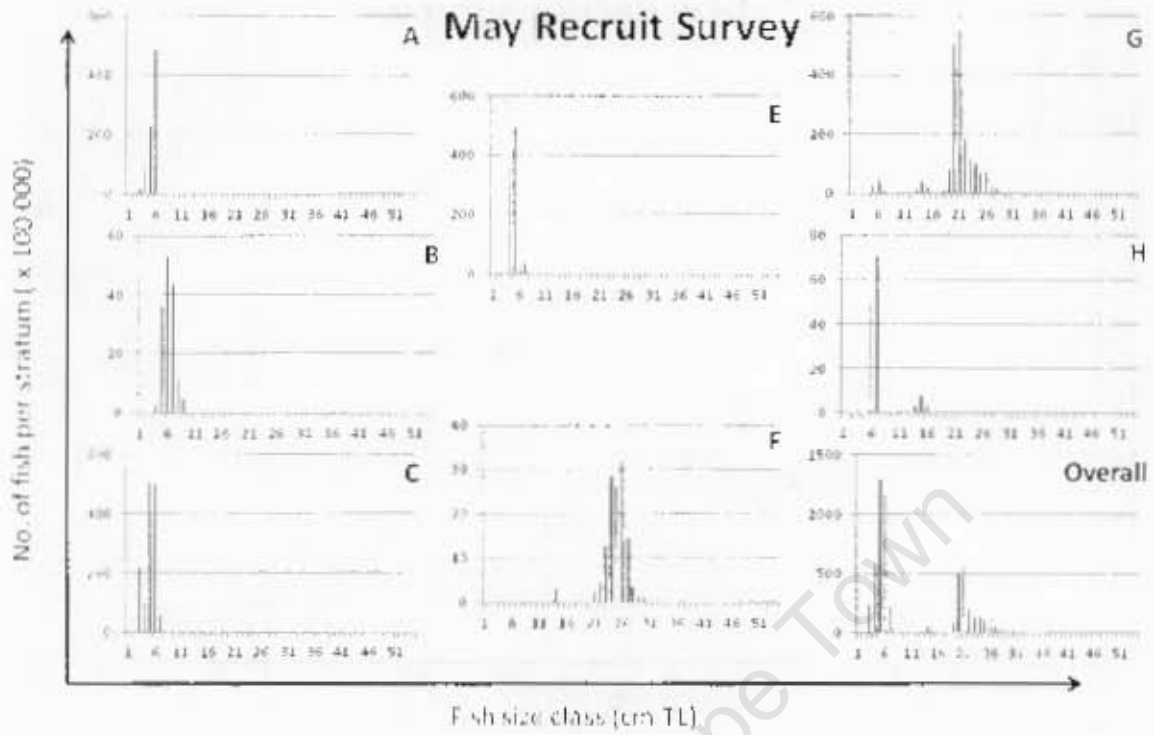


## 2007 November Spawner Survey



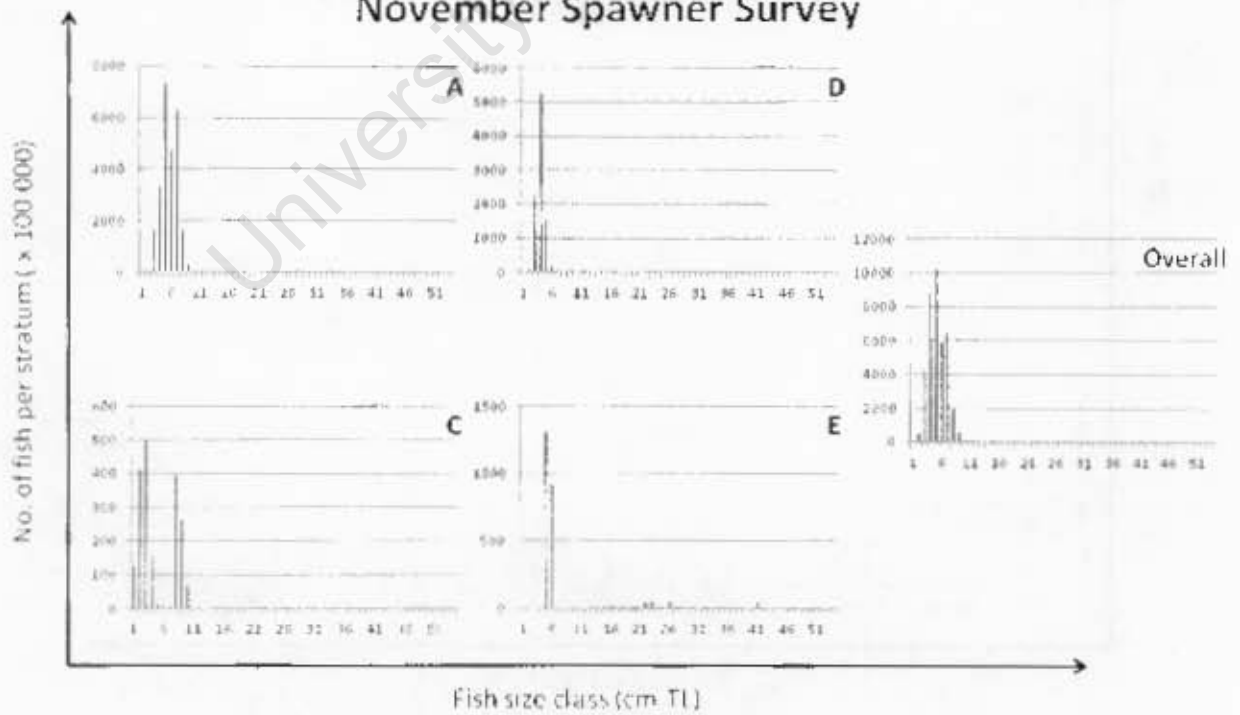


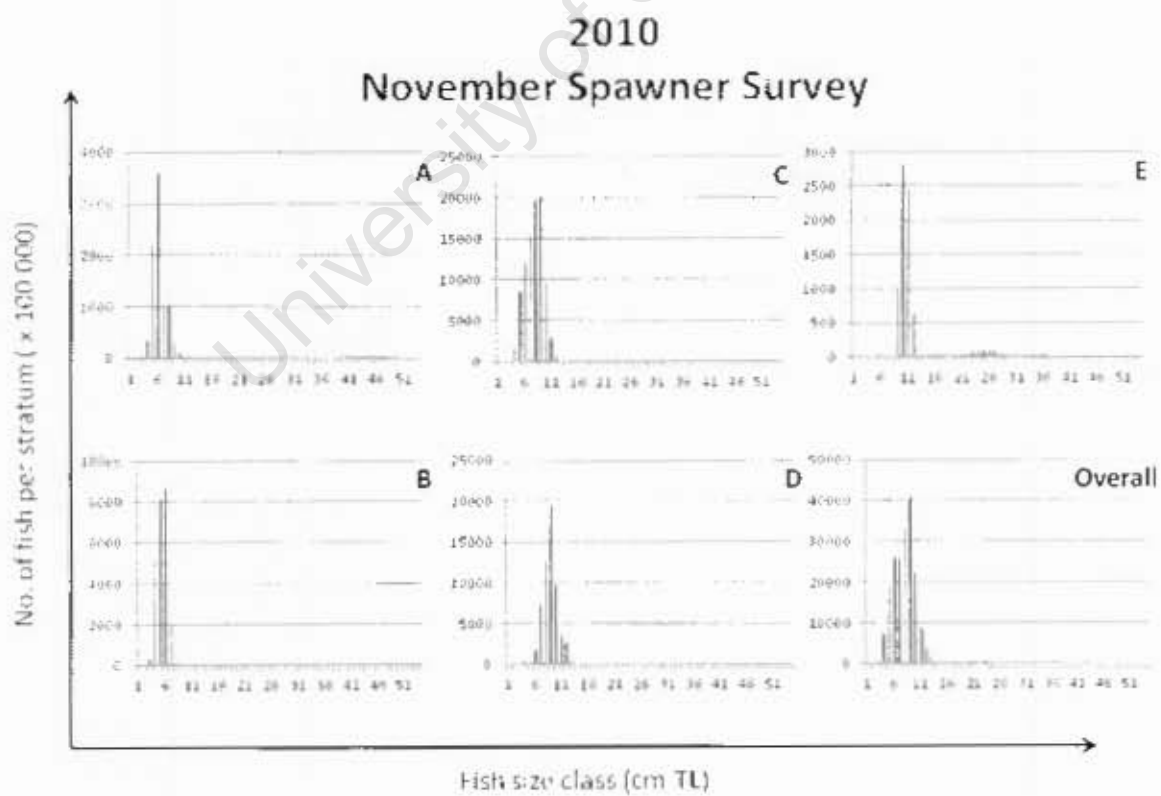
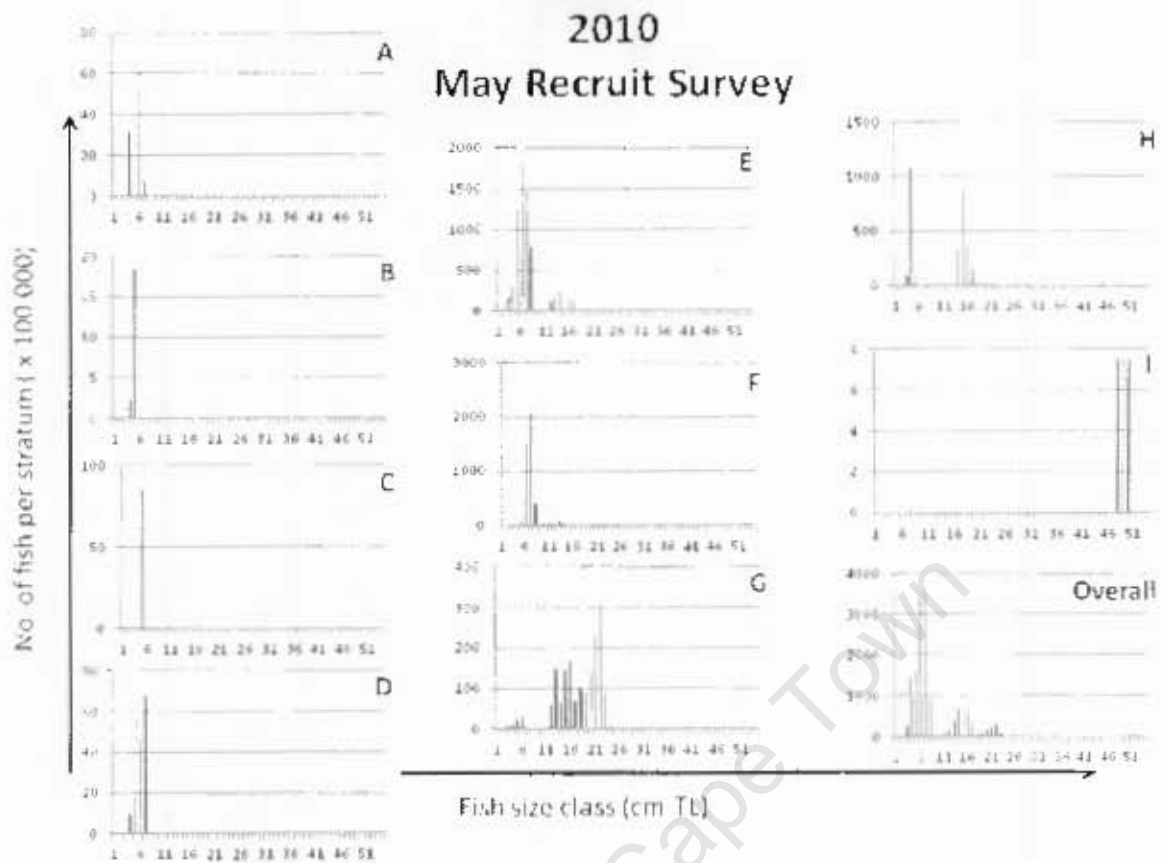
2009

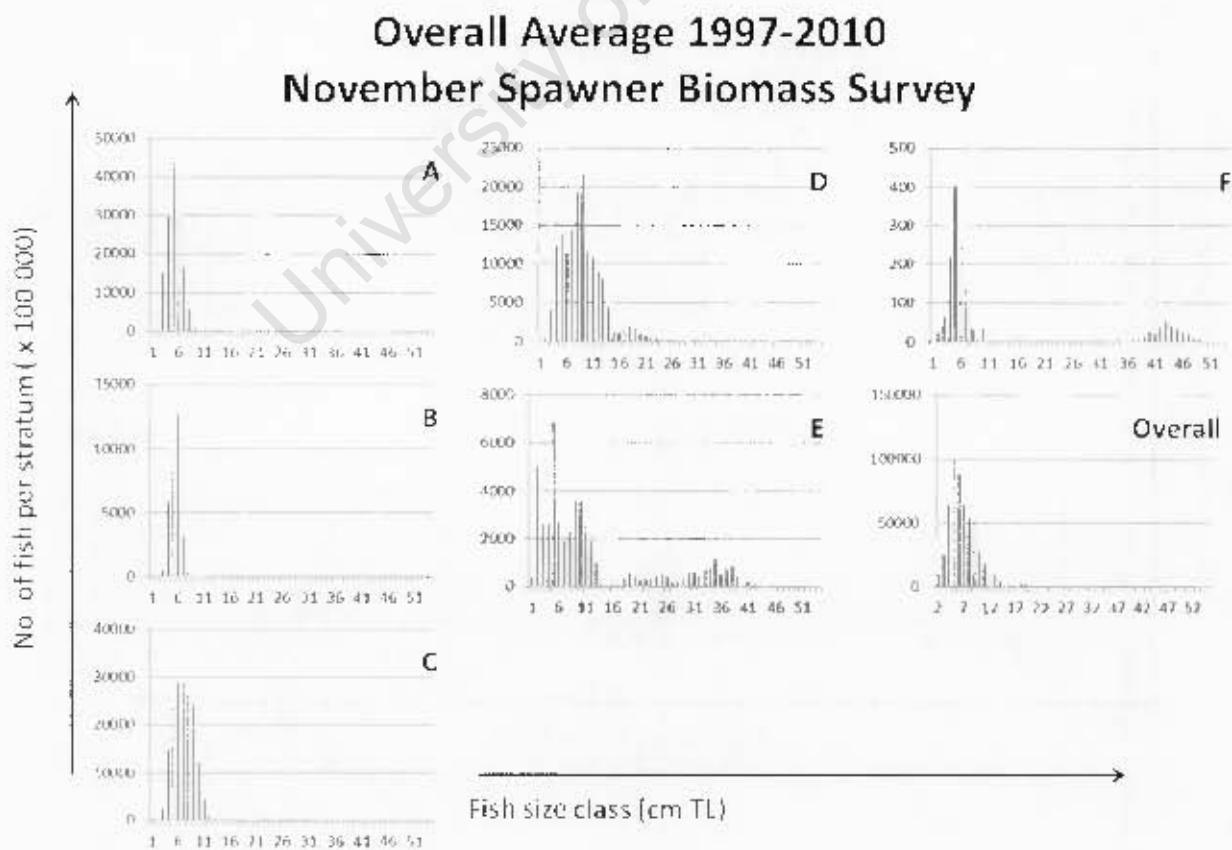
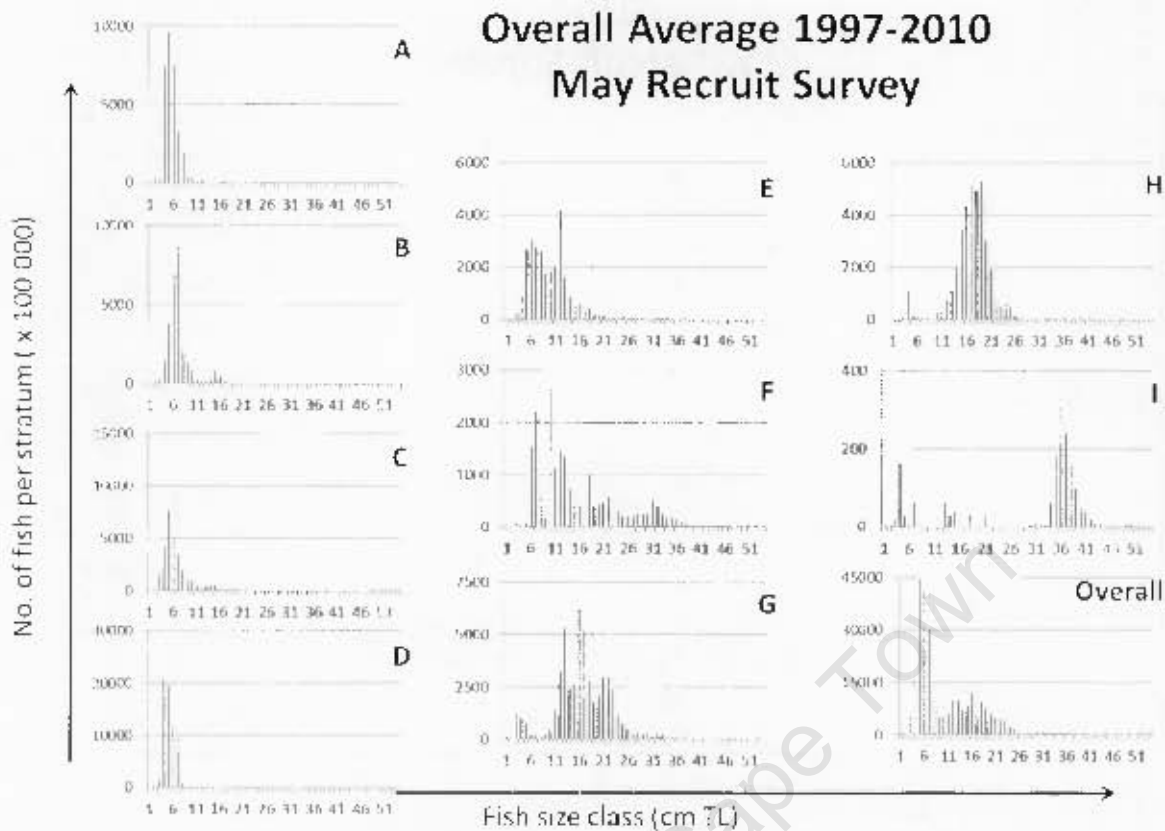


2009

**November Spawner Survey**







**Appendix 4: An interpretation of the annual length frequency distribution of horse mackerel from the May Recruit and November spawner biomass surveys from 1997-2010 shown in Appendix 3.**

1997

May: Very few fish >11cm TL were found and these were concentrated in stratum E (WAB) and of the size range 25-31cm TL. Small individuals <11cm TL dominated strata A to E (west coast southwards up to and including the WAB) but were absent from stratum F (CAB) and eastwards.

Nov: Fish from 26-38cm TL dominate stratum A (upper west coast north of Cape Columbine) with just over 16 million fish of 33cm TL within the stratum. Strata B (lower west coast between Cape Town and Cape Columbine) and E (EAB) were completely absent of fish. Stratum C (WAB) was dominated by fish <6cm TL. Fish of 4cm TL were present in the greatest numbers of any size class across all stratum reaching just over 70 million fish for stratum C. Stratum D (CAB) dominated by fish from 15-20cm TL, just over 1.5 million fish of 18cm TL recorded within the stratum.

1998

May: Fish were absent from stratum I (far EAB near Port Elizabeth and Port Alfred). Fish <10cm TL were the most abundant followed by fish of 10-16cm TL, 20-25cm TL and then 25-35cm TL. Strata A to E (west coast up to and including the WAB) are dominated by individuals <16cm TL. Strata F, G and H (CAB and EAB) dominated by fish >15cm TL but particularly fish >20cm TL.

Nov: Strata A and B (west coast) were absent of any fish whereas fish of <15cm TL dominated stratum C (WAB). Stratum D (CAB) had over 30 million fish of <6cm TL, this suggests strong evidence of nursery areas on the south coast. Also within stratum D less than 5 million fish of 10-20cm TL were recorded. Stratum E (EAB) had an abundance (~ 700 000 fish) of fish 50cm TL and stratum F (far EAB) had a range of size classes, 35-50cm TL, greatest of which was 43cm TL with an abundance of ~ 5 500 000 fish.

1999

May: Strata A-D only had fish of <9cm TL, the maximum was recorded in stratum A (high west coast) and C (west coast around St. Helena Bay) of ~ 100 million fish of 6cm TL and 8cm TL recorded within each stratum. Stratum E (WAB) had some small fish <6cm TL but most fish were 22-35cm TL (maximum ~ 8 million fish of 24cm TL). Strata F, G and H (CAB and EAB) only had fish >15cm TL with the average length frequency increasing eastwards.

Nov: No fish were recorded in strata A and B (west coast up to Cape Point) or F (far EAB). Fish of 6-36cm TL were recorded in strata C, D and E (WAB, CAB and EAB) with the average length frequency increasing eastwards.

2000

May: Strata A and B (high west coast) only had fish <6cm TL while some slightly larger individuals were found further south in stratum C near St. Helena Bay. Stratum D (south west coast) and E (WAB) had mostly recruits of <10cm TL in high abundance of just less than 1

billion fish recorded within the stratum. The CAB comprising stratum F and G had a large size range (6-54cm TL) with strata H and I (EAB) with mainly larger individuals of >30cm TL and a few <10cm TL.

Nov: Strata A, B and C (west coast and WAB) only had fish of <10cm TL. Stratum D (CAB) had a range of sizes mostly 10-15cm TL with the greatest abundance of almost 600 million fish of 14cm TL recorded within this stratum. Stratum E (EAB) had fish of 30-40cm TL.

## 2001

May: Stratum A and B (upper west coast) and stratum D (from Cape Columbine to Cape Point) only had fish <10cm TL. Stratum C (west coast around St. Helena Bay) had individuals of up to 20cm TL, much larger than the surrounding west coast strata. Stratum E (WAB) had individuals up to 16cm TL but the majority were <12cm TL. Stratum F (CAB) has a large size range of 10-31cm TL, but the majority were 13-18cm TL. Strata G and H (CAB and EAB) has some larger individuals of up to 35cm TL but mainly 12-20cm TL. No fish were recorded on the far EAB in stratum I.

Nov: Stratum A (west coast up to Cape Columbine) only had individuals <10cm TL whilst stratum B (Cape Columbine to Cape Point) was absent of fish. Stratum C (WAB) had a range of sizes from 15-34cm TL length, while the CAB (stratum D) had a small range of 15-25cm TL. Stratum E (EAB) had larger individuals of up to 48cm TL but the majority were 16-22cm TL.

## 2002

May: Along the entire west coast up to Cape Point (strata A-D) only individuals of <10cm TL were recorded. From strata E-I (entire Agulhas Bank) individuals of 10-25cm TL were recorded with an increase in average length frequency moving eastwards. There were very few large individuals recorded across all strata compared to size classes <25cm TL.

Nov: Strata A-C (west coast and WAB) only had individuals <10cm TL, whilst stratum D (CAB) had fish of 15-35cm TL the majority of which were 16-22cm TL. Stratum E (EAB) had some small individuals <10cm TL, suggesting the presence of south coast nursery areas otherwise the majority of fish in this stratum were 15-25cm TL. Overall mainly fish of <10cm TL with a maximum abundance of ~ 800 million were recorded overall across all strata.

## 2003

May: Strata A and B (upper west coast) only had individuals of <11cm TL with strata C and D (lower west coast) with slightly larger individuals of <13cm TL but mainly <10cm TL. Stratum I (far EAB) was completely absent of fish while strata G and H (CAB and EAB) had individuals larger than 15cm TL mainly 15-25cm TL.

Nov: Strata A-D (west coast up to and including CAB) were dominated by individuals <10cm TL while stratum E (EAB) had individuals <15cm and 22-28cm TL. Overall small fish of <10cm TL dominated with abundances of ~ just under 1.5 billion fish of 5cm TL recorded overall and ~ 1 billion fish for size classes 4cm TL, 6cm TL and 7cm TL recorded overall. This is the greatest abundance of recruits recorded since surveying began in 1997.

## 2004

May: Strata A-D (west coast up to Cape Point) was dominated by fish <11cm TL. Stratum E (WAB) had fish up to 20cm TL but these were mainly 11cm TL. Stratum F (CAB) had fish of 8-25cm TL the majority of which were 8cm TL. Strata G and H (CAB and EAB) only had fish >10cm TL of approximately 10cm TL and 25cm TL. Stratum I (far EAB) only had individuals >35cm TL.

Nov: Strata A and C (west coast and the WAB) dominated by individuals <10cm TL while stratum B (Cape Columbine to Cape Point) was completely absent of all fish. Stratum D (CAB) had a large size range of 6-40cm TL but the majority were 10-20cm TL. Stratum E (EAB) individuals of 19cm TL and 20cm TL dominate. In stratum F (far EAB), although minimal sampling was done here, individuals of <10cm TL dominate.

## 2005

May: Strata A-E (west coast up to and including the WAB) was dominated by individuals <10cm TL. Stratum F (CAB) had a large range of size classes from 8-35cm TL the majority of which were 20-25cm TL. Stratum G (CAB) has individuals from 13-25cm TL most of which are 13cm TL. Stratum H (EAB) had individuals of 15-25cm TL the majority of which were 20cm TL while no fish were found in stratum I (far EAB).

Nov: Individuals of <11cm TL dominate the entire coastline particularly strata A and B (west coast up to Cape Point). Small fish were particularly abundant this year with a total of ~ 1.8 billion fish of 5cm TL being recorded across all strata.

## 2006

May: Strata A-D (west coast up to Cape Point) only had fish <11cm TL while stratum E (WAB) had a greater size range of fish up to 25cm TL with two main groupings of those <6cm TL and those 15-23cm TL. Strata F and G (CAB) had individuals ranging from 10-24cm TL the majority of which were 12cm TL. Strata H and I (EAB) were completely absent of fish.

Nov: Strata A, C and D (west coast, WAB and CAB) were dominated by fish <10cm TL while strata B (Cape Columbine to Cape Point) was completely absent of fish. Stratum E (EAB) had a few larger individuals of 25-35cm TL but the majority were <10cm TL. Following high numbers of small fish recorded overall in 2005, in 2006 an equally high number of small fish were recorded the greatest was the 5cm TL size class with ~ 1.8 billion fish recorded overall.

## 2007

May: In strata A-D (west coast up to Cape Point) only fish <10cm TL were recorded while in strata E-H (entire Agulhas Bank) generally the fish were 6-20cm TL. In stratum I (far EAB) some individuals <10cm TL were recorded, this could suggest some south coast nursery areas in the area. Once again, for the third consecutive year, a large overall abundance of small individuals was recorded. A maximum of ~ 2 billion 4cm TL and 5cm TL fish was recorded. This is the greatest number of recruits recorded in a single year to date.

Nov: Only individuals <10cm TL were recorded in strata A and B (west coast up to Cape point) with maximum abundances occurring at approximately 6cm TL. In strata C (WAB) a large number of individuals of approximately 10cm TL were recorded. Very few fish were

recorded in strata D and E (CAB and EAB). In stratum F (far EAB) some individuals of <10cm TL were recorded. Overall surprisingly low abundances were recorded in the November survey compared to the May 2007 survey and considering the high recruitment from the previous 2 years.

#### 2008

May: Strata A-E (west coast up to and including the WAB) was dominated by individuals <10cm TL. Strata F and G (CAB) had individuals of 14-22cm TL while strata H and I (EAB) were completely absent of fish. No fish larger than 22cm TL were recorded.

Nov: In strata A, B and C (west coast and WAB) only fish <10cm TL were recorded. Stratum D (CAB) was completely absent of fish while in stratum E (EAB) some larger individuals of 22-28cm TL were recorded.

#### 2009

May: Strata A, B, C and E (west coast up to Cape Columbine and WAB) was dominated by individuals <10cm TL while no fish were recorded in stratum D (Cape Columbine to Cape Point) or I (far EAB). In strata F and G (CAB) fish of 18-28cm TL were recorded while stratum H (EAB) had mostly small individuals <10cm TL but also some individuals of 14-16cm TL.

Nov: Stratum A, C and D (west coast, western and CAB) were dominated by fish of <10cm TL, the greatest abundance of ~ 700 million fish of 5cm TL were recorded in stratum A. Stratum B (Cape Columbine to Cape Point) was completely absent of fish while stratum E (EAB) had fish of mainly <10cm TL there were a few larger fish of 26cm TL and 41cm TL recorded.

#### 2010

May: Strata A-D (west coast up to Cape Point) only had fish of <10cm TL, while stratum E and F (western and CAB) was also mainly fish <10cm TL there were some larger individuals of up to 20cm TL recorded. Strata G and H (central and EAB) had fish of 10-25cm TL and 12-20cm TL respectively with some small fish <6cm TL recorded suggesting the presence of nursery areas on the south coast. Stratum I (far EAB) had a large abundance (~ 700 000 fish) of larger individuals of 49-51cm TL.

Nov: Strata A-C (west coast and WAB) are dominated by fish of <10cm TL. Stratum D (CAB) had fish of 6-12cm TL while stratum E (EAB) had fish ranging 8-12cm TL and 22-28cm TL. Overall fish of <11cm TL dominated with a maximum abundance of ~ 4 billion fish of 10cm TL being recorded overall across all strata. This is the most recruits recorded to date and suggests the emergence of a strong year class.

#### Composite

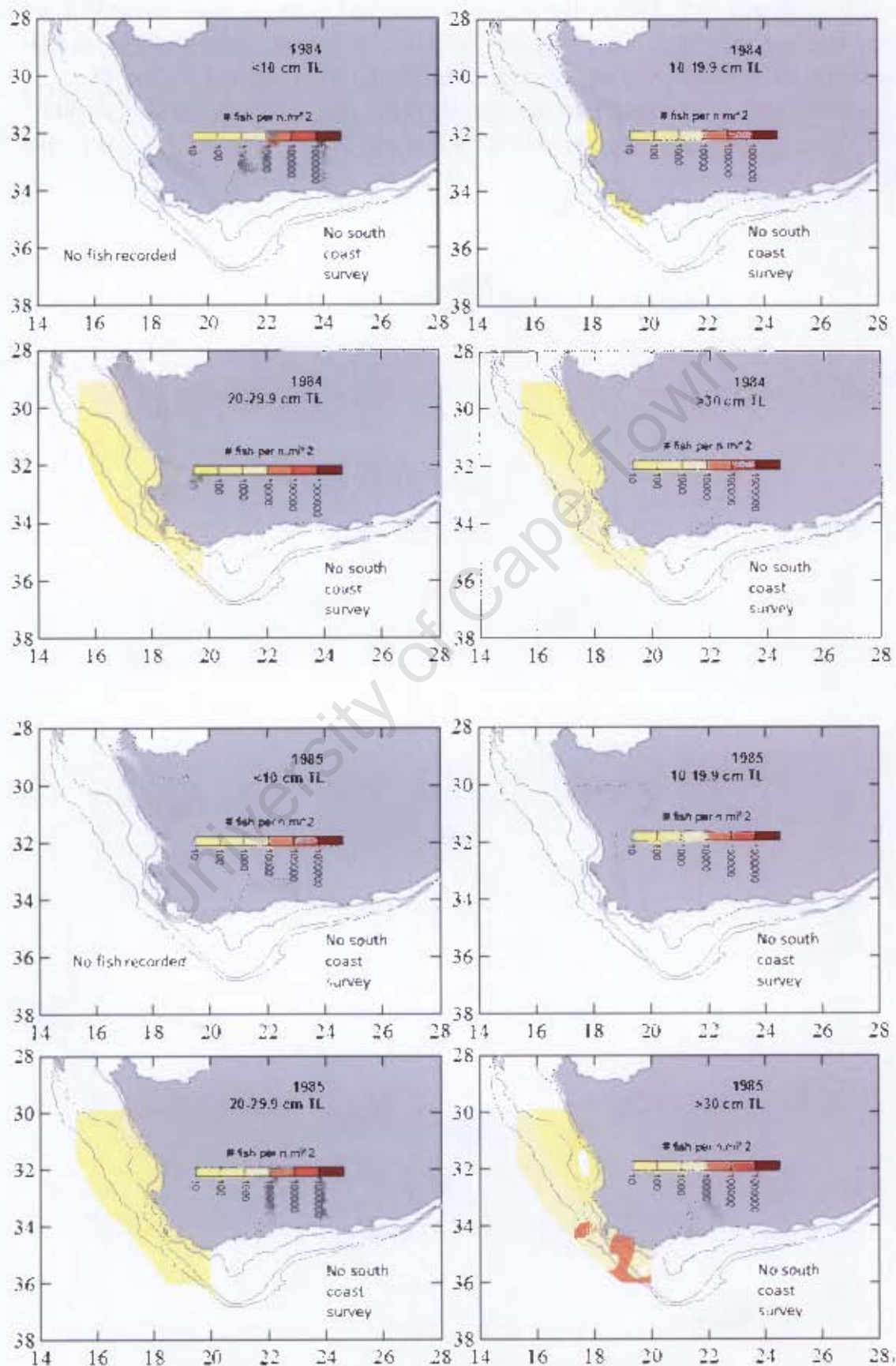
May: Strata A-D (west coast to Cape Point) were dominated by individuals of <10cm TL. Stratum C consistently has a slightly larger size range compared to the other west coast strata; this could be as a result of larger fish occurring in and around St. Helena Bay. Strata E and F (western and CAB) had a larger range of sizes from 4-38cm TL but the majority of these are still <10cm TL. Strata G, H and I (central and EAB) had the largest size range of 3-50cm TL with strata G and H consisting of fish mainly 12-24cm TL while stratum I is mostly fish of

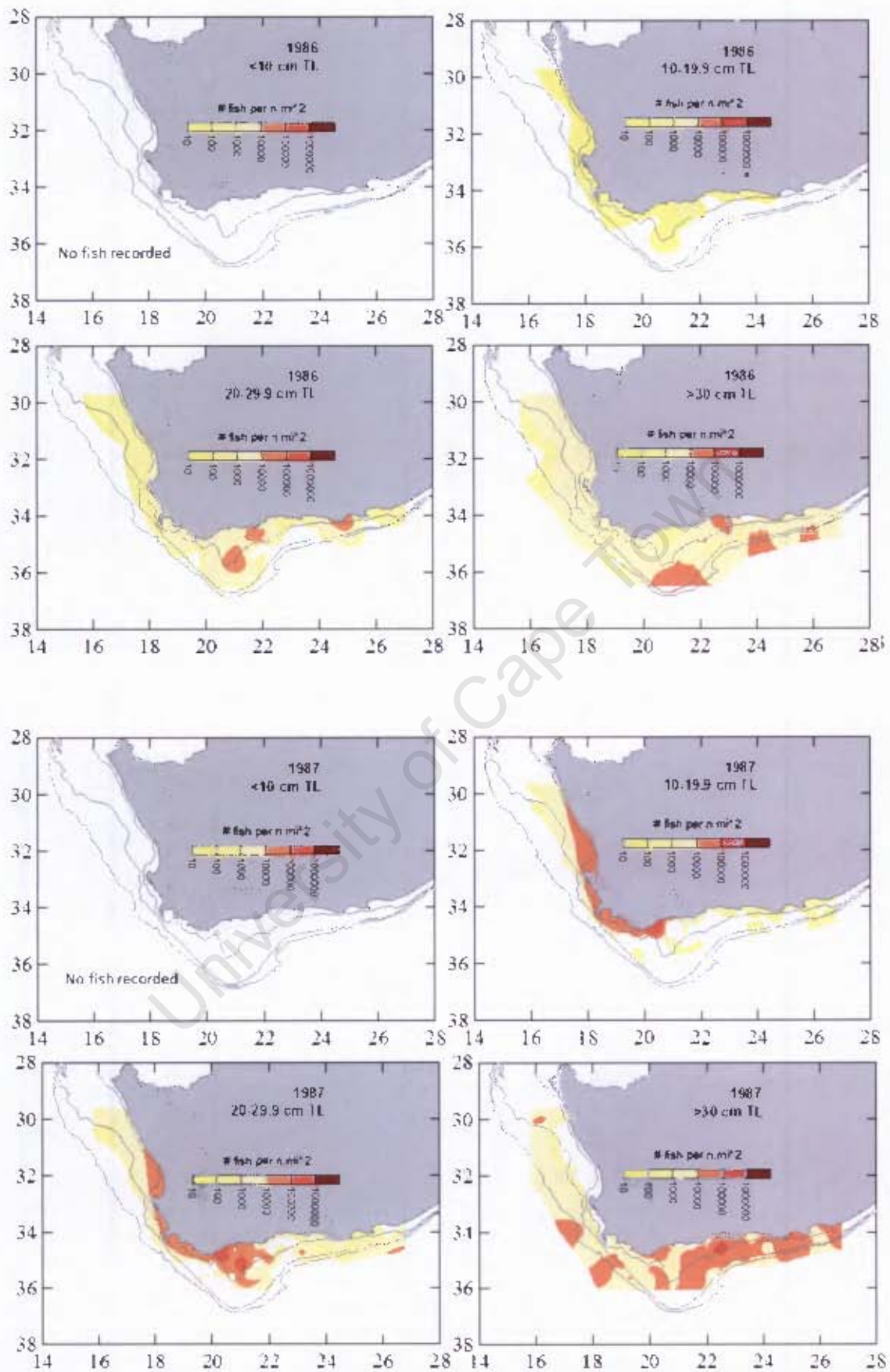
34-42cm TL.

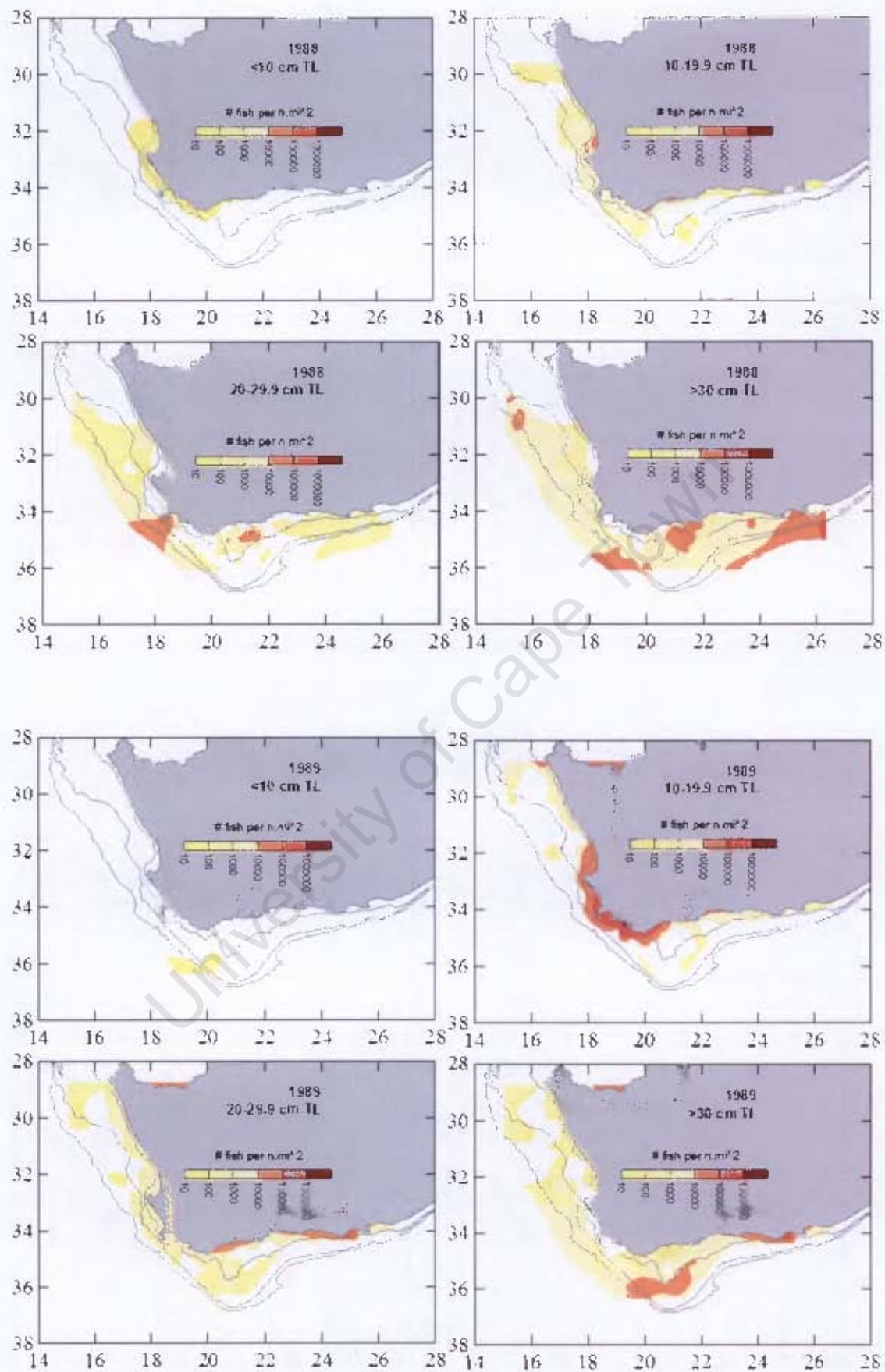
Nov: Stratum A (west coast up to Cape Columbine) overall has two main size ranges, 3-10cm TL and 26-38cm TL. Although the majority of this is fish of <10cm TL, the large size range could be attributed to St. Helena Bay that is often habitat to larger fish. Stratum B (Cape Columbine to Cape Point) is mainly individuals from 3-9cm TL while stratum C and D (western and CAB) have slightly larger size ranges of 3-12cm TL, and 3-23cm TL, respectively with an increase in the average length moving eastwards. Stratum E and F (EAB) have a much larger size range with the majority of individuals of 1-12cm TL and 30-46cm TL.

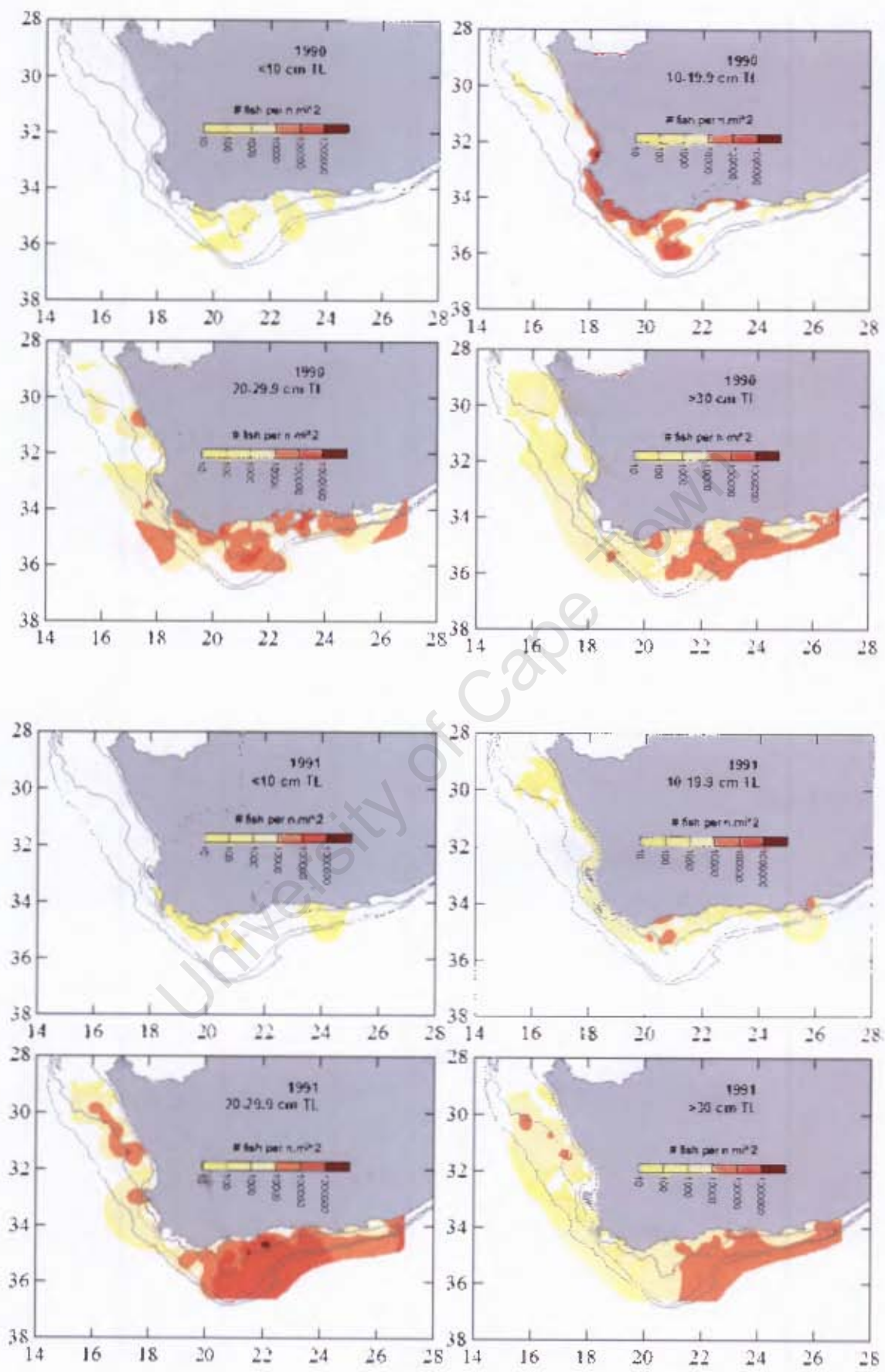
University of Cape Town

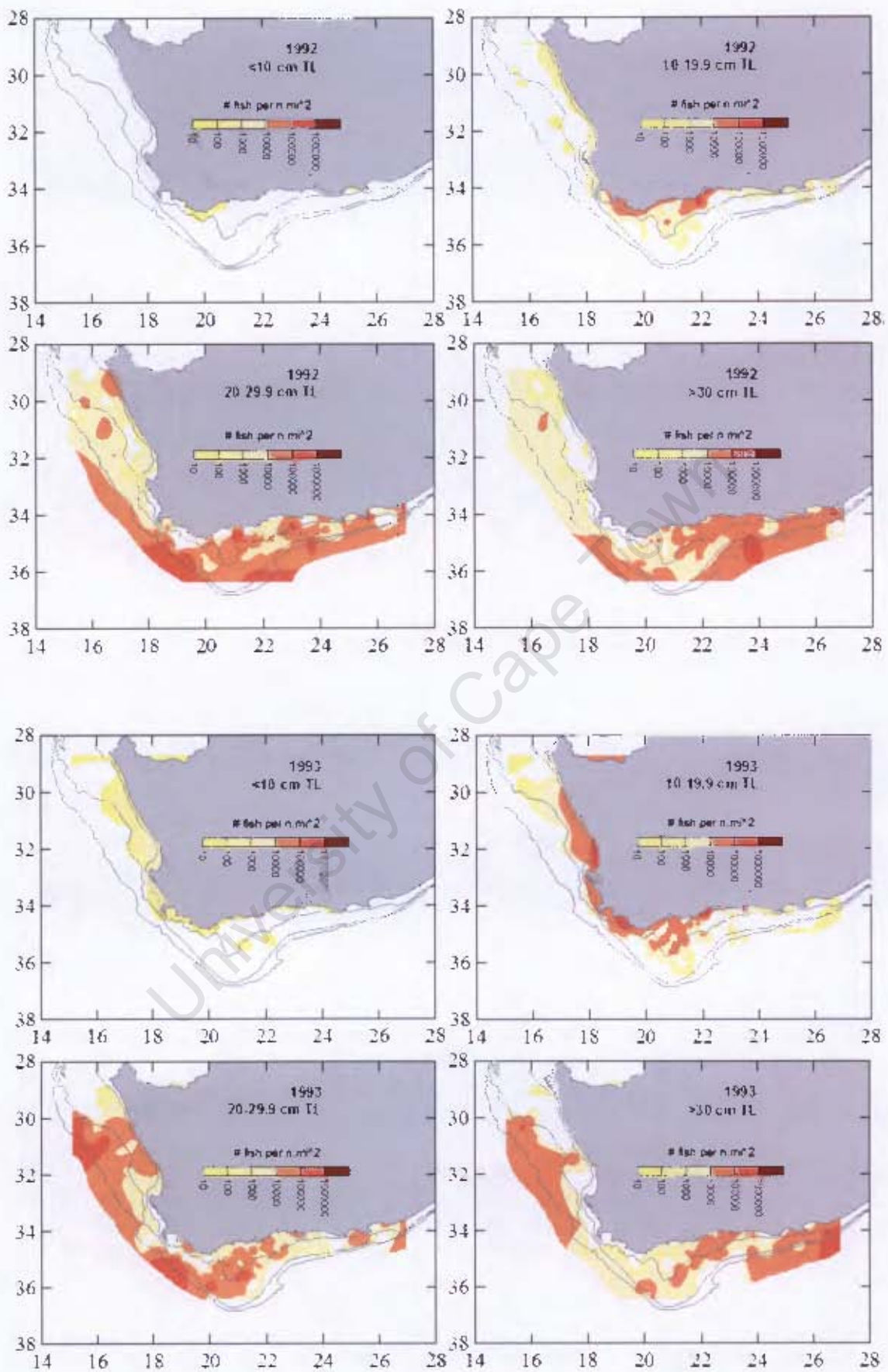
Appendix 5: The annual distribution and abundance of horse mackerel along the South African coast by size class from 1984-2011 according to Demersal survey data. Units = no. of fish per  $\text{nm}^2$ . Size classes: <9.9, 10-19.9, 20-29.9 and >30cm TL.

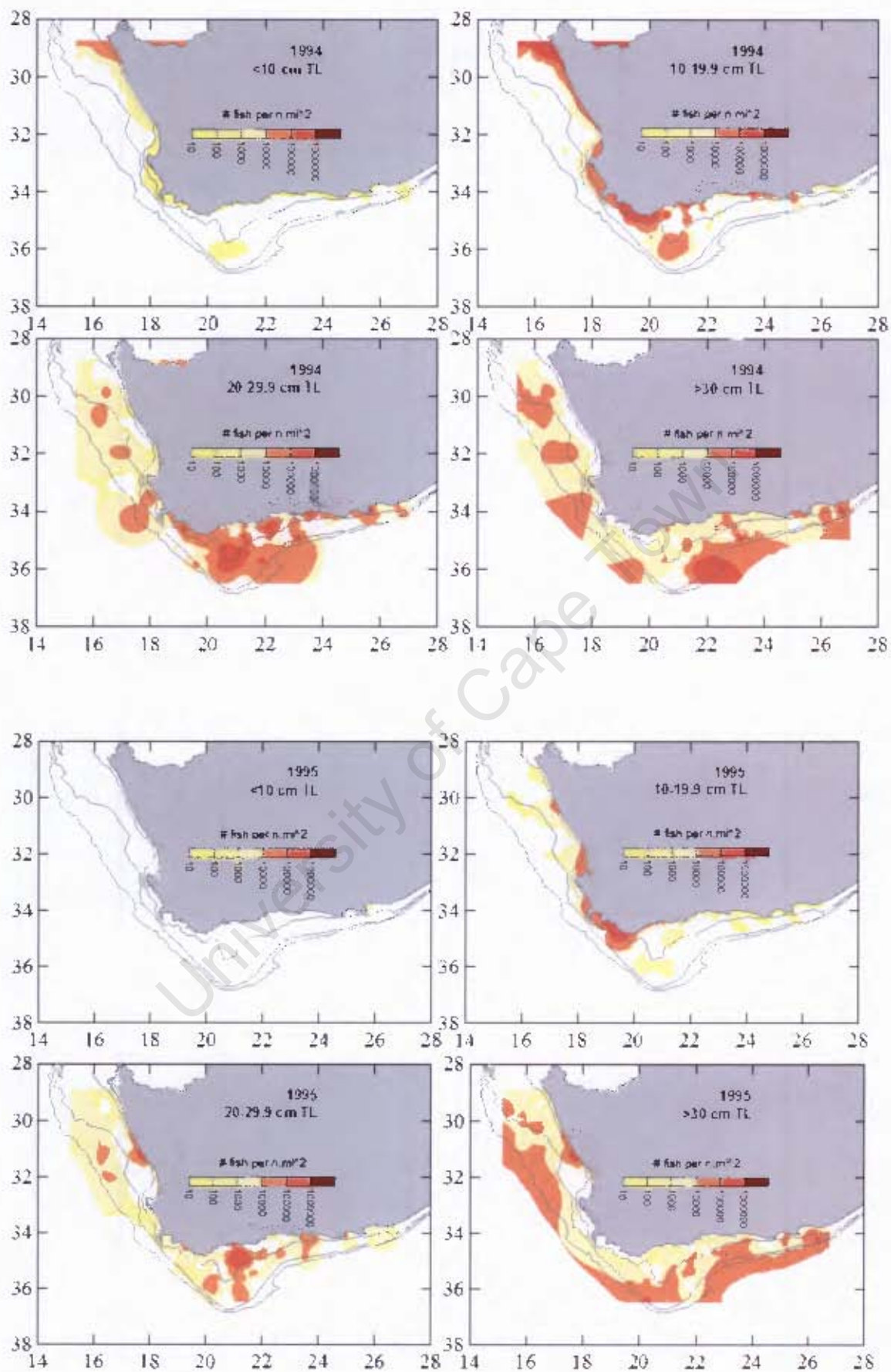


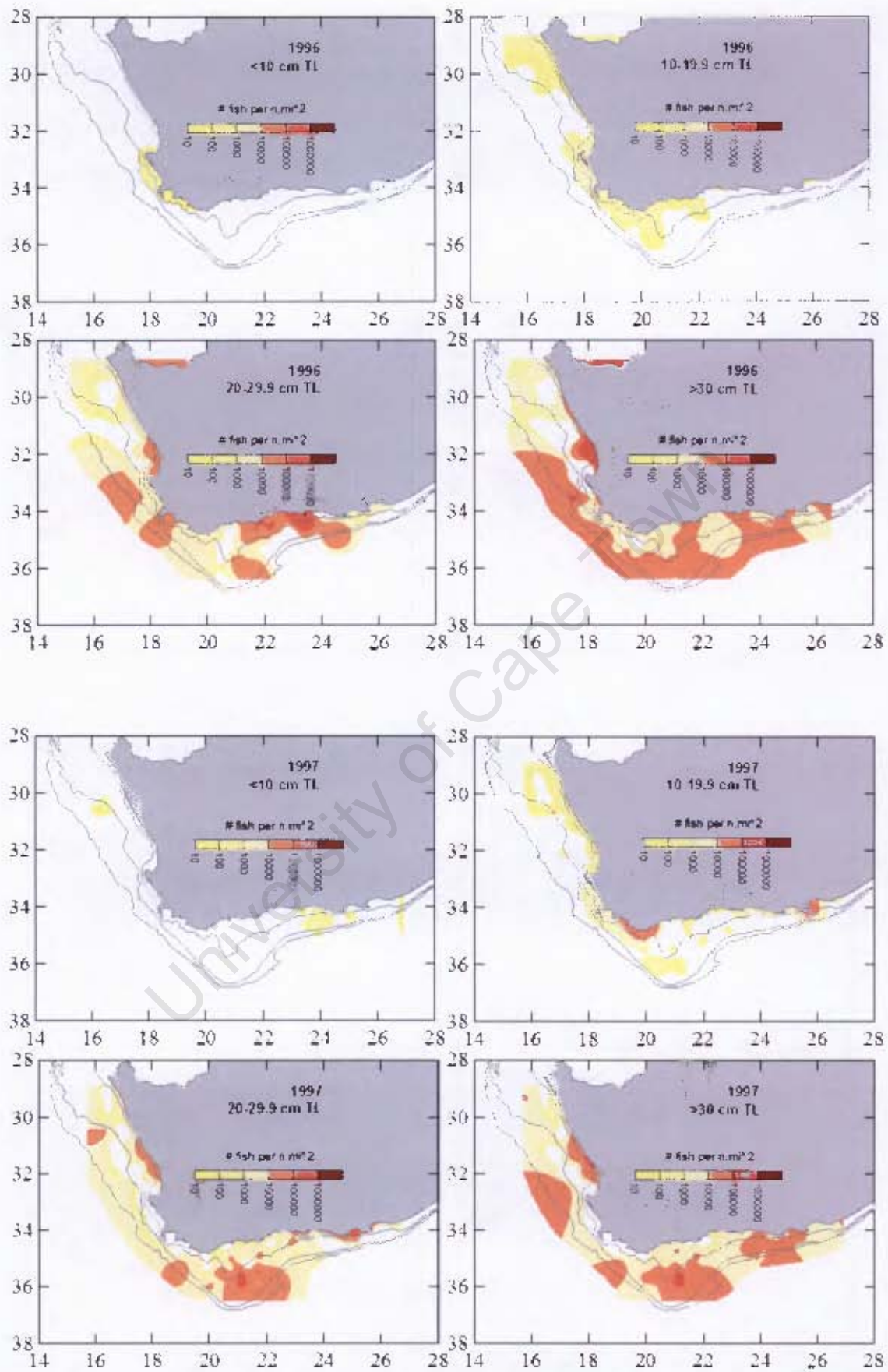


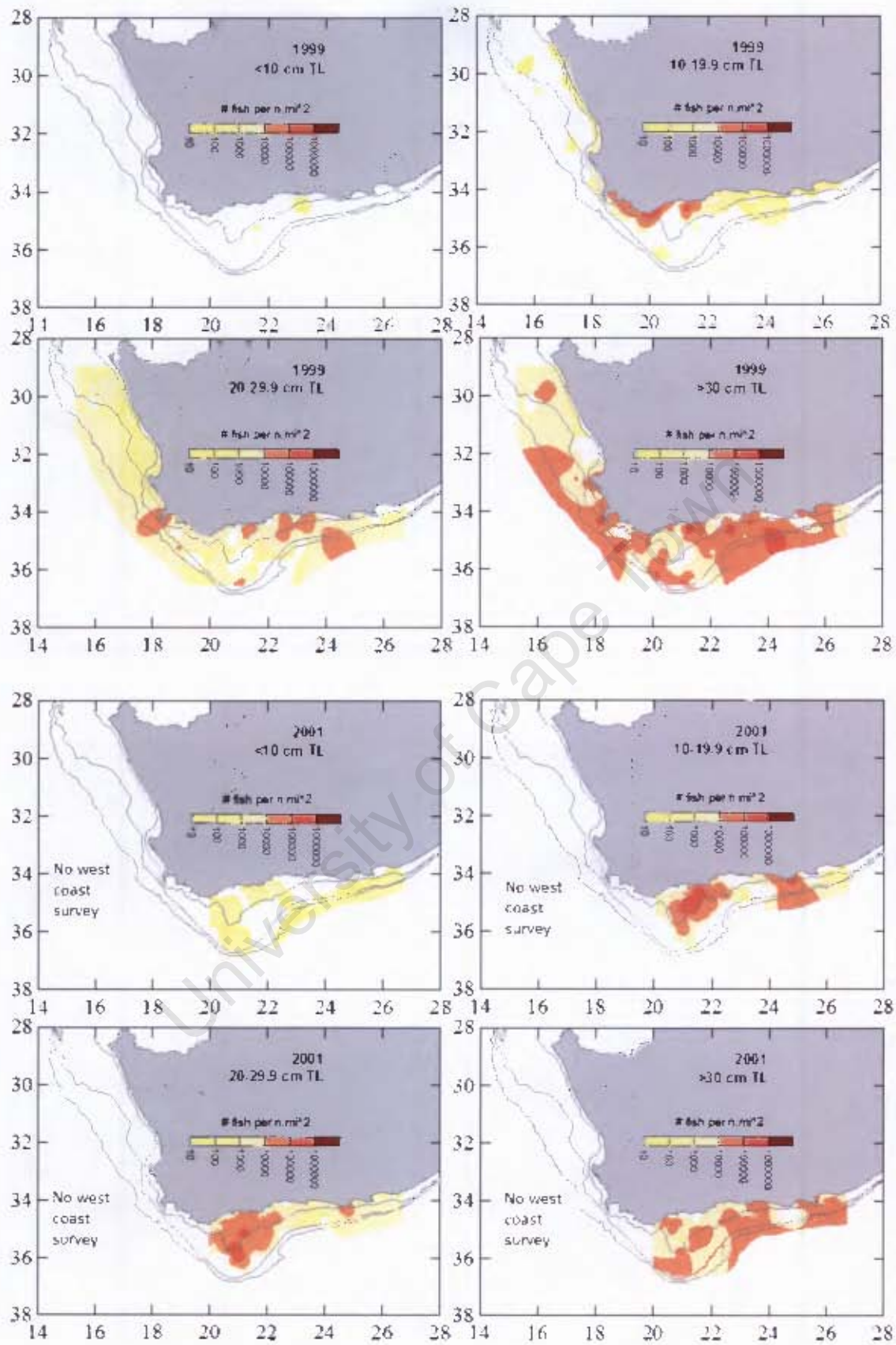


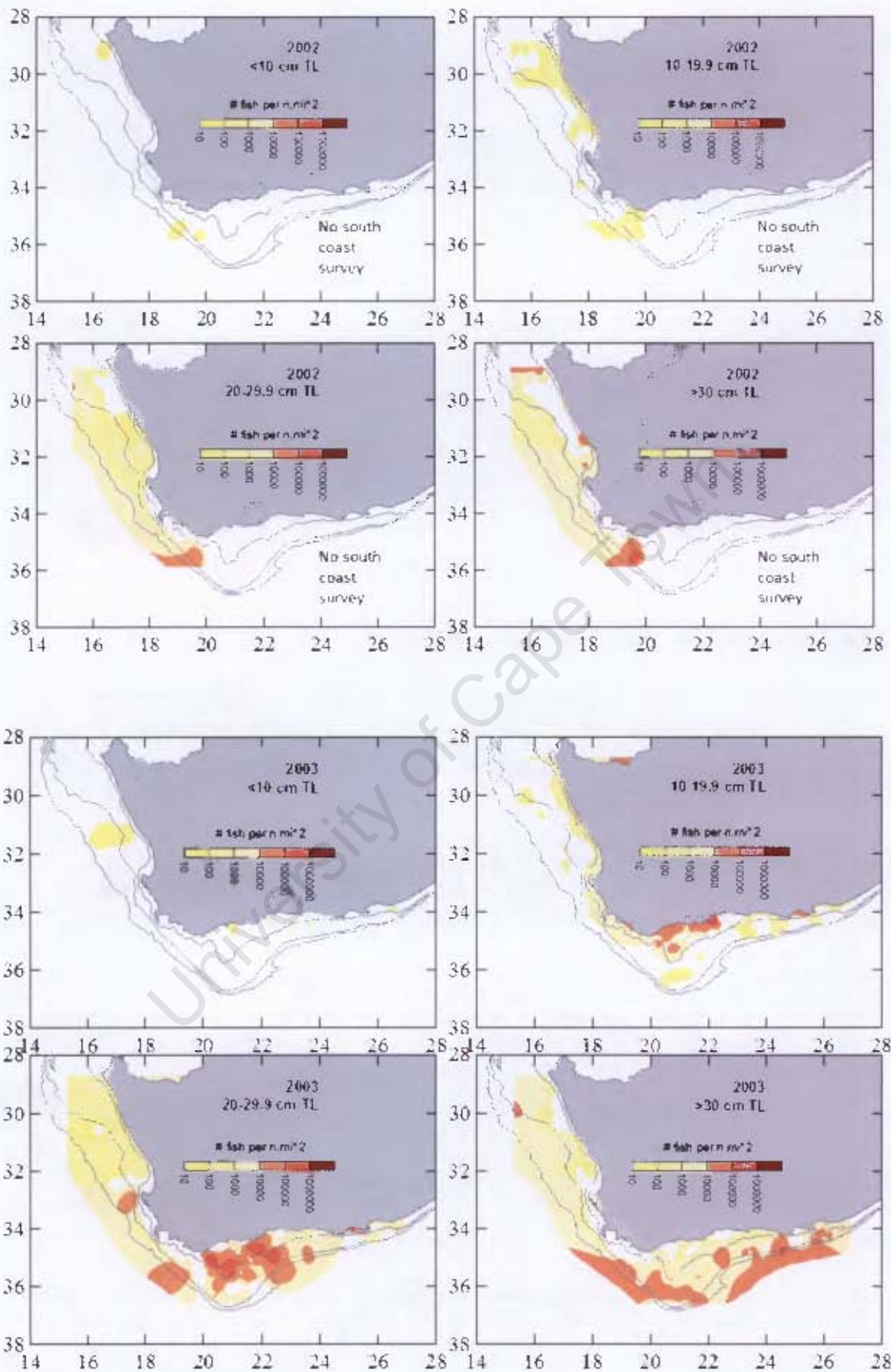


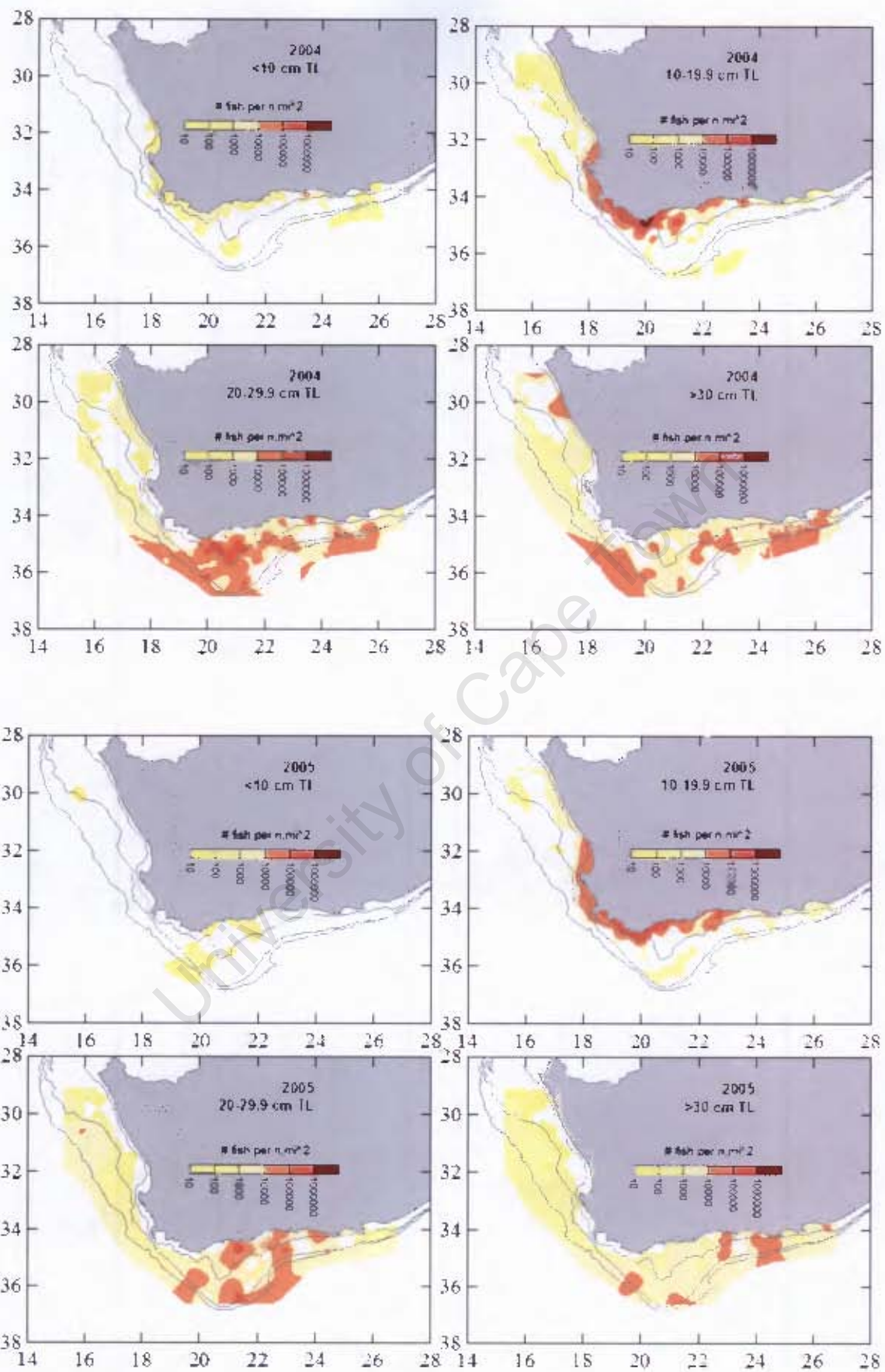


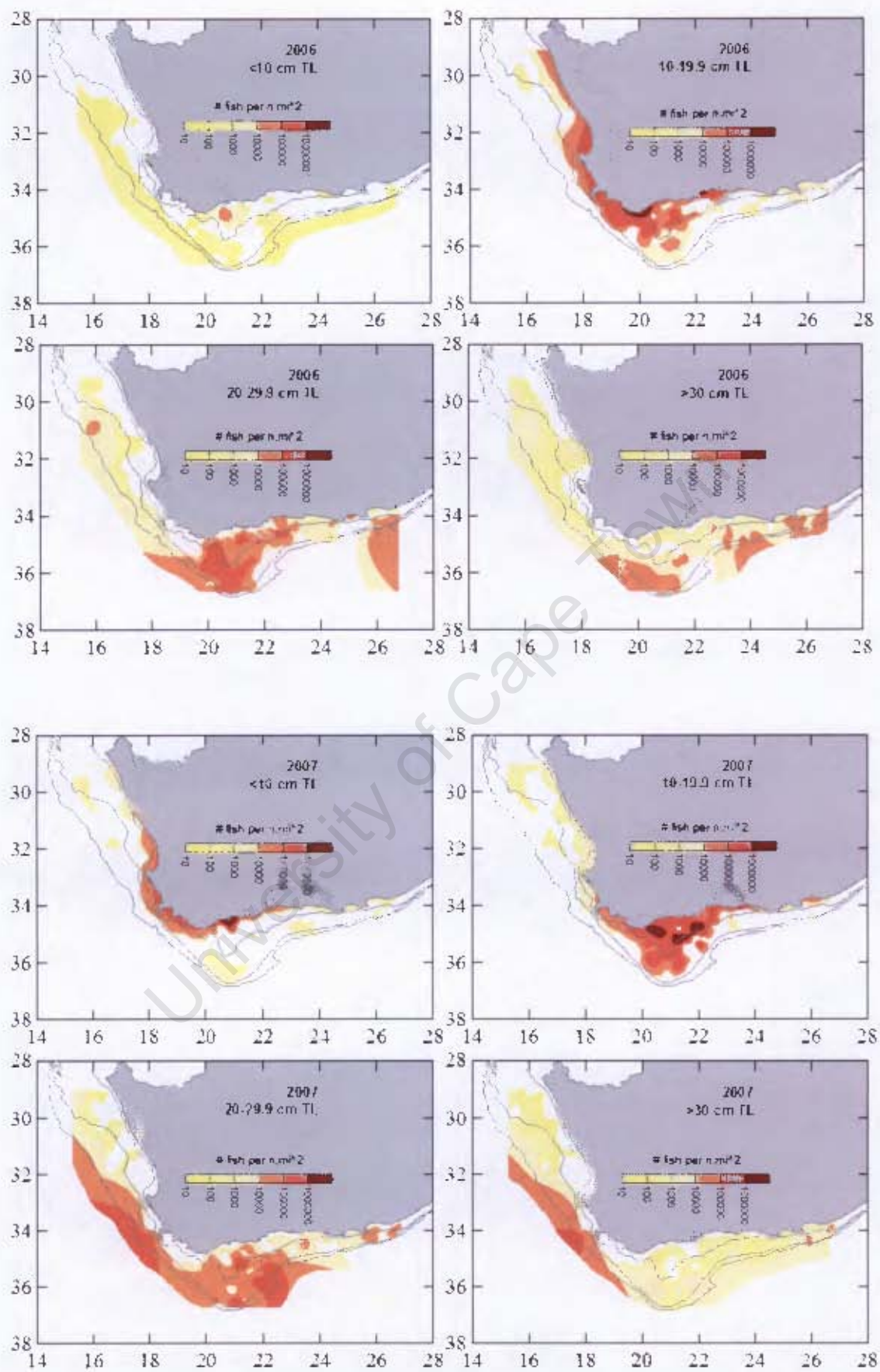


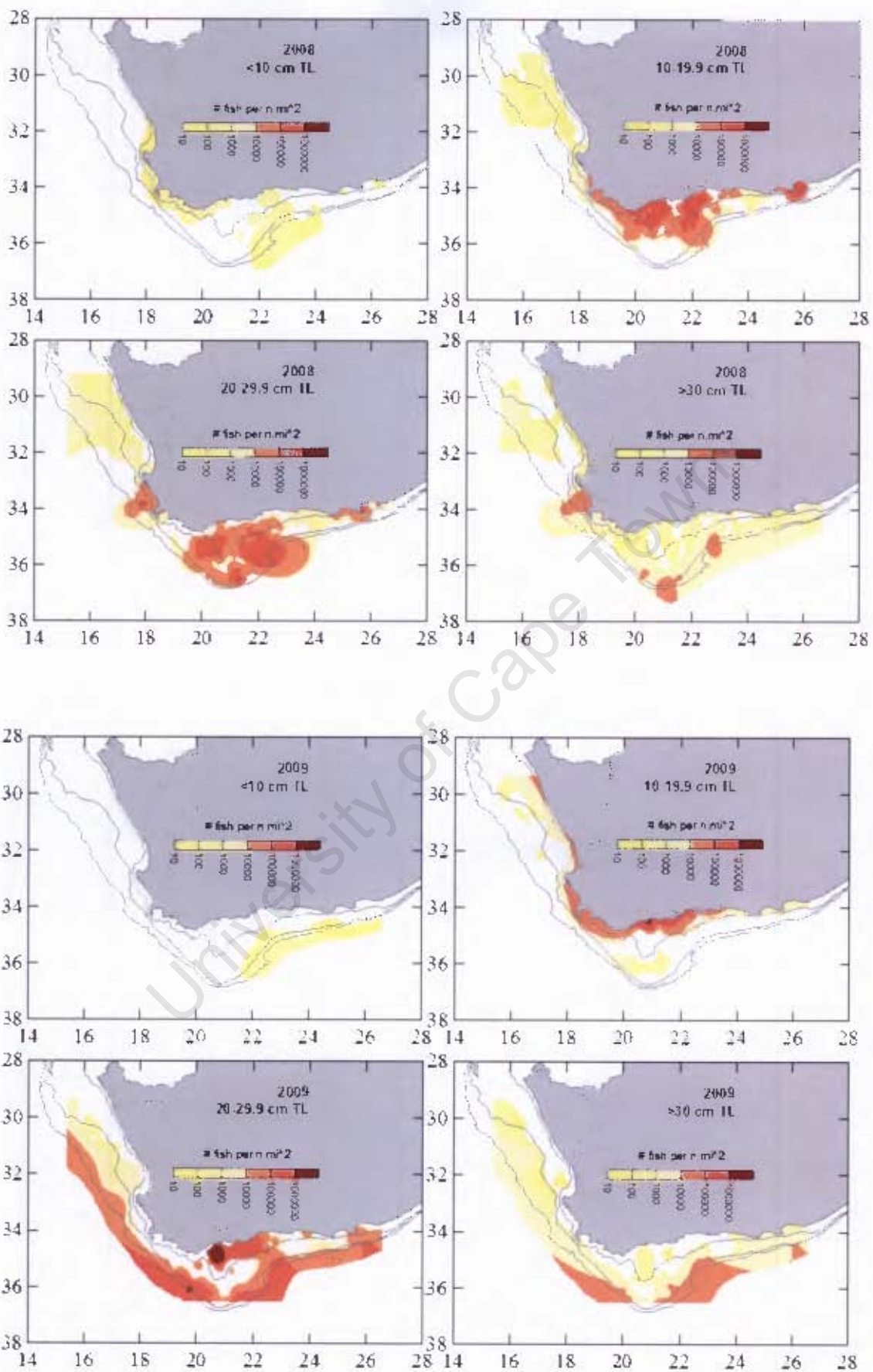


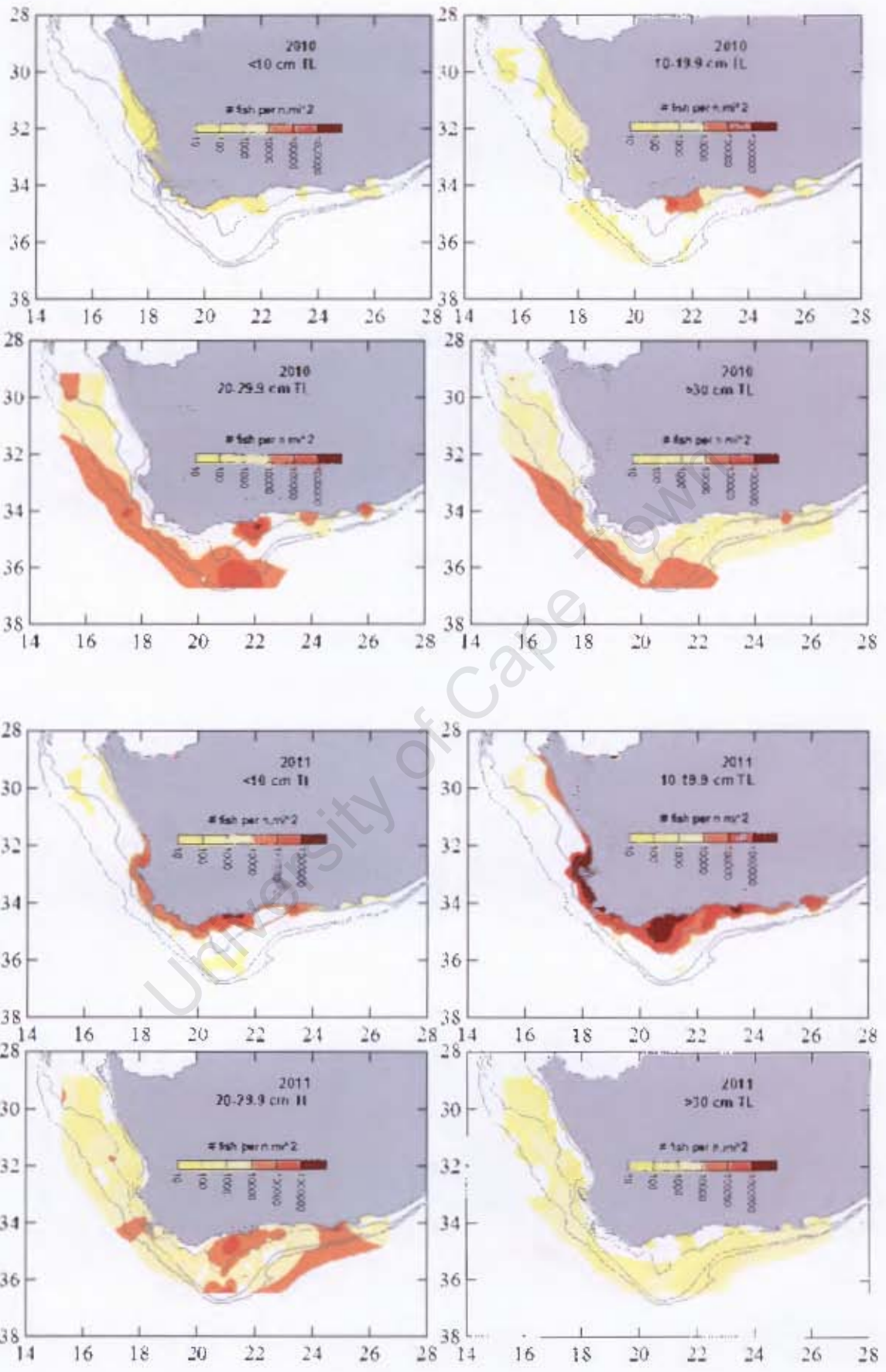












**Appendix 6: An interpretation of the annual distribution and abundance of horse mackerel along the South African coast by size class from 1984-2011 according to Demersal survey data shown in Appendix 5.**

1984

No south coast samples were collected. Based on the west coast survey, no fish <10cm TL were recorded, fish of 20-29.9cm TL and those >30cm TL were found along the length of the west coast in low concentrations of <1 000 fish per nmi<sup>2</sup>.

1985

No south coast samples were collected. Based on the west coast samples collected no fish <10cm TL or 10-19.9cm TL were recorded. Fish from 20-29.9cm TL were recorded in small amounts on the west coast and WAB. Fish of >30cm TL dominate the WAB in abundances of about a maximum of 10 000 fish per nmi<sup>2</sup>.

1986

Samples were collected along the entire coastline for the first time with sampling on the west coast being much less extensive than the south coast. No fish <10cm TL were recorded, this could be due to reduced sampling intensity on the west coast and the sampling was done offshore rather than inshore where the recruits are typically found. Fish of 10-19.9cm TL fish were recorded inshore along the west coast and Agulhas Bank up to the mid-shelf on the CAB. 20-29.9cm TL fish occurred in highest densities on the CAB mid-shelf and fish >30cm TL dominating the shelf edge of the CAB and EAB.

1987

No fish <10cm TL were recorded. Fish of 10-19.9cm TL and 20-29.9cm TL were found in high densities along the west coast and WAB, with the latter occurring in highest densities on the CAB mid-shelf. Large fish of >30cm TL were distributed further east on the CAB and EAB.

1988

Small fish <10cm TL and 10-19.9cm TL were recorded in low densities in St. Helena Bay on the west coast and inshore on the WAB. Fish of 20-29.9cm TL were found on the WAB but particularly mid-shelf on the CAB, while fish >30cm TL were found in small numbers high up on the west coast, CAB off Mossel Bay but particularly on the EAB off Port Elizabeth.

1989

Very few small individuals <10cm TL were recorded on the shelf edge of the CAB, while fish of 10-19.9cm TL were recorded in high densities on WAB particularly between False Bay and Cape Agulhas. Large fish of 20-29.9cm TL and >30cm TL were found respectively inshore and mid-shelf on the CAB with both found in high densities on the EAB off Port Elizabeth.

1990

Very few individuals <10cm TL were recorded and they were mainly distributed on the CAB and EAB. Fish of 10-19.9cm TL were recorded in large densities on the west coast in St. Helena Bay and across the WAB, CAB (mid-shelf) and inshore on the EAB to a lesser extent.

20-29.9cm TL fish were found in high densities on the CAB mid-shelf and the western EAB. Large fish >30cm TL were found across the CAB but were recorded in greatest densities on the EAB off Port Elizabeth.

#### 1991

Recruits <10cm TL were found on the EAB, suggesting there were several bays on the south coast that were nursery areas for small fish. Fish of 10-19.9cm TL were found inshore on the CAB and inshore off Port Elizabeth on the EAB. 20-29.9cm TL fish were found in large densities from inshore to shelf edge on the CAB and EAB. Large fish >30cm TL were recorded in greatest densities on the EAB.

#### 1992

Few individuals <10cm TL recorded inshore on the south coast. Fish of 10-19.9cm TL were found inshore on the CAB in large densities. Fish of 20-29.9cm TL were found across the full extent of the Agulhas Bank but were in greatest abundance on the WAB and CAB shelf edge. Larger fish >30cm TL were found on the CAB but in particularly high densities on the EAB shelf edge.

#### 1993

Small fish <10cm TL distributed along the entire west coast up to 200m-depth and inshore on the south coast. Some individuals of 10-19.9cm TL were found in St. Helena Bay and inshore on the CAB and WAB. Some fish from 20-29.9cm TL were found offshore north on the west coast and on the WAB shelf edge. Large fish of >30cm TL were found in greatest densities on the EAB near Port Alfred.

#### 1994

Small individuals <10cm found north on the west coast near the Orange River, inshore along the entire Agulhas Bank and in low densities mid-shelf on the CAB. Fish of 10-19.9cm TL were recorded north on the west coast near the Orange River, inshore along the WAB and mid-shelf on the CAB. 20-29.9cm TL fish were recorded in greatest densities on the CAB mid-shelf. Large fish of >30cm TL were recorded in greatest densities on the CAB shelf edge.

#### 1995

Small individuals <10cm TL were found in small densities inshore on the EAB. 10-19.9cm TL fish were recorded in greatest densities in St. Helena Bay on the west coast and inshore on the WAB. 20-29.9cm TL fish and >30cm TL fish were recorded in large densities on the west coast inshore and the CAB mid-shelf.

#### 1996

Very few small fish <10cm TL were recorded occurring on the west coast near Cape Columbine. Fish of 10-19.9cm TL were recorded mainly in same area and in lower densities in St. Helena Bay and north on the west coast. Fish of 20-29.9cm TL were distributed on the EAB while larger fish were found in particularly high densities in St. Helena Bay on the west coast and on the CAB and EAB in lower densities.

#### 1997

Very few small individuals <10cm TL were found. 10-19.9cm fish were distributed inshore on the WAB and on the EAB near Port Elizabeth. Fish of 20-29.9cm TL were distributed on the west coast but were recorded in greatest densities on the CAB mid-shelf and the EAB near Port Elizabeth. Larger >30cm TL fish were recorded on the EAB and on the west coast but were recorded in greatest densities on the CAB.

#### 1998

No survey conducted.

#### 1999

Very few small fish were recorded. Fish of 10-19.9 cm TL were recorded inshore on the WAB and CAB. Fish of 20-29.9cm TL were found in patches of high density on the EAB. Large fish >30cm TL were recorded in patches of high density across the Agulhas Bank but most extensively on the EAB.

#### 2000

No survey conducted.

#### 2001

No west coast survey was conducted. Based on the south coast survey some small fish of <10cm TL were recorded on the EAB shelf edge. Fish of 10-19.9cm TL and 20-29.9cm TL were recorded in greatest densities on the CAB particularly on the mid-shelf. Large fish of >30cm TL were recorded in greatest densities on the EAB.

#### 2002

No south coast survey was conducted. Based on the west coast survey some small fish of <10cm TL were found high on the west coast near the Orange River mouth and offshore on the WAB. Fish of 10-19.9cm TL were found distributed inshore along the west coast and on the WAB. Fish of 20-29.9cm TL and >30cm TL were recorded in greatest densities offshore on the WAB.

#### 2003

Very few smaller fish were recorded. Fish of 10-19.9cm TL were distributed on the CAB inshore in high densities. 20-29.9cm TL fish dominated the CAB particularly in the mid-shelf region and on the EAB near Port Elizabeth. Large fish of >30cm TL were recorded in greatest densities along the shelf edge of the WAB and EAB.

#### 2004

Fish <10cm TL were found inshore on the CAB but particularly on the EAB between Mossel Bay and Port Elizabeth. This is the largest density of recruits recorded to date. 10-19.9cm TL fish were recorded inshore on the WAB and CAB in large densities. Fish of 20-29.9cm TL dominated the CAB offshore region with lower densities occurring on the EAB. Large fish >30cm TL were recorded in greatest densities on the WAB shelf edge and the EAB.

#### 2005

Low densities of small fish <10cm TL were recorded offshore on the WAB. Fish of 10-

19.9cm TL were recorded in high densities inshore from St. Helena Bay to Mossel Bay on the south coast. 20-29.9cm TL fish were recorded in greatest densities on the CAB both inshore and shelf edge. Large fish >30cm TL occurred across the Agulhas Bank but most densely on the EAB.

#### 2006

Fish <10cm TL were recorded in small numbers along the shelf edge from the west coast to Port Elizabeth on the EAB. Fish of 10-19.9cm TL were recorded in greatest densities from the west coast to Mossel Bay on the south coast particularly on the WAB. Fish of 20-29.9cm TL dominated the CAB mid-shelf region. Large fish >30cm TL were recorded along the shelf edge on the WAB, CAB and EAB.

#### 2007

Fish <10cm TL were recorded on greatest densities inshore from St. Helena Bay on the west coast to Mossel Bay on the south coast particularly confined to a small area inshore on the CAB between Cape Agulhas and Mossel Bay. Fish from 10-19.9cm TL were recorded in equally large densities inshore and mid-shelf on the CAB. Fish from 20-29.9cm TL were recorded in the greatest densities mid-shelf and shelf edge on the CAB but were also distributed outside False Bay on the west coast and near Port Alfred on the EAB. Large fish were found on the EAB near Port Elizabeth but were recorded in greatest densities on the west coast between Cape Columbine and Cape Point.

#### 2008

Small fish of <10cm TL were found inshore on the CAB in low densities. Fish from 10-19.9cm TL dominate the inshore regions of the CAB and EAB in high densities. Fish of 20-29.9cm TL fish were mostly distributed mid-shelf and shelf edge on the CAB in large densities. Large fish >30cm TL were found on the shelf edge on the CAB but in greatest densities between Cape Columbine and Cape Point.

#### 2009

Very few small fish <10cm TL were recorded with the greatest densities occurring on the shelf edge of the EAB. Fish of 10-19.9cm TL were abundant inshore from the Orange River on the west coast to Mossel Bay on the south coast particularly between Cape Agulhas and Mossel Bay. Fish of 20-29.9cm TL were recorded in greatest densities extensively across the WAB, CAB and EAB in high densities. Large fish >30cm TL were found on the CAB and EAB shelf edge.

#### 2010

Small fish <10cm TL were recorded inshore on the west coast and the CAB and EAB. 10-19.9cm TL fish were recorded inshore on the CAB in high densities and 20-29.9cm TL fish were found on the EAB off Port Elizabeth and in the eastern region of the CAB particularly inshore and shelf edge. Large fish >30cm TL were recorded in greatest densities along the shelf edge from the west coast to the CAB.

#### 2011

Small fish <10cm TL were recorded in very large densities from St. Helena Bay on the west

coast to the EAB. A similar and but even more extensive pattern is seen for fish from 10-19.9cm TL which were found in large densities along the full length of the coastline. Fish of 20-29.9cm TL were recorded on the EAB and CAB extending from inshore to shelf edge but particularly mid-shelf region. Very low densities of large fish were recorded.

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Appendix 7: The overall length weight relationship of horse mackerel samples collected from the eastern Agulhas Bank from June to December 2011.

$$W = a L^b$$

Where:

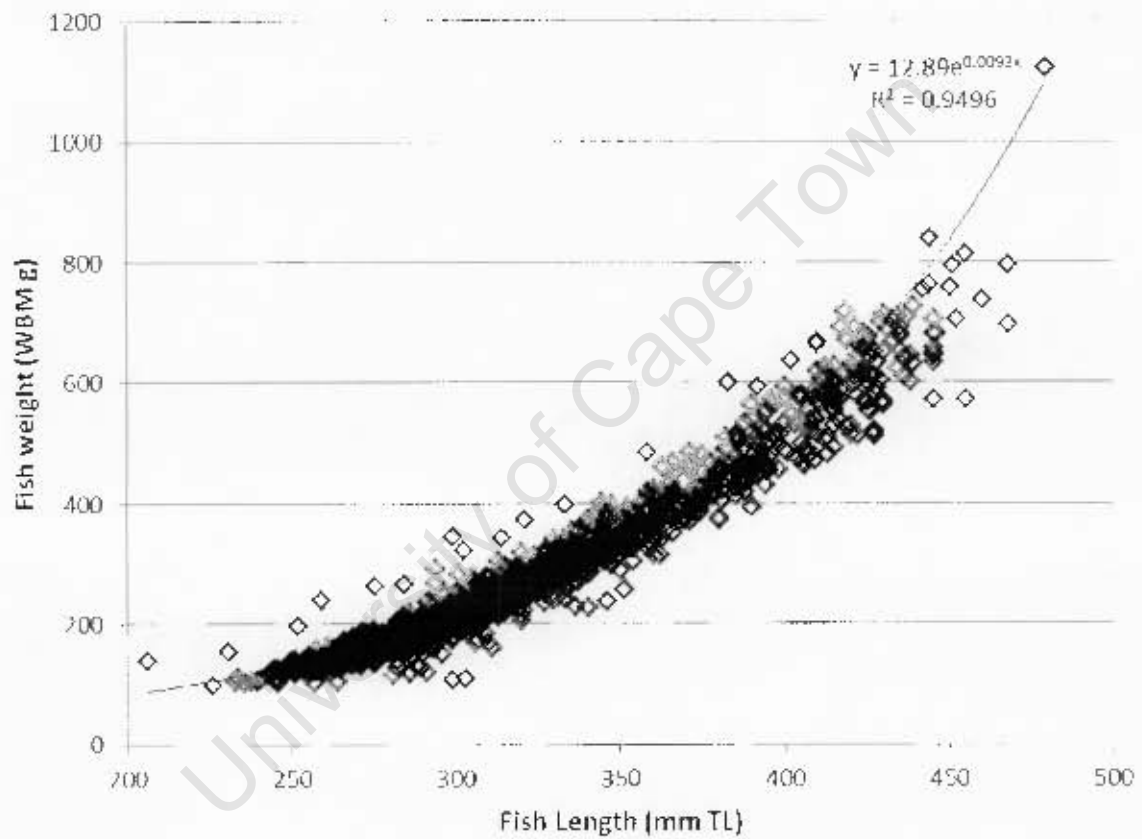
W = weight of fish (g)

L = length of fish (mm)

a = 12.8900

b = 0.0093

$R^2 = 0.9496$



Appendix 8: The length frequency distribution of horse mackerel samples collected from the eastern Agulhas Bank from June to December 2011.

