

An assessment of abundance trends and biology of
langoustines (*Metanephrops mozambicus*) and
pink prawns (*Haliporoides triarthrus*) from the
deep-water trawl fishery off eastern South Africa.

BY

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ABSTRACT

Deep-water trawling (>200 m deep) for crustaceans in the South West Indian Ocean (SWIO) yields catches of several species, including prawns (*Haliporoides triarthrus*, *Aristaeomorpha foliacea*, *Aristeus antennatus* and *Aristeus virilis*), langoustine (*Metanephrops mozambicus*), spiny lobster (*Palinurus delagoae*) and geryonid crab (*Chaceon macphersoni*). Infrequent deep-water trawling takes place off Tanzania, Kenya and Madagascar; however, well-established fisheries operate off Mozambique and South Africa. Regular trawling off South Africa started in the 1970's, mainly targeting *M. mozambicus* and *H. triarthrus*.

Catch and effort data for the South African fishery were regularly recorded in skipper logbooks over a 23 year period (1988 – 2010); this database was obtained from the Department of Agriculture, Forestry and Fisheries (DAFF) in order to assess abundance trends of *M. mozambicus* and *H. triarthrus*. Generalized linear models (GLM) were used to quantify the effects of year, month, depth and vessel on catch per unit effort (CPUE). By year, the standardized CPUE of *M. mozambicus* increased, and three factors (or a combination of them) could explain the trend: reduced effort saturation, improved gear and technology, or an increase in abundance. By month, CPUE peaked in July and was highest between depths of 300 and 399 m. The standardized CPUE of *H. triarthrus* fluctuated more by year than for *M. mozambicus*, possibly because it is a shorter-lived and faster growing species. The monthly CPUE peaked in March, and was highest between depths of 400 and 499 m.

Totals of 2 033 *M. mozambicus* (1 041 males and 992 females) and 5 927 *H. triarthrus* (2 938 males and 2 989 females) were sampled at sea between December 2010 and March 2012, during quarterly trips on-board a fishing trawler. A GLM framework was used to explore their size composition, sex ratio variability, size at maturity and reproductive cycles. Male and female *M. mozambicus* size distributions were similar, but varied by month and decreased as depth increased. Female *H. triarthrus* were significantly larger than males; size structure varied by month, but showed no change over depth. The sex ratio of *M. mozambicus* favoured males (1 : 0.89), but was close to parity in all months, except November when males predominated. *H. triarthrus* exhibited parity (1 : 1.002) with no significant variations in sex ratios by month. The proportion of egg-bearing *M. mozambicus*

in the population declined between March and August (hatching period) and then increased until December (spawning period). The L_{50} (length at 50% maturity) of *M. mozambicus* was estimated to be 49.4 mm carapace length (CL), and the smallest and largest observed egg-bearing females were 33.5 and 68.6 mm, respectively. No reproductively active female *H. triarthrus* were recorded during the sampling period.

Growth parameter estimates for *M. mozambicus* (male and female combined) using Fabens method were $K = 0.48 \text{ year}^{-1}$ and $L_{\infty} = 76.4 \text{ mm CL}$. Estimates for the von Bertalanffy growth formula (VBGF) were: $K = 0.45 \text{ year}^{-1}$ and $L_{\infty} = 76.4 \text{ mm CL}$. *H. triarthrus* male and female growth parameter were estimated separately. For males they were $K = 0.5 \text{ year}^{-1}$ and $L_{\infty} = 46.6 \text{ mm CL}$ using Fabens method, and $K = 0.76 \text{ year}^{-1}$ and $L_{\infty} = 46.6 \text{ mm CL}$ using the VBGF. For females they were $K = 0.3 \text{ year}^{-1}$ and $L_{\infty} = 62.9 \text{ mm CL}$ using Fabens method, and $K = 0.47 \text{ year}^{-1}$ and $L_{\infty} = 62.9 \text{ mm CL}$ using the VBGF.

CL to total weight regressions were calculated for both species; no significant differences were found between male and female *M. mozambicus*, although *H. triarthrus* females became larger and heavier than males.

Comparisons with three earlier studies (Berry, 1969; Berry et al., 1975; Tomalin et al., 1997) revealed no major changes in the biology of either species off eastern South Africa. Stocks appear to be stable at current levels of fishing pressure, although some factors are not yet fully understood. Disturbance caused by continual trawling over a spatially limited fishing ground may affect distribution and abundance patterns, especially in *M. mozambicus*, which was less abundant in the depth range trawled most frequently. The absence of reproductive *H. triarthrus* in samples suggests that they occur elsewhere, and there is some evidence of a possible spawning migration northwards to Mozambique; this suggests that *H. triarthrus* is a shared stock between South Africa and Mozambique. The results from this thesis will add to the knowledge of *M. mozambicus* and *H. triarthrus* in the SWIO, and provide a basis for developing sustainable management strategies for the deep-water crustacean trawl fishery off eastern South Africa.

PREFACE

The work described in this thesis/dissertation was carried out at the Oceanographic Research Institute (ORI) which is an affiliated institute of the School of Life Sciences, University of KwaZulu-Natal (UKZN), Durban. Work was conducted from October 2010 to November 2012, under the supervision of Prof. Johan Groeneveld (ORI), Dr. Sean Fennessy (ORI) and Dr. Ursula Scharler (UKZN).

This thesis/dissertation represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

DECLARATION – PLAGIARISM

I, _____, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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TABLE OF CONTENTS

Title page	
Abstract	i
Preface	iii
Declaration - plagiarism	iv
Acknowledgements.....	vi
Chapter 1 INTRODUCTION.....	8
1.1 Background	8
1.2 South West Indian Ocean (SWIO)	9
1.3 Deep-water trawling for crustaceans in the SWIO	11
1.4 South African deep-water crustacean trawl fishery	12
1.5 Langoustine <i>Metanephrops mozambicus</i> (Macpherson, 1990)	13
1.6 Pink prawn <i>Haliporoides triarthrus</i> (Stebbing, 1914)	15
1.7 Aims of this study	17
Chapter 2 MATERIALS and METHODS	18
2.1 Study area and gear	18
2.2 Sampling procedure	19
2.3 Data analysis	23
Chapter 3 RESULTS	30
3.1 General	30
3.2 <i>Metanephrops mozambicus</i>	33
3.3 <i>Haliporoides triarthrus</i>	47
Chapter 4 DISCUSSION	59
4.1 General	59
4.2 <i>Metanephrops mozambicus</i>	61
4.3 <i>Haliporoides triarthrus</i>	72
4.4 Management of the fishery	80
Chapter 5 CONCLUSIONS and FUTURE RESEARCH DIRECTION.....	82
REFERENCES	84
APPENDIX 1 Permit conditions: KZN prawn trawl fishery	101

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“Farming as we do it is hunting, and in the sea we act like barbarians. We must plant the sea and herd its animals using the sea as farmers instead of hunters.”

– Jacques-Yves Cousteau

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Chapter 1 – INTRODUCTION

1.1 – Background

Decapod crustaceans (including crabs, lobsters, shrimps and prawns*) are highly diverse and abundant throughout the oceans and are vital to marine ecosystems (De Grave et al., 2009). They are also important species for both commercial and artisanal fisheries worldwide, and are harvested by more nations than almost any other marine organism (King, 1981; Neal & Maris, 1985; Tully et al., 2003; Ye & Cochrane, 2011). Consequently, many decapod taxa have been extensively studied.

With finfish stocks in decline throughout the world's oceans (Smith & Addison, 2003) crustacean fisheries are becoming more important. In 2010 the global catch of marine crustaceans amounted to 5.5 million tons (7% of 77.4 million t of all marine catches combined), an increase from 5.3 million t (6% of total catches in 2004) (www.fao.org). Nevertheless, the annual capture of some groups of crustaceans has shown a decreasing trend over the last few years (Ye & Cochrane, 2011).

The Western Indian Ocean (WIO) is listed by the Food and Agriculture Organization of the United Nations (FAO) as their fisheries statistical area 51 (Figure 1.1). It has a surface area of approximately 30 million km², of which 6.3% is made up of the continental shelf, and has a high diversity of oceanographic and fisheries resources. The countries of area 51 include islands and continental states in Africa and Asia. These countries have diverse economies, culture, fishing practices and fisheries management capabilities (De Young, 2006). Fisheries in area 51 are highly important in terms of income and as a major source of animal protein to burgeoning coastal populations, however many fisheries remain relatively unknown and unregulated (van der Elst et al., 2005, 2009; Ye, 2011).

Within area 51, crustaceans account for 9% of the total marine fishery landings. In 2003, total landings of 350 000 t of crustaceans were reported, mainly crab and prawns (van der Elst et al., 2009; Ye 2011). Catches have declined since the 1990's and recorded catches in 2009 were only half that of the peak catches in the 1980's and 90's (Ye, 2011). The cause for

* The common names 'shrimps' and 'prawns' have been used interchangeably throughout the world for both Caridea and Penaeoidea with no consistency and there is much confusion around their use. In Southern Africa the term 'prawn' generally refers to larger Natantia (including Penaeoidea) and smaller species are generally called 'shrimps' (Holthuis, 1980; Neal and Maris, 1985; de Freitas, 1995). Hereafter the word prawn will be used for all species, unless otherwise stated.

the decline in crustacean catches, both overall and at species level, is not always clear; in some cases it may be related to overfishing, whereas in others the cause might be environmental change or degradation of habitats (Ye, 2011; Ye & Cochrane, 2011).

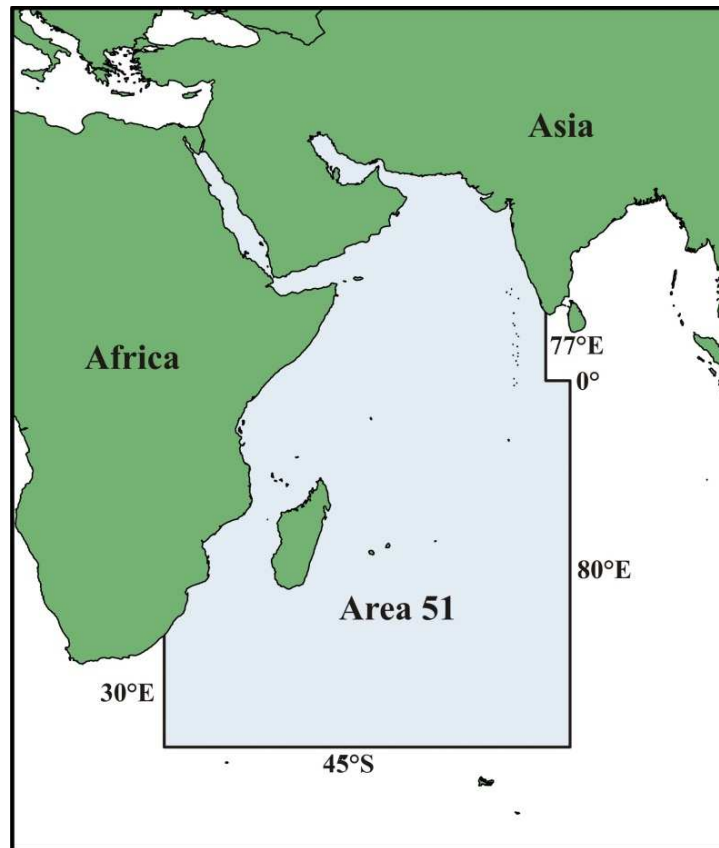


Figure 1.1. The Western Indian Ocean, FAO fisheries statistical area 51.

1.2 – South West Indian Ocean (SWIO)

Geographically, the study area covered in this thesis (i.e. eastern coast of South Africa) falls within the South West Indian Ocean (SWIO), which consists of mainly southern hemisphere countries of FAO area 51, along the western edge of the Indian Ocean. The SWIO region includes the exclusive economic zones (EEZ, up to 200 nm from the shore) of nine continental and island nations: Kenya, Tanzania, Mozambique, South Africa, Madagascar, Comoros, Mauritius, Seychelles and France, the latter because of its islands in the region, including La Reunion and Mayotte (Figure 1.2; van der Elst et al., 2009).

The SWIO region is characterised by two major western boundary current systems forming two large marine ecosystems (LME) which encompass coastal areas, the continental shelf

and the outer margins of the main currents, these LME's are characterised by distinct bathymetry, hydrography and productivity (Vousden et al., 2008). The Agulhas Current LME stretches from the northern Mozambique Channel to Cape Agulhas; it is dominated by warm and fast-flowing water of the Agulhas Current, which forms part of the anti-cyclonic Indian Ocean gyre. The Somali Current LME extends from the Comoros Islands and northern Madagascar to the Horn of Africa. The Somali Current is dominated by monsoon winds, and flows northwards during the boreal summer (SE monsoon), but its flow is reversed during winter (NE monsoon). Both the Agulhas and Somali LME's are interactive and influenced by the South Equatorial Current, which is funnelled across the Mascarene Plateau east of Madagascar before diverging north and south to become components of the two LME's. These systems influence the climate, weather patterns, sea temperatures, productivity and fisheries of the SWIO region (Lutjeharms, 2006; van der Elst et al., 2009).

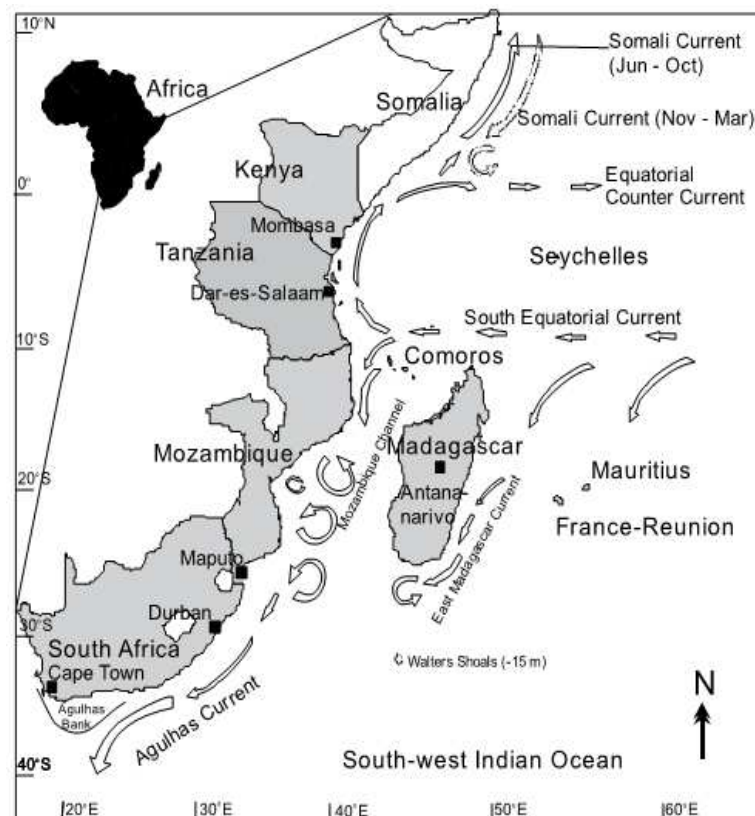


Figure 1.2. Countries and major oceanic currents of the SWIO (van der Elst et al., 2009).

The Global Environment Facility (GEF) LME Programme has funded three closely linked projects in a programmatic approach over 5 years (2008 – 2012). These projects were designed to develop and promote scientifically-grounded national and regional fisheries management plans that promote sustainable use of fish resources, while conserving

ecosystems and biodiversity (Payet & Groeneveld, 2012). The three projects were the Agulhas and Somali Currents LME project (ASCLME, dealing with physical oceanography and productivity), the Western Indian Ocean Land-based impacts on the environment (WIO-Lab, dealing with land-based sources of marine degradation) and the South West Indian Ocean Fisheries Project (SWIOFP, dealing with offshore and shared fisheries resources) (van der Elst et al., 2009). The research in this thesis was funded by SWIOFP, and aimed to provide guidance for the management of deep-water crustacean resources in the SWIO, both at a national level, and at a regional level for shared stocks.

1.3 – Deep-water trawling for crustaceans in the SWIO

The majority of crustaceans captured in the SWIO region are shallow-water (<50 m depth) species, which are easily accessed by artisanal fishers, whereas the deep-water (>200 m depth) stocks are limited to industrialised trawling (van der Elst et al., 2009). Multi-species deep-water crustacean trawl fisheries in the SWIO region catch several species of deep-water prawns (*Haliporoides triarthrus*, *Aristaeomorpha foliacea*, *Aristeus antennatus* and *Aristeus virilis*) as well as langoustine (*Metanephrops mozambicus*), spiny lobster (*Palinurus delagoae*) and geryonid crab (*Chaceon macphersoni*) at depths of 100 to 600 m (Groeneveld & Melville-Smith, 1995; Fennessy & Groeneveld, 1997; van der Elst et al., 2009; Groeneveld, 2012). Besides the target crustaceans, non-target species are caught as bycatch (van der Elst et al., 2005); these organisms include many species of teleosts, elasmobranchs and cephalopods which may be retained if their commercial value is high, or discarded if their value is considered too low (Fennessy, 2001). Deep-water crustacean trawl fisheries in the SWIO region are not well known and scientific peer-reviewed publications are scarce (Cunningham & Bodiguel, 2006; Ye & Cochrane, 2011). Data for the majority of countries are minimal and are mainly in the form of survey and stock assessment reports (Groeneveld, 2012).

Deep-water trawling off Madagascar, Tanzania and Kenya is infrequent, due to limited trawling grounds and difficult trawling conditions in comparison to shallow-water trawl fisheries in these regions (Groeneveld, 2012). Several deep-water trawl surveys have taken place in these countries over the past few decades (Crosnier & Jouannic, 1973; Sætersdal et al., 1999; Cunningham & Bodiguel, 2006; Groeneveld, 2012). Mozambique has the largest trawl fishery for deep-water crustaceans in the SWIO region, with trawlable grounds

covering over 15 000 km² and landings of crustaceans ranging between 1 000 and 3 000 t annually (Silva & Sousa, 1988; Dias et al., 2011). Landings mostly comprise deep-water prawns, with *H. triarthrus* accounting for 70 to 80% of the catch, and langoustine *M. mozambicus* contributing about 10 % (Silva & Sousa, 1988; Dias et al., 2011; Groeneveld, 2012). The neighbouring South African deep-water crustacean trawl fishery is smaller, but fulfils an important niche in the South African fishing industry. Trawling is not permitted in the other SWIO (island) countries.

1.4 – South African deep-water crustacean trawl fishery

Trawling along the eastern coast of South Africa originated from exploratory surveys undertaken as early as the 1920's which revealed large quantities of the spiny lobster *P. delagoae* (Gilchrist, 1922). The spiny lobster was initially targeted and all other species were considered as by-catch, however, in the 1960's catches of *P. delagoae* began to decline and the fishery switched to targeting prawns and langoustines (Berry, 1972). Trawling became more regular after 1976, which prompted the development and promulgation of a regulation and control system for the fishery: this was finally implemented in 1988 (Fennessy & Groeneveld, 1997).

Landings of target crustaceans (*H. triarthrus*, *M. mozambicus*, *P. delagoae* and *C. macphersoni*) combined ranged between 58 and 215 t/year between 2005 and 2010. During the same period, the average annual landings of *M. mozambicus* were 36.04 t/year and those of *H. triarthrus* were 66.34 t/year (Warman, 2011). Trends in effort, catch and catch composition (both crustacean and by-catch, mainly teleosts and elasmobranchs) of this fishery have been described in earlier studies (Groeneveld & Melville-Smith, 1995; Bailey et al., 1997; Fennessy & Groeneveld, 1997; Tomalin et al., 1997; Fennessy, 2001), however, despite the longevity of this fishery and its commercial importance, few biological studies on the target species have been undertaken. Nevertheless, preliminary studies have been done for *M. mozambicus* (Berry, 1968, 1969; Tomalin et al., 1997) and *H. triarthrus* (Berry et al., 1975; Tomalin et al., 1997). These two species are the most profitable (Fennessy, 2001) and are captured by deep-water crustacean trawlers within the SWIO region.

1.5 – Langoustine *Metanephrops mozambicus* (Macpherson, 1990)



The family Nephropidae supports many fisheries in the world's oceans (Cobb & Wang, 1985), either as targeted organisms or as a retained by-catch (Bell et al., 2006), and nephropids generally have a high commercial value (Chan & Yu, 1991). The majority of fisheries for *Metanephrops* species, a sub-family of the Nephropidae, occur in the Indo-West Pacific. A multi-species trawl fishery on the continental slope of north-west Australia catches between 50 and 100 t/year of several *Metanephrops* species, including *M. australiensis*, *M. neptunus*, *M. boschmai* and *M. velutinus* (Holthuis, 1991; Lynch & Garvey, 2005, Bell et al., 2006). The fishery concentrates on muddy substrata at depths of 260 to 500 m. *M. challengerii* is fished on the continental shelf of New Zealand, on fine sand and muddy bottoms at 140 to 640 m (Wear, 1976; Smith, 1999). Commercial trawlers in the East China Sea capture *M. thomsoni* on sand and mud bottoms along with several other species (Choi et al., 2008). *M. japonicus* is fished on sandy mud substrata between depths of 200 and 400 m along the Pacific coast of Japan (Bell et al., 2006; Okamoto, 2008). By far the largest fishery for any nephropid, however, is that for *Nephrops norvegicus* (Linnaeus, 1758) in the north-east Atlantic and Mediterranean, where total annual landings amount to 50 000 – 60 000 t (Bell et al., 2006). *N. norvegicus* is caught as a target species and retained as by-catch of multi-species fisheries trawling over muddy substrata in both shallow (20 – 200 m) and deep-water (200 – 800 m) (Chang & Yu, 1991; Graham & Ferro, 2004; Bell et al., 2006). The above fisheries share many similarities: they target similar depth zones (mainly 200 to 500 m) and substrata (sand, mud), and are multi-species in character. Fisheries for

Metanephrops species are generally not large, with only a few active vessels, and with limited catches which are sold locally or exported.

The langoustine or African lobster *M. mozambicus* (Macpherson, 1990) occurs in the Indo-West Pacific region, where it is distributed off eastern Africa between Kenya and eastern South Africa, and off the western coast of Madagascar (Holthuis, 1991). It occurs along the edge of the continental slope on soft muddy substrata at depths of 200 – 750 m, but is most commonly found between 400 and 500 m (Berry, 1968; Berry, 1969; Holthuis, 1991). Prior to 1990, langoustine catches along the east African coast were attributed to *M. andamanicus* (Wood-Mason, 1891), a morphologically very similar species from Kenya, the Andaman Sea, the south China Sea and Indonesia (Holthuis, 1991). Macpherson (1990) described *M. mozambicus* from material collected in Madagascar, and Chan & Yu (1991) identified the main differences between *M. mozambicus* and *M. andamanicus* as a more eroded dorsal carina and other sculpturation in *M. mozambicus*. It remains unclear whether specimens from Tanzania belong to *M. andamanicus* or *M. mozambicus* or whether, perhaps, both species occur there (Chan & Yu, 1991). *M. mozambicus* supports multi-species crustacean trawl fisheries in the SWIO region.

The majority of biological and fisheries research on nephropids have focussed on *N. norvegicus*. Many studies have been undertaken and reviews on the biology and fisheries of *N. norvegicus* are numerous and extensive (see Farmer, 1975; Chapman, 1980; Dow, 1980; ICES, 1982; Sardá, 1995; Graham & Ferro, 2004; Bell et al., 2006). Studies on *Metanephrops* species (see Berry, 1968; Berry, 1969; Wear, 1976; Bailey et al., 1997; Tomalin et al., 1997; Lynch & Garvey, 2005; Choi et al., 2008; Okamoto, 2008) are far less extensive, and many make reference to studies based on *N. norvegicus*, which include analysis of catch rates, seasonality, growth rates, densities, sex ratios, reproduction and maturity. These studies are helpful for comparative purposes in studies on *M. mozambicus* within the SWIO region.

Some of the biological characteristics of *M. mozambicus* along the eastern coast of South Africa were investigated by Berry (1969) and Tomalin et al. (1997). These studies examined morphometry, catch composition, moulting and reproduction. The more recent of the two studies was however undertaken 15 years ago, and since then much more fisheries data has become available. The past 15 years have also seen climate induced changes in marine ecosystems as well as increased anthropogenic impacts on fisheries resources around the

world (Richardson & Schoeman, 2004; Allison et al., 2009; Brander, 2010). Given these factors, a re-examination of the biology and fishery targeting *M. mozambicus* off eastern South Africa was considered to be justified.

1.6 – Pink prawn *Haliporoides triarthrus* (Stebbing, 1914)



Prawns are divided into two superfamilies; 1) Penaeoidea, which form the basis of many artisanal and trawl fisheries in tropical and sub-tropical regions and 2) Caridea, which are more widely distributed, but less commonly fished (Holthuis, 1980; King, 1981; Neal & Maris, 1985). Of the Penaeoidea, the family Solenoceridae includes the genus *Haliporoides* which comprises three species of medium to large prawns important to commercial fisheries (Holthuis, 1980). *H. diomedae* is distributed in the eastern Pacific from Panama to Chile where it is caught by multi-species deep-water crustacean trawl fisheries (Holthuis, 1980; Arana et al., 2003; Parraga et al., 2010). *H. sibogae* and *H. triarthrus* are distributed along the continental shelves or slopes of the Indo-West Pacific, where they also support multi-species deep-water crustacean trawl fisheries (Holthuis, 1980; de Freitas, 1985).

H. sibogae has been reported off Madagascar, the Malay Archipelago and New Zealand (Holthuis, 1980), but it is more common in the waters of Australia, Japan and in the East China Sea (Baelde, 1991; Kosuge & Horikawa, 1997; Ohtomi & Matsuoka, 1998). The Australian fishery is small, but well established and stable, and is located off the south-east coast (Baelde, 1992). This species is targeted by trawlers on muddy grounds at depths of 270 to 850 m (mostly 400 to 500 m) and annual production ranges between 300 and 350 t at

a catch rate of around 80 to 100 kg/trawl hour (Baelde, 1991, 1992, 1994). *H. sibogae* off Japan and in the East China Sea has been targeted by commercial bottom trawlers since the 1960's, with annual landings ranging from 350 to 500 t (Kosuge & Horikawa, 1997; Ohtomi & Matsuoka, 1998). These landings have decreased since the 1980's, stimulating increased research (Ohtomi & Matsuoka, 1998).

Multi-species trawl fisheries off the east coast of Africa catch *H. triarthrus*, along with other deep-water crustaceans, on soft muddy bottoms along the continental slope, most commonly between 360 and 460 m depth (Holthuis, 1980; de Freitas, 1985). *H. triarthrus* is commercially fished off Mozambique and South Africa and potential deep-water trawl fisheries have been found by trawl surveys off Madagascar and Tanzania (Groeneveld, 2012). However, in the latter two countries the trawl grounds are limited and fishing conditions are difficult due to strong currents and bottom topography; fishing companies have therefore focussed mainly on the extensive shallow-water fishing grounds (Groeneveld, 2012). The Mozambique deep-water crustacean fishery is the largest in the SWIO region, with annual landings ranging between 1 500 and 2 700 t of crustaceans, of which *H. triarthrus* contributes 70 to 90% (Torstensen, 1989; Torstensen & Pacule, 1992), whereas the South African fishery lands <100 t of this species per year.

Many fisheries surveys of the deep-water trawl grounds of Mozambique have taken place over the past few decades (see Brinca et al., 1983; Sobrino et al., 2007a; Sobrino et al., 2007; Dias et al., 1999, 2008, 2009, 2011; Dias & Caramelo, 2005, 2007) and the data have, *inter alia*, been used to assess the abundance and biology of *H. triarthrus* (see also Torstensen, 1989; Torstensen & Pacule, 1992). However, fewer studies of this species are available from South Africa (Berry et al., 1975; de Freitas, 1985; Tomalin et al., 1997), despite its importance to the local fishing industry, its trans-boundary distribution pattern, and the high likelihood that *H. triarthrus* is a shared resource between South Africa and Mozambique. The research in this thesis was justified due to the large time gaps between studies of *H. triarthrus* off South Africa as well as the possible impacts of climate change on fisheries over the last few decades (Allison et al., 2009).

1.5 – Aims of this study

Studies of animal communities inhabiting the continental shelf and slope are an important aspect of marine ecology, particularly where they have a significant commercial value (Abelló et al., 1988). The effects of trawling on the environment may include altered habitats, reduced biodiversity, and changed population demographics (i.e. abundance, size and sex distributions) of affected species, which may result in reduced productivity, and impact on the sustainability of a fishery (Tuck et al., 1998; Hansson et al., 2000; Schratzberger et al., 2002; Bell et al., 2006; Zhou et al., 2010).

With this in mind, the aims of the present study were to use fisheries and biological data collected during sampling trips at sea on-board commercial trawlers off the east coast of South Africa, to investigate langoustine *M. mozambicus* and pink prawn *H. triarthrus* populations so as to determine: (a) distribution patterns on the fishing grounds; (b) population demographic structure (sex and size structure); (c) reproductive biology (size at maturity, breeding season); and d) somatic growth rates. A long-term database (1988 – 2010) comprising logbook information of catches and effort per trawl recorded by the skippers of fishing vessels, and stored by the national Department of Agriculture, Forestry and Fisheries (DAFF), was analysed to determine trends in abundance of the two species over the past two decades.

The results of the present study were compared to the findings of Berry (1969), Berry et al. (1975), de Freitas (1985), Bailey et al. (1997) and Tomalin et al. (1997) on *M. mozambicus* and *H. triarthrus* off eastern South Africa. The outcome of this study was used as the basis for developing fisheries management strategies based on best-available information.

Chapter 2 – MATERIALS and METHODS

2.1 – Study area and gear

Samples were collected from bottom trawls undertaken on the trawling grounds off the eastern coast of South Africa, between 28 and 31° S (Figure 2.1). Between these latitudes, in the Natal Bight, the continental shelf is at its widest, extending up to 50 km offshore (Lutjeharms et al., 1989), and providing a relatively large trawlable area of about 1 750 km² between 100 and 600 m (mostly 300 – 500 m) (Berry, 1969; Groeneveld & Melville-Smith, 1995; Fennessy & Groeneveld, 1997). At these depths the substratum ranges from areas of hardened sediment to mud, mainly consisting of foraminiferous remains (Berry, 1969; Berry et al., 1975). The Agulhas Current core meanders close to the continental shelf edge in this region (Lutjeharms, 2006), and generally flows in a south westerly direction, with speeds of up to 3 knots being common (Berry, 1969; Lutjeharms, 2006). Berry (1969) found the average bottom temperatures on the trawl grounds to range between 9 and 12 °C, however recent measurements suggest that it is somewhat cooler, between 8 and 10 °C at 500 m depth (L. Guastella, University of Cape Town, unpubl. data).

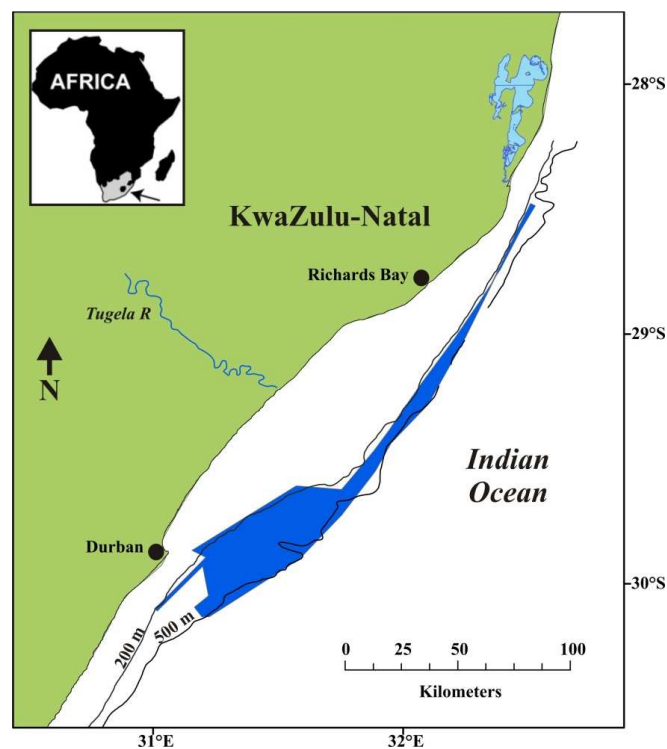


Figure 2.1. Deep-water trawling grounds off eastern South Africa.

All sampling trips were undertaken during normal fishing operations on board a commercial deep-water trawler operating from Durban harbour. The FV Ocean Spray is a stern trawler (LOA of 35 m; GRT of 282 t; 800 hp engine) using a single otter trawl with 'V' shaped doors, weighing 630 kg each. The nylon trawl net was attached directly to the doors, and had a 60 mm stretched mesh size over the body, wings and cod end (Figure 2.2). The net had a foot rope length of 50 m with 45 m of chain attached, and a head rope length of 40 m. The effective height between the foot and head rope, while fishing, was approximately 1.5 m.

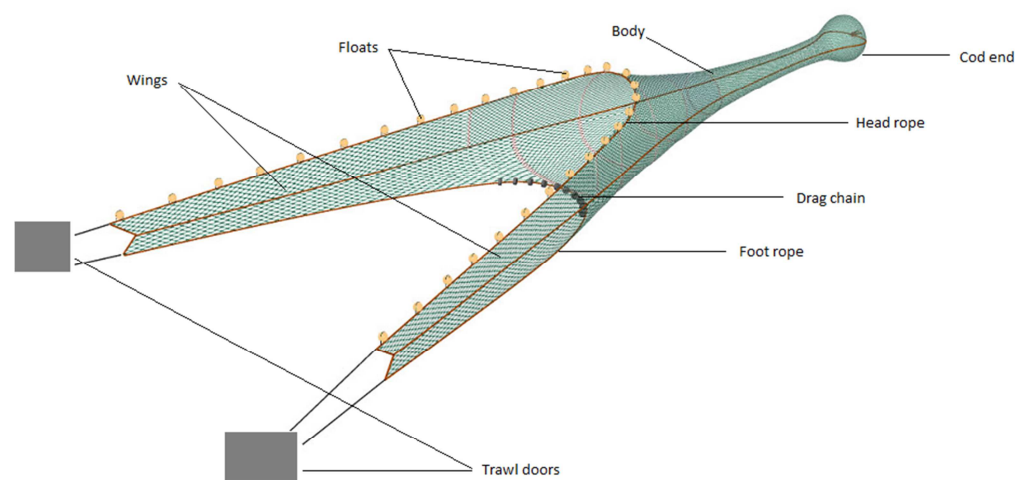


Figure 2.2. Generalised otter trawl net.

2.2 – Sampling procedure

Six quarterly sampling trips were undertaken between December 2010 and March 2012. Trawl data including set and haul time, GPS position (start of trawl), depth range and trawl speed were recorded for each drag. Once the net was emptied onto the deck, a random sample was collected by shovelling 10 to 20 kg of the catch into a plastic crate. The sample was weighed to the nearest kg and the targeted crustacean component was separated from the rest of the crate contents and reweighed. An estimate of the total weight of *M. mozambicus* and *H. triarthrus* caught per trawl, based on the number of boxes of packed by the crew, was obtained from the skipper.

Biological data were collected from all individuals of *M. mozambicus* and *H. triarthrus* in the subsample. *M. mozambicus* individuals were sexed based on the position of the external genital openings (Figure 2.3); females have paired oviducts which open on the coxae of the third pereopods and the vas deferens of males opens through a slightly raised aperture on the coxae of the fifth pereopods (Berry, 1969; Farmer, 1975). Female *H. triarthrus* were identified by the presence of the thelycum, between the 3rd and 5th pereopods, and males were identified by the petasma, found on the first pleopod (de Freitas, 1985) (Figure 2.4). Carapace lengths (CL \pm 0.1 mm) for both species were measured as the distance between the base of the inner eye socket and the posterior margin of the carapace, using vernier callipers. The shell condition was recorded as being either 'hard' or 'soft'.



Figure 2.3. Positions of female (left) and male (right) *M. mozambicus* genital openings.



Figure 2.4. Positions of the male petasma (left) and female thelycum (right) of *H. triarthrus*.

The numbers of egg-bearing *M. mozambicus* females in samples were recorded, and eggs carried on the abdomen of females were staged as follows (Berry, 1969) (Figure 2.5):

- | | | |
|-----------------------------|---|--|
| 1. Freshly spawned | = | Bright royal blue/no embryo development |
| 2. Early embryo development | = | Dark blue-purplish/embryo visible as thin tissue |
| 3. Well-formed embryo | = | Dark purple to pink/appendages just visible |
| 4. About to hatch | = | Red/fully formed, eyes of larvae visible |

Male reproductive organs could not be staged macroscopically and due to time and space constraints on board the vessel the maturity status of *M. mozambicus* males was not recorded.



Figure 2.5. Four development stages of *M. mozambicus* eggs, stage 1 on the left through to stage 4 on the right.

The numbers of reproductively active *H. triarthrus* females were recorded and ovarian development was staged as follows (Berry et al., 1975):

- | | | |
|------------------------|---|---|
| 1. Inactive / immature | = | Thin, clear or faintly pink/not swollen |
| 2. Active | = | Pink to red/slightly swollen |
| 3. Ripe | = | Blue-grey/swollen |
| 4. Spent | = | Grey-yellow/flaccid |

The staging of *H. triarthrus* female ovaries was conducted macroscopically, as the ovaries were visible through the dorsal exoskeleton (Figure 2.6). However, male reproductive organs were not macroscopically visible and they were therefore not staged.



Figure 2.6. Colour change of female *H. triarthrus* ovaries, visible as a bright blue mass in the top prawn (ripe), and as a faint thin line in the bottom prawn (inactive/immature) (Photo by S. Fennessy, Oceanographic Research Institute).

In addition to the onboard sampling, boxes of *M. mozambicus* and *H. triarthrus* packed by the crew in three size classes (large, medium and small, 2 kg of each) were purchased directly from the vessel during months in which sampling at sea did not take place. The CL, sex, egg developmental stage (*M. mozambicus*), ovarian stage (*H. triarthrus*) and shell condition of these specimens were determined in the same way as during field trips and in addition individual weights were recorded to the nearest gram in the laboratory. These samples were used solely in the determination of the length-weight relationships for both species.

2.3 – Data analysis

CPUE

Information on catches and effort was obtained from the Department of Agriculture, Forestry and Fisheries (DAFF) for the entire commercial trawling fleet, as recorded in logbooks by skippers as part of permit conditions (DAFF 2012; Appendix 1), between 1988 and 2010. The data were cleaned by removing anomalous records, in which the trawl localities, depth, date or catches were clearly inaccurate. The dataset contained a large number of zero catches per trawl of *M. mozambicus* and *H. triarthrus*; this was considered to reflect the multispecies nature of the fishery, in which other crustacean species (i.e. spiny lobster or geryonid crab) were targeted on occasion. Nevertheless, the zero catches contain information on the distribution patterns of the two species being investigated, and therefore they were included in the analysis.

The catch (packed weight per trawl) and effort (trawl hours) were used to determine the nominal catch per unit effort (CPUE, in kg/hour) for both species. The nominal data provide a coarse indication of CPUE and abundance, however this index may be biased by gear-effects, changes in catchability, and spatio-temporal variation within the stock (Kimura, 1981; Salthaug & Godo, 2001; Sbrana et al., 2003).

The effects of year, month, depth and vessel on CPUE were first quantified using a generalised linear model (GLM), and thereafter a standardised index of abundance was calculated to correct for the influences of the variables shown above. The statistical software package R version 2.14.0 (R Development Core Team, 2011) was used to fit the GLMs.

One of the main challenges of modelling catch rates (or CPUE) in fisheries is that these data often have many zero catches per unit of effort (i.e. per trawl or per trap set) and these must, in some way, be included in the analyses. Currently, the most popular way for dealing with large numbers of zero catches is to use the delta method, in which the zero and non-zero records are analysed separately (Maunder & Punt, 2004). This involves fitting two sub-models to the data (Lo et al., 1992; Maunder & Punt, 2004; Shono, 2008; Carlson et al., 2012). The first sub-model assigns a value of zero or one based on the respective absence or

presence of a species, and assumes a binomial error distribution (2.1) with a Logit link function, and quantifies the probability of occurrence (or of capture) of the species.

The binomial probability density function as described by Haddon (2001) is:

$$P\{m|n, p\} = \left[\frac{n!}{m!(n-m)!} \right] p^m (1-p)^{(n-m)} \quad (2.1)$$

where: p is the probability of an event, m , occurring in, n , trials.

In the second sub-model, only the positive catches are modelled assuming either a gamma, log-normal or Poisson distribution. Preliminary tests showed that the relationship between the logarithms of the mean and variance of the CPUEs (positive values) were close to two, showing that the data were highly dispersed, and consequently a gamma model (2.2) with a Log link function was selected to fit the second sub-model.

The gamma distribution function as described by Haddon (2001) is:

$$L\{x|c, b\} = \left[\frac{\left(\frac{x}{b}\right)^{(c-1)} e^{-\frac{x}{b}}}{b\Gamma(c)} \right] \quad (2.2)$$

where: x is the value of variate b , c is the shape parameter and $\Gamma(c)$ is the Gamma function for parameter c .

Explanatory variables tested included year, month, depth and vessel (Table 2.1). Latitude and longitude were excluded as explanatory variables from this model, because the majority of trawling takes place within a small well defined area of the fishing grounds, causing an unbalanced spread of the data over the entire fishing ground as well as uncertainty in trawl locality data prior to 2000, when a coarse grid method of positioning was in use. The standardised CPUEs were computed by multiplying the probability of catch (from the binomial model) with the conditional catch (from the gamma model) which were in turn obtained from the coefficients of each model. For both sub-models the year 1988, month August, depth 400 m and the most active vessel in the fleet were used as reference points, as these were the most frequent and representative observations of these factors. The standardised and nominal CPUEs were plotted for each explanatory variable.

Size

A GLM framework, using R software, was further used to analyse size, sex ratios and maturity of *M. mozambicus* and *H. triarthrus*. Data for these analyses were obtained from the onboard sampling as detailed above. A Gaussian error distribution (2.3) with a Log link function was selected to model the size data, for both species. The explanatory variables year, month, depth and sex were tested and those not significant in explaining deviations from the mean were omitted from the final selected model (Table 2.1). The outcome from the standardised size models was plotted for each explanatory variable.

The Gaussian distribution function as described by Haddon (2001) is:

$$L\{X|\mu, \sigma\} = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(\frac{-(X-\mu)^2}{2\sigma^2}\right)} \quad (2.3)$$

where: $L\{X|\mu, \sigma\}$ is the likelihood of any individual observation X , given μ population mean and σ population standard deviation.

Sex ratio

A binomial error distribution (2.1) with a Logit link function was selected to model sex ratios of both species. The explanatory variables tested included year, month, depth and CL. The only significant variable explaining the sex ratio of *M. mozambicus* was month and for *H. triarthrus* month and CL were significant (Table 2.1). The outcomes from the standardised models were plotted as a probability of capturing a male for both species.

Maturity

The presence of eggs on female *M. mozambicus* was used as the indicator of maturity and only females were therefore considered in the model. Month, depth and CL were significant explanatory variables in determining maturation of *M. mozambicus*. These data were modelled using a binomial error distribution (2.1) with a Logit link function (Table 2.1). The outcomes from the standardised maturity model were plotted, as a probability of capturing a mature female by month and depth, and as a logistic curve to determine maturity. Carapace lengths at which 25% (L_{25}), 50% (L_{50}) and 75% (L_{75}) of females reached maturity were estimated using a logistic ogive (2.4) and numeric values were determined by back calculation, using the inverse Logit.

The logistic ogive of any number (α) is given by the inverse-logit as follows:

$$\text{Logit}^{-1}(\alpha) = \frac{1}{1+e^{(-\alpha)}} = \frac{e^{\alpha}}{1+e^{\alpha}} \quad (2.4)$$

No reproductively active *H. triarthrus* females were recorded in any samples and subsequently no analyses could be performed.

Model and explanatory variable selection

All final GLMs were selected based on a stepwise approach, which involved modeling all possible combinations of error structures, link functions and explanatory variables (Table 2.1). Explanatory variables were selected based on factors that were likely to influence the catchability of each species. Those model combinations with the smallest AIC values and best fits to the data (based on visual assessments of residual plots) were selected for the final model (Akaike, 1974; Maunder & Punt, 2004). An assumption of the models including the variable 'vessel' was that vessel was considered a fixed effect, thus allowing models of CPUEs of each vessel to be calculated in relation to a reference vessel. Maunder & Punt (2004) showed that interactions in the models between variables (e.g. year and vessel) are common and can be significant, but are difficult to account for. These interactions were ignored in this study, an approach used by Vignaux (1994) (Maunder & Punt, 2004), however it should be noted that abundance indexes may be biased in the approach. The decision as to the choice of categorical or continuous variables, in the case of length and depth, was based on the AIC values as well as residual plots of each model run. However, Maunder & Punt (2004) recommend that continuous variables be treated as categorical, if it simplifies the model and better explains the data. Where appropriate in the analysis these considerations were taken into account.

Table 2.1. Factors retained in the final GLMs for *M. mozambicus* and *H. triarthrus*. The delta method was used to model CPUEs. Year, month and depth were treated as categorical variables and length as a continuous variable. The Akaike information criterion (AIC) was used in the selection of final models.

Model	Species	Error	Link	Explanatory Variables	AIC
CPUE	<i>M. mozambicus</i>	Binomial	Logit	Year + month + depth + vessel	43027
	<i>M. mozambicus</i>	Gamma	Log	Year + month + depth + vessel	231985
	<i>H. triarthrus</i>	Binomial	Logit	Year + month + depth + vessel	29079
	<i>H. triarthrus</i>	Gamma	Log	Year + month + depth + vessel	320583
Size	<i>M. mozambicus</i>	Gaussian	Log	Month + depth	14848
	<i>H. triarthrus</i>	Gaussian	Log	Month + depth	33770
Sex ratio	<i>M. mozambicus</i>	Binomial	Logit	Month	2804.8
	<i>H. triarthrus</i>	Binomial	Logit	Month + length	7863.7
Maturity *	<i>M. mozambicus</i>	Binomial	Logit	Month + depth + length	758.06

* Calculated only for *M. mozambicus* females

Growth

Growth estimates were calculated from data obtained from the onboard sampling as detailed above. Descriptions of growth patterns in crustaceans frequently rely on analysis of length-frequency distributions (Farmer, 1973; Hillis, 1979; Gulland & Rosenberg, 1992). With this approach, the first step was to assess if there were differences between the onboard-sampled monthly distributions of CL for males and females using Pearson's χ^2 tests of independence (Townend, 2002). Length-frequency distributions were pooled, as samples were collected from a small area, narrow depth range and from a commercially operating vessel, thereby disallowing a carefully planned random stratified approach to sampling. These were plotted and visually analysed to assess the presence and number of modes, which were interpreted as cohorts or age classes, and for signs of progression of these cohorts. After a preliminary assessment of the modes, more exact estimates of their proportions, mean lengths, standard deviations and standard errors were calculated using Solver, the optimization tool available in MS Excel. Software developed in MS Excel mimicked the program MIX (Macdonald & Pitcher, 1979; Macdonald & Green, 1988) and assisted in the separation of mixtures of normal or gamma distributed modes. Either the likelihood of the multinomial distribution, or simple least squares of the totals could be used as fitting criteria (Haddon, 2001).

In order to discriminate between modes in the length frequencies three major assumptions were made in the fitting and characterization of the modes: (1) that the length observations within each mode were normally distributed (2) that increments between mean lengths of the same cohort decreased with size (or time) and (3) that standard deviations remained relatively constant. This ensured that the model fitted to the obvious modes correctly, by setting constraints on the mean, proportion and standard deviation of the modes.

The best fitting parameters of the different modes (proportion, mean and standard deviation) were then searched by minimization of least squares using Solver in MS Excel. Although many modes were identified for *M. mozambicus*, discrimination within the oldest and youngest modes proved difficult, and thus only two cohorts were used in the analysis. Those two best represented the data, as they had the highest number of modes, and could be traced over the entire study period. Male and female *H. triarthrus* showed only one cohort each, which could be more easily traced over time.

The von Bertalanffy growth function (VBGF) was fitted to the length data of *M. mozambicus* for sexes combined and individually by sex for *H. triarthrus*, using two methods. The first method was the traditional VBGF (2.5) with the following equation:

$$L_t = L_{\infty} (1 - e^{-K(t - t_0)}) \quad (2.5)$$

where: L_t is the length at time t , L_{∞} is the mean asymptotic length, K is the growth coefficient and t_0 is the theoretical age at the start of growth.

This method required an explicit definition of the age or time of birth and operated with temporal growth. The age or birth date was assigned to the initial cohort, which was determined based on the proposed reproductive cycles and biological characteristics of both species (see Berry, 1969; Berry et al., 1975; de Freitas, 1985) and then the age of each cohort was traced over time.

The second method used was Fabens (1965) method (2.6) with the following equation:

$$\Delta L = L_{t+1} - L_t = (L_{\infty} - L_t) \cdot (1 - e^{-K \cdot \Delta t}) \quad (2.6)$$

where: ΔL is the change in size increments, L_t and L_{t+1} are the mean cohort lengths measured at Δt time periods apart, L_{∞} is the mean asymptotic length and K the growth coefficient.

Fabens method, which is based on a transformation of the VBGF, does not require a known age, and circumvents this requirement by dealing with size increments instead. In the present study the units of the parameters were millimetres and years. During the fitting process it was often difficult to obtain convergence to a reasonable asymptote, and the maximum CL recorded was set to be 95% of L_{∞} for both species, a method described by Pauly (1980). The two cohorts selected from the *M. mozambicus* data followed similar growth trajectories and a single VBGF was fitted to the combined data, as the Pearson's χ^2 test indicated no significant differences between the monthly length frequencies. However, the VBGF were fitted to male and female *H. triarthrus* separately as this test indicated there were significant differences in the monthly length frequencies (see results). The two versions of the VBGF were fitted using Solver, by means of non-linear least squares assuming a normal error structure of the observations.

Length weight relationships

Data collected from samples bought monthly (as described above) were used to determine the relationship between CL and whole weight (WW) by fitting linear models using a least-squares algorithm in Microsoft Excel for both species. Data were non-linear and consequently the data were log-transformed, and relationships compared by sex using linear models.

Length weight curves (2.7) were drawn using the exponential equation:

$$W = \alpha \cdot L^{\beta} \quad (2.7)$$

where: W is the whole weight and L the carapace length, of an individual and α and β are parameters of the model.

Chapter 3 – RESULTS

3.1 – General

A total of 49 991 deep-water crustacean trawls were analysed, as captured onto a database by DAFF, from logbooks returned by skippers over a 23 year period. The total landed catch of both species during this time was 4177.67 t with an average of 181.64 ± 53.43 t/year. The average trawl duration over this period was 4.24 ± 1.23 hours and the average trawl depth was 399.35 ± 82.07 m.

The trawl and biological data collected during the 6 on-board sampling trips undertaken for this thesis are summarised below (Table 3.1), and the locations of the sampled trawls are shown in Figure 3.1.

Table 3.1. Summary of the trawl and biological data collected during on-board sampling trips.

Date	Trawls sampled	Number of individuals sampled		Average depth (m)	Average trawl time (hrs)	Total catch (kg)	
		<i>M. mozambicus</i>	<i>H. triarthrus</i>			<i>M. mozambicus</i>	<i>H. triarthrus</i>
13-22 Dec 2010	19	363	870	429.77	4.49	672.0	687.2
21 Feb-1 Mar 2011	19	275	1772	418.73	4.75	667.2	2313.6
11-18 May 2011	15	344	791	441.75	4.58	597.6	1388.8
9-16 Aug 2011	10	253	879	417.37	4.60	481.6	1209.6
28 Nov-5 Dec 2011	16	358	699	438.95	5.11	496.4	1092.4
7-12 Mar 2012	16	467	921	425.08	5.06	561.4	523.2

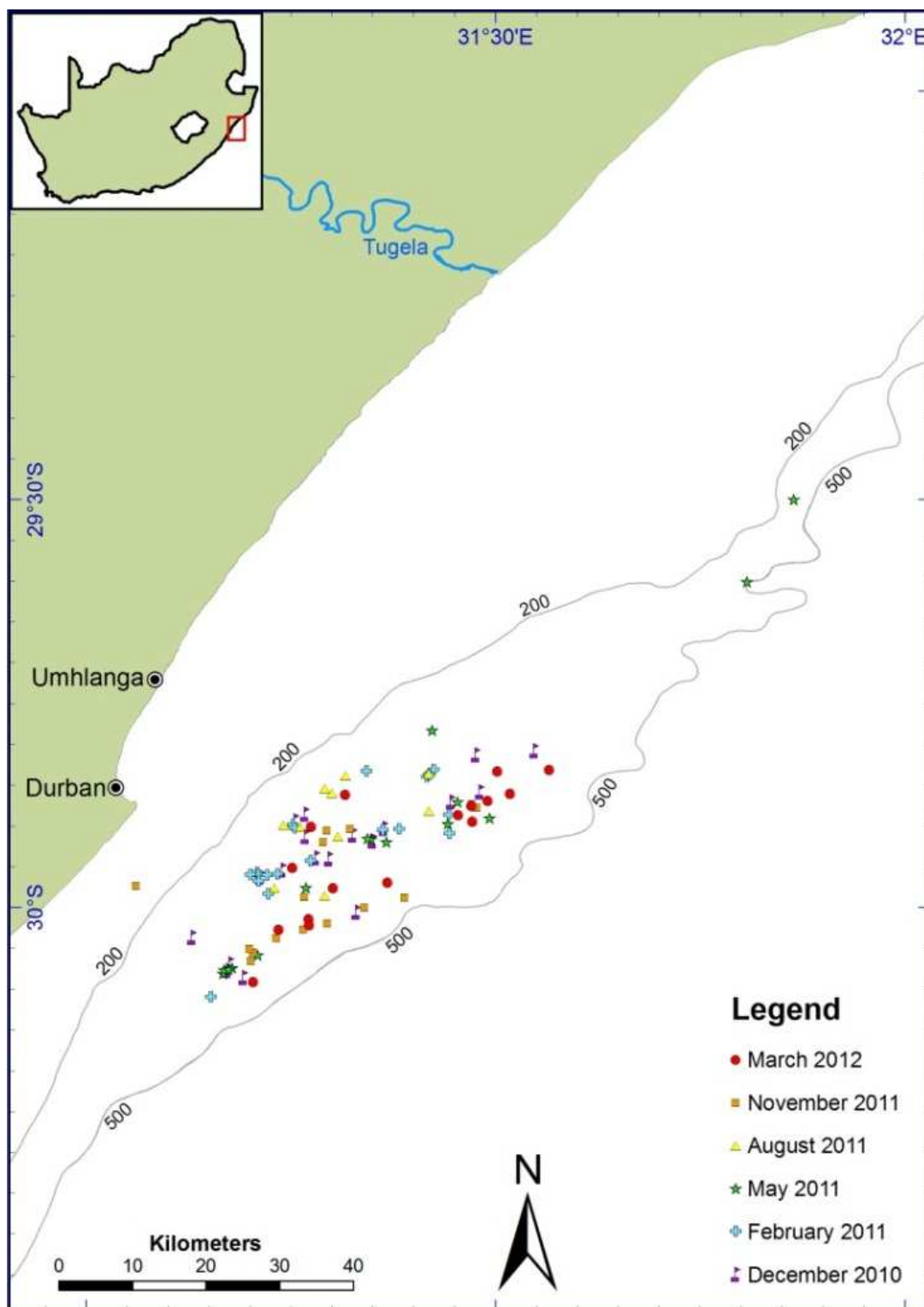


Figure 3.1. Start positions of trawls sampled during on-board sampling trips.

Nominal effort and landings

Nominal fishing effort (total time trawled) over the 23 year period peaked in 1989 at over 16 600 trawling hours (Figure 3.2a), but during 1994 it declined to only 27% of the peak effort, mainly because a major fishing company did not fish during that year. Fishing effort recovered between 1995 and 2003. In 2004 fishing effort declined to almost half that of the 2001 peak of 12 300 trawl hours, and remained at this low level up to 2008, whereafter it recovered. The landed mass of *M. mozambicus* increased between 1988 and 1993, remained relatively constant up to 2000, and then declined up to 2008. A recovery in landings was reported for 2009 and 2010. Landed catches of *H. triarthrus* peaked in 1990 at just over 240 t, whereafter they declined. A low of 52 t was reported in 1994 (when there were fewer vessels in the fishery), but overall a gradually increasing trend was observed between 1994 and 2009, when catches amounted to 190 t.

By month, fishing effort was highest in spring and summer (September to February) with a decrease in December and was lowest over the autumn and winter months, between April and August (Figure 3.2b). Monthly aggregated catches of *M. mozambicus* steadily increased from January to a peak of 140 t in October, thereafter declining towards November and December. The monthly trend in catches of *H. triarthrus* showed a peak in March (335 t) followed by a gradual decline to a low by December (196 t).

Little time was dedicated to trawling shallower than 200 m and deeper than 500 m, with the majority of the effort concentrated in the 200 to 499 m depth range, and over 80% of this effort occurred between 400 and 499 m (Figure 3.2c). The landed catches of both *M. mozambicus* and *H. triarthrus* increased with depth to peak between 400 and 499 m depth, whereafter they declined sharply beyond 500 m.

3.2 – *Metanephrops mozambicus*

CPUE

M. mozambicus was one of the targeted species and was present in 79.95% of all trawls made between 1988 and 2010. The total catch over the 23 year period was 1 231.45 t, at an average of 53.54 ± 18.97 t/year. The average nominal CPUE was 5.9 ± 8.89 kg/hour.

Year, month, depth and vessel were all significant explanatory variables in the first sub-model (presence/absence, binomial model) of the CPUE for *M. mozambicus* (Table 3.2). The probability of capturing *M. mozambicus* increased between 1989 and 2007, and thereafter it remained high up to 2010. By month, the highest probability of capturing *M. mozambicus* was July; the probability decreased up to December and remained low from January to April, but increased again in May and June. By depth, the probability of capturing *M. mozambicus* was lowest between 100 and 299 m, and peaked between 300 and 399 m. As depth increased beyond 400 m the probability began to decline, and this decrease correlated with a marked increase in trawling effort in the 400 to 500 m depth stratum.

There was no identifiable trend in the probability of capture by vessel, with some vessels having significantly greater probabilities than others; factors affecting this may include vessel power, gear configuration, the total time each vessel operated in the fishery and experience level of the skipper. The same explanatory variables were also significant in the second sub-model, the gamma model for positive catches (Table 3.2), and the product of these two sub-models were used to generate the standardised CPUE.

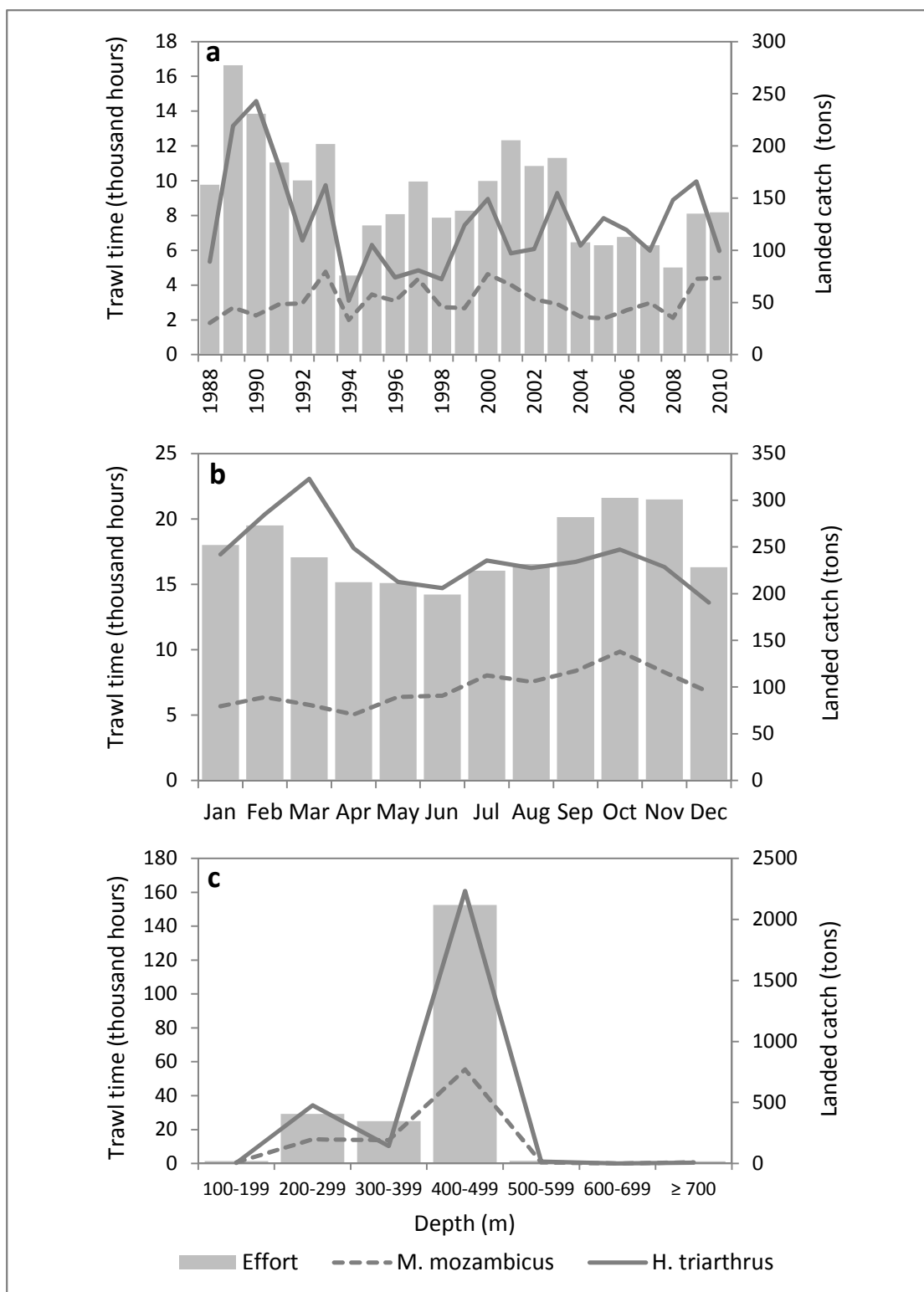


Figure 3.2. Nominal fishing effort (hours trawled) and landed catch of *H. triarthrus* and *M. mozambicus* for the fishing fleet by a) year, b) month and c) depth.

Table 3.2. Coefficients (\pm SE) of parameters tested in the final GLMs describing CPUE of *M. mozambicus* and *H. triarthrus*. $p < 0.0001$ indicated by ***, $p < 0.001$ **, $p < 0.01$ * and $p < 0.05$.

	<i>M. mozambicus</i> CPUE		<i>M. mozambicus</i> CPUE		<i>H. triarthrus</i> CPUE		<i>H. triarthrus</i> CPUE	
Error	Binomial		Gamma		Binomial		Gamma	
Link	Logit		Log		Logit		Log	
n	50815		50815		50815		50815	
AIC	43027		231985		29079		320583	
Explained deviance	27550		359472		41492		1108107	
Df	66		66		66		12365	
Chisq (P)	0		0		0		0	
Explanatory variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
1988	-4.388 ***	0.152	2.041 ***	0.087	-3.488 ***	0.191	2.094 ***	0.120
1989	-4.798 ***	0.147	1.664 ***	0.084	-3.818 ***	0.183	2.264 ***	0.119
1990	-4.659 ***	0.148	1.737 ***	0.085	-3.615 ***	0.198	2.434 ***	0.120
1991	-4.294 ***	0.149	1.890 ***	0.084	-4.791 ***	0.184	2.352 ***	0.120
1992	-3.835 ***	0.149	1.837 ***	0.083	-4.693 ***	0.177	2.093 ***	0.120
1993	-4.156 ***	0.145	2.291 ***	0.083	-4.982 ***	0.173	2.218 ***	0.119
1994	-4.087 ***	0.152	2.393 ***	0.087	-5.552 ***	0.182	2.101 ***	0.122
1995	-3.619 ***	0.155	2.232 ***	0.086	-4.798 ***	0.187	2.257 ***	0.121
1996	-3.757 ***	0.151	2.063 ***	0.084	-5.575 ***	0.179	1.869 ***	0.120
1997	-3.420 ***	0.151	2.132 ***	0.083	-4.827 ***	0.178	1.719 ***	0.120
1998	-3.616 ***	0.152	1.917 ***	0.084	-5.151 ***	0.178	1.836 ***	0.120
1999	-3.365 ***	0.155	1.884 ***	0.084	-4.887 ***	0.187	2.161 ***	0.120
2000	-2.719 ***	0.161	2.045 ***	0.083	-5.449 ***	0.178	2.237 ***	0.120
2001	-2.804 ***	0.151	1.826 ***	0.082	-5.337 ***	0.174	1.810 ***	0.119
2002	-2.873 ***	0.152	1.666 ***	0.082	-4.943 ***	0.175	1.968 ***	0.119
2003	-2.996 ***	0.152	1.577 ***	0.082	-4.859 ***	0.179	2.125 ***	0.119
2004	-2.690 ***	0.160	1.843 ***	0.083	-4.937 ***	0.183	2.301 ***	0.120
2005	-3.110 ***	0.161	1.854 ***	0.084	-4.797 ***	0.191	2.527 ***	0.120
2006	-3.189 ***	0.162	1.844 ***	0.085	-5.099 ***	0.186	2.369 ***	0.121
2007	-0.487 ***	0.145	2.032 ***	0.077	-1.320 ***	0.161	2.275 ***	0.115
2008	-0.936 ***	0.152	1.995 ***	0.081	-1.268 ***	0.171	2.795 ***	0.119
2009	-0.263 .	0.143	2.201 ***	0.078	-2.018 ***	0.159	2.539 ***	0.116
2010	-0.198	0.140	2.250 ***	0.078	-1.571 ***	0.157	2.034 ***	0.117
Jan	0	0	0	0	0	0	0	0
Feb	0.091 .	0.053	0.014	0.024	0.195 **	0.073	0.130 ***	0.023
Mar	0.073	0.056	0.043 .	0.025	0.166 *	0.077	0.294 ***	0.024
Apr	-0.097 .	0.057	0.073 **	0.026	0.264 ***	0.077	0.228 ***	0.025
May	0.345 ***	0.061	0.160 ***	0.025	-0.009	0.076	0.104 ***	0.025
Jun	0.655 ***	0.065	0.276 ***	0.025	0.729 ***	0.086	0.091 ***	0.025
Jul	0.867 ***	0.065	0.322 ***	0.025	0.752 ***	0.085	0.012	0.025
Aug	0.555 ***	0.061	0.285 ***	0.025	0.788 ***	0.083	0.033	0.024
Sep	0.604 ***	0.058	0.198 ***	0.024	0.378 ***	0.077	-0.140 ***	0.023
Oct	0.370 ***	0.056	0.294 ***	0.023	-0.132 .	0.071	-0.108 ***	0.023
Nov	0.618 ***	0.058	0.129 ***	0.023	-0.187 **	0.071	-0.179 ***	0.023
Dec	0.408 ***	0.062	0.144 ***	0.025	-0.282 ***	0.074	-0.058 *	0.025
100-199 m	0	0	0	0	0	0	0	0
200-299 m	2.477 ***	0.122	-0.177 *	0.074	3.184 ***	0.139	0.681 ***	0.113
300-399 m	4.979 ***	0.137	0.157 *	0.079	4.520 ***	0.155	0.462 ***	0.117
400-499 m	4.839 ***	0.133	-0.191 *	0.078	7.474 ***	0.156	0.705 ***	0.116
500-599 m	4.092 ***	0.179	0.193 .	0.100	6.981 ***	0.262	0.515 ***	0.128
600-699 m	4.107 ***	0.921	-0.865 .	0.489	6.627 ***	1.117	0.157	0.459
≥ 700 m	4.114 ***	0.205	-0.181 .	0.100	4.926 ***	0.208	0.545 ***	0.136
Vessel 6	0	0	0	0	0	0	0	0
1	0.840 ***	0.121	0.133 ***	0.025	1.279 ***	0.106	-0.031	0.026
4	0.083 .	0.047	0.157 ***	0.021	-0.036	0.061	-0.128 ***	0.021
8	-0.302	0.224	-0.627 ***	0.144	-0.577 .	0.323	-0.048	0.116
9	0.240 ***	0.044	-0.136 ***	0.016	0.095 .	0.051	-0.132 ***	0.016
15	0.299 ***	0.076	-0.204 ***	0.035	0.295 *	0.124	-0.191 ***	0.033
18	0.309	0.315	-0.344 *	0.140	0.994	1.092	0.482 ***	0.128
31	0.238	0.607	-0.986 **	0.324	-2.546 ***	0.745	-1.040 **	0.333
39	-0.005	0.202	-1.264 ***	0.126	11.153	78.859	-0.609 ***	0.099
40	-0.262	0.190	-0.700 ***	0.118	-1.161 ***	0.328	-0.747 ***	0.098
44	-0.594 ***	0.123	0.018	0.057	-0.253	0.168	-0.168 **	0.055
47	-0.981 ***	0.062	0.157 ***	0.026	-0.298 ***	0.075	-0.281 ***	0.026
52	-0.189 ***	0.051	-0.459 ***	0.025	0.346 ***	0.083	-0.163 ***	0.023
62	0.277 ***	0.077	-0.493 ***	0.038	-0.646 ***	0.117	-0.534 ***	0.035
64	-0.115	0.435	0.145	0.186	0.494	0.738	0.034	0.177
65	2.038 ***	0.287	-0.249 ***	0.053	0.381 .	0.206	-0.342 ***	0.055
67	-0.922 ***	0.081	0.162 ***	0.032	-0.522 ***	0.094	-0.216 ***	0.032
68	0.480 ***	0.086	0.371 ***	0.024	-0.070	0.078	-0.079 **	0.026
69	-2.011 ***	0.225	-0.510 **	0.191	2.563 *	1.021	0.152 .	0.089
71	2.109 ***	0.134	-0.268 ***	0.065	2.297 ***	0.212	-0.630 ***	0.058
72	-0.174 **	0.065	-0.231 ***	0.036	0.056	0.115	-0.417 ***	0.031
81	0.073	0.091	0.043	0.028	1.519 ***	0.132	0.040	0.028
83	2.885 **	1.010	-0.408 ***	0.120	0.543	0.469	-0.706 ***	0.128
88	0.542	0.479	-0.256 .	0.149	2.084 *	1.040	-0.821 ***	0.147
89	-0.581 **	0.211	-0.252 *	0.104	0.762 .	0.397	-0.204 *	0.095
96	10.879	76.487	0.902 ***	0.141	1.825 *	0.729	0.679 ***	0.148
293	1.239 ***	0.357	0.277 ***	0.078	0.222	0.386	0.136 .	0.080

The standardised CPUE trend correlated well with nominal trends by year, month and depth (Figure 3.3). By year, the standardised CPUE was initially low, but increased from 1989 to a peak of 9.46 kg/hr in 1994 (Figure 3.3a). This coincided with the decline in fishing effort over the same period (see above). The standardised CPUE generally followed a decreasing trend between 1995 and 2003; by then it was only half the 1994 value, conversely, fishing effort increased over the same period. The CPUE generally increased between 2004 and 2010, when it reached its highest level of the entire period of 10.36 kg/hr. The monthly trend showed a marked increase in standardised CPUE from April to July, when the highest level was reached at 7.21 kg/hr (Figure 3.3b). The monthly CPUE was lowest between January and April and increased between May and July, during which time the fishing effort decreased (Figure 3.2b), whereafter the CPUE then declined again until December. CPUE was lowest between 100 and 299 m, and highest between 300 and 399 m depth (9.09 kg/hr; Figure 3.3c). There was a marked decrease in catches within the depth range 400 – 499 m, which also experienced the highest amount of fishing effort.

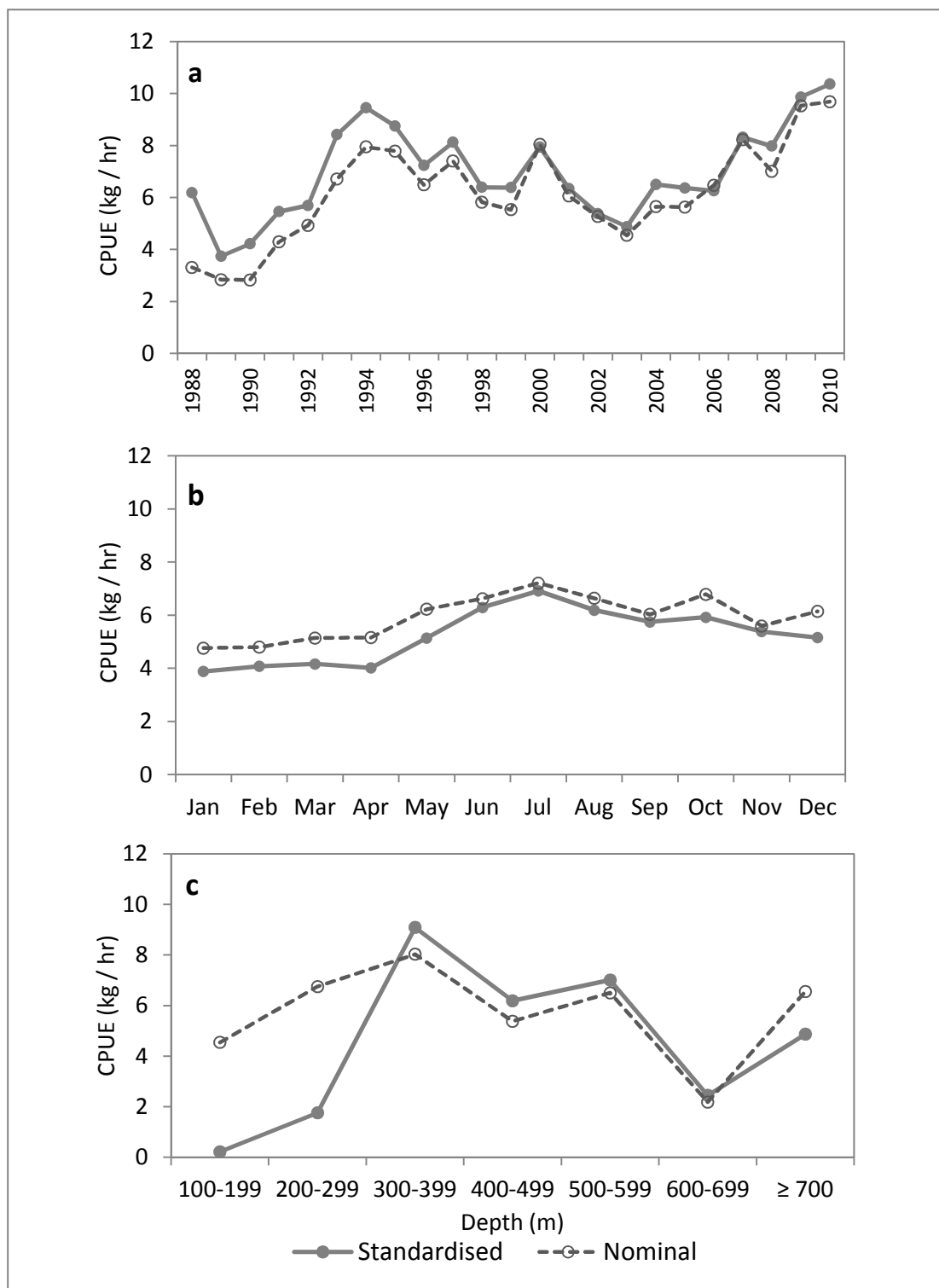


Figure 3.3. Nominal and standardised (based on final delta model) CPUE (kg/hr) of *M. mozambicus* by a) year, b) month and c) depth.

Size

Carapace lengths ranged from 17.5 to 72.6 mm and both sexes displayed a bimodal size distribution with modes at approximately 34 to 42 mm and at 50 to 56 mm (Figure 3.4). No significant difference was found between the average CL of males (45.26 ± 9.89 mm) and females (45.42 ± 9.33 mm) (t-test, $p = 0.731$).

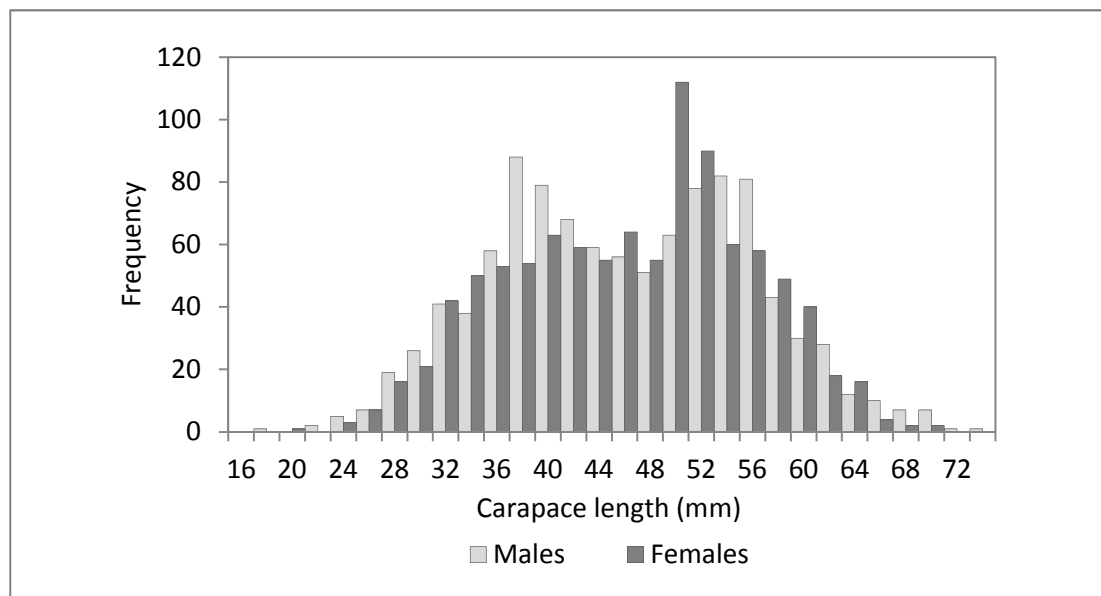


Figure 3.4. Length-frequency histogram of male ($n = 1041$) and female ($n = 922$) *M. mozambicus*.

In the size GLM the effects of month and depth were found to be significant (Table 3.3). There was an increase in CL from March to August and smaller individuals were apparent in samples taken in March and November more than in other months (Figure 3.5a), although it should be noted that the size difference between the smallest and largest months was only 4 mm. Carapace length decreased consistently as depth increased from 325 m to deeper than 425 m, and the difference in average CL between the two extremes was 9.26 mm (Figure 3.5b), although it should be noted that data were only available for a relatively narrow depth range.

Table 3.3. Coefficients (\pm SE) of parameters tested in the final GLMs describing the size, sex ratio, maturity and size at maturity of *M. mozambicus*. $p < 0.0001$ indicated by ***, $p < 0.001$ indicated by ** and $p < 0.05$ indicated by *.

	Size		Sex ratio		Maturity	
Error	Gaussian		Binomial		Binomial	
Link	Log		Logit		Logit	
n	2033		2033		992	
AIC	14848		2792.8		758.06	
Explained deviance	4009764		25.5		641.14	
Df	11		6		12	
Chisq (P)	0		0.0003		< 0.00001	
Explanatory variable	Estimate	SE	Estimate	SE	Estimate	SE
Feb	3.983 ***	0.032	0.469	0.121	-11.757 ***	1.187
Mar	3.981 ***	0.031	0.485	0.094	-11.437 ***	1.130
May	3.948 ***	0.033	0.461	0.109	-11.858 ***	1.113
Aug	3.895 ***	0.030	0.514	0.126	-13.591 ***	1.252
Nov	3.949 ***	0.025	0.623 ***	0.110	-11.810 ***	1.168
Dec	3.910 ***	0.030	0.518	0.105	-11.124 ***	1.170
325-349 m	0	0			0	0
375-399 m	-0.079 **	0.034			-1.581 **	0.806
400-424 m	-0.110 ***	0.030			-1.272 *	0.744
425-449 m	-0.149 ***	0.029			-1.147	0.721
450-474 m	-0.178 ***	0.030			-1.884 **	0.763
≥ 475 m	-0.209 ***	0.052			-1.891 *	1.028
Length					0.258 ***	0.018

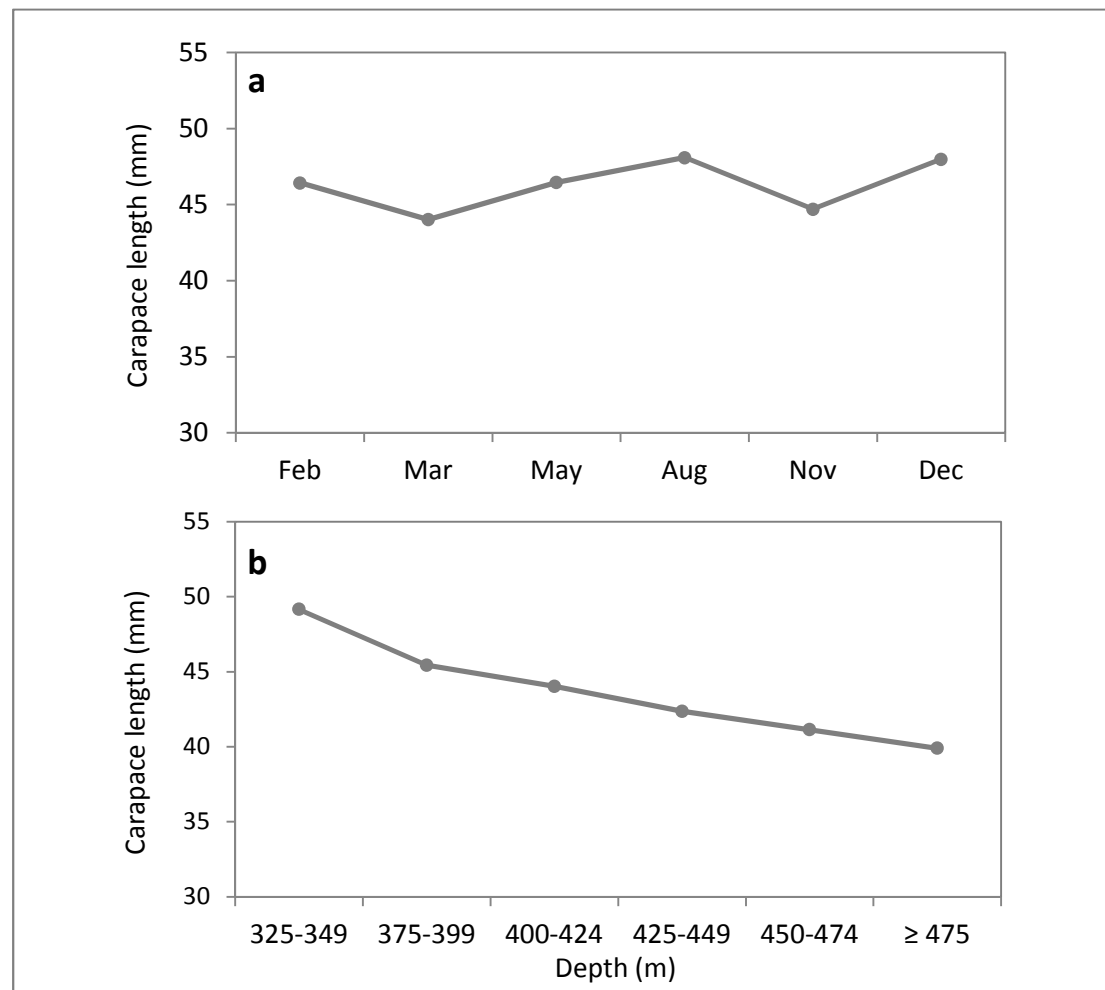


Figure 3.5. Standardised carapace lengths of *M. mozambicus* for a) month and b) depth.

Sex ratio

Over the six sampling trips, 1 041 males and 992 females were sampled with the sex ratio marginally skewed in favor of males (1 : 0.89). The only significant explanatory variable in the final GLM was month. The probability of capturing a male was close to parity with that of a female for every month except November, when it was significantly higher (0.62, Table 3.3). Although not significant, females were marginally more prevalent in catches in February, May and March, with the probability of capturing a male slightly higher in August and December (Figure 3.6).

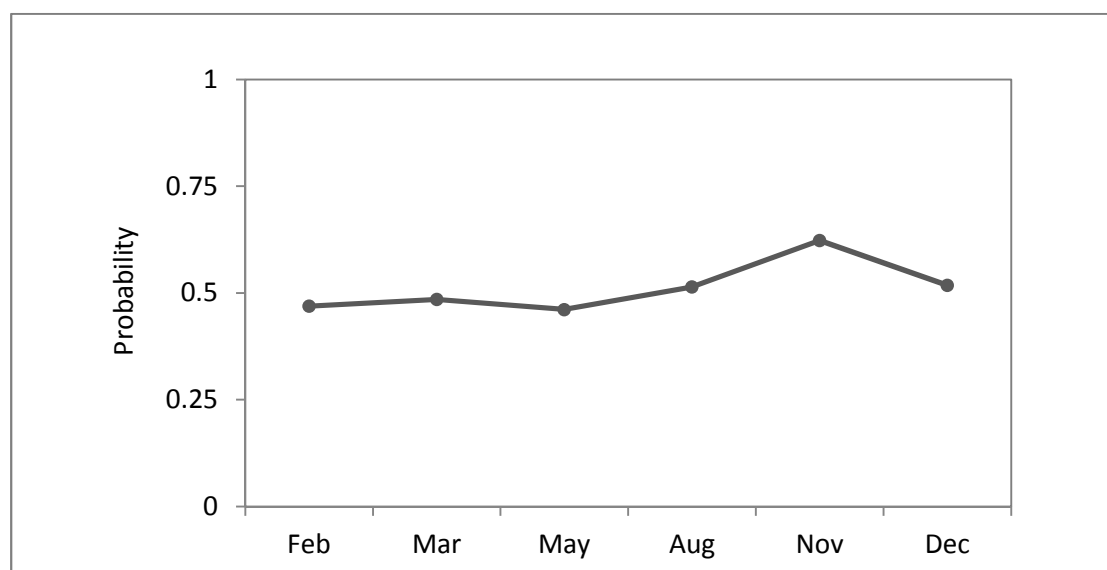


Figure 3.6. Probability of capturing a male *M. mozambicus* during the onboard sampling months.

Maturity – egg-bearing cycle and size at sexual maturity of females

Month, depth range and CL were significant explanatory variables in the final GLM for maturity of female *M. mozambicus* (Table 3.3). By month, August had the lowest probability of capturing a mature (egg-bearing) female (0.04) and the probability increased to a maximum in December (0.31), after which it remained high and began decreasing again in May (Figure 3.7a). As depth increased the probability of capturing a mature female decreased sharply from 0.54 in the 325 to 349 m depth range to 0.19 between 375 and 399 m, 0.27 between 425 and 449 m, and 0.15 in depths greater than 450 m (Figure 3.7b). The maturity ogive showed an increase in the probability of a female being mature as the CL increased (Figure 3.8). Of the 992 females sampled 33.17% were mature. The expected CL at which 50% of females were mature was 49.4 mm (L_{50}) and the standard range of

maturation, the CL between 25 and 75% maturity, was 45.1 to 53.6 mm. The smallest mature female recorded had a CL of 33.5 mm and the largest was 68.6 mm.

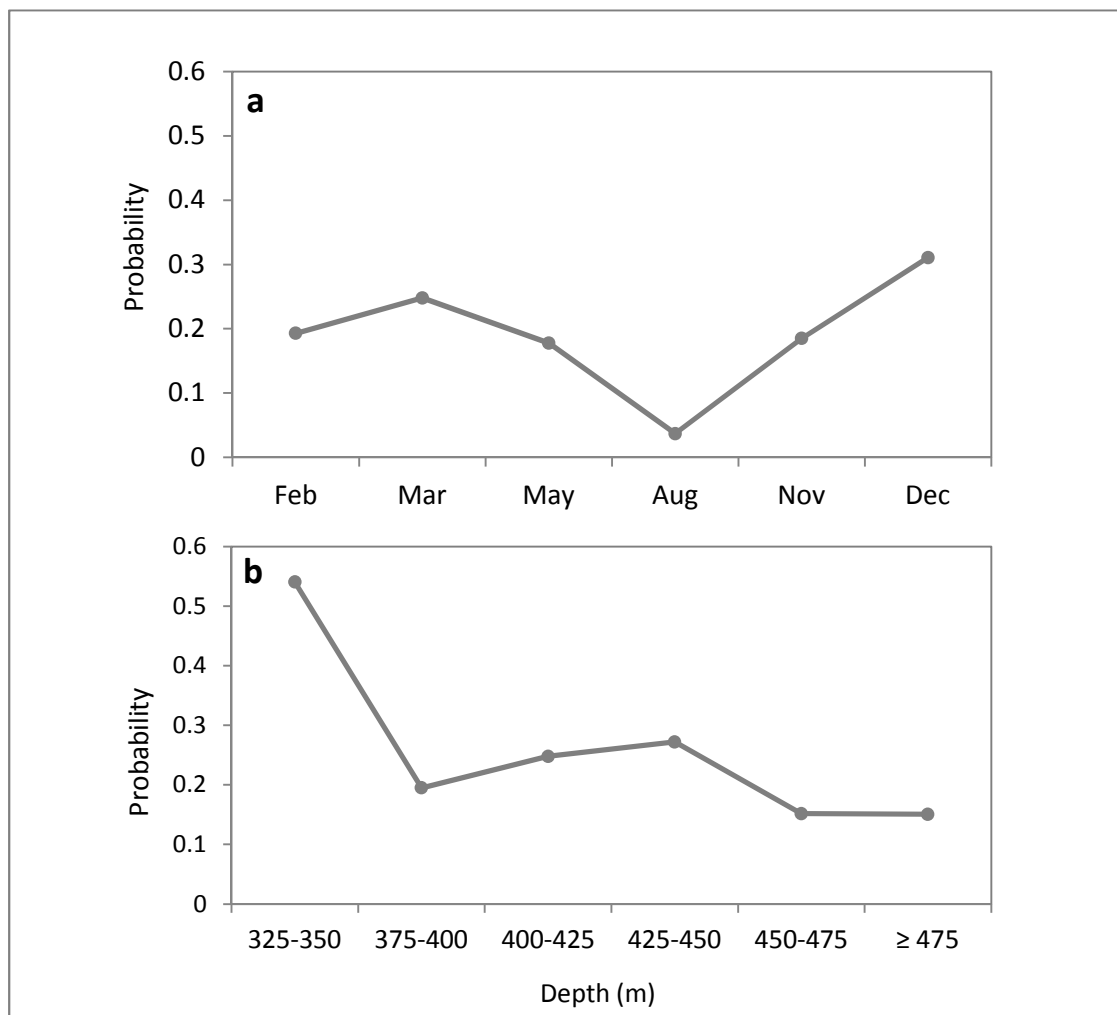


Figure 3.7. Probability of capturing a mature (egg-bearing) female *M. mozambicus* by a) month and b) depth.

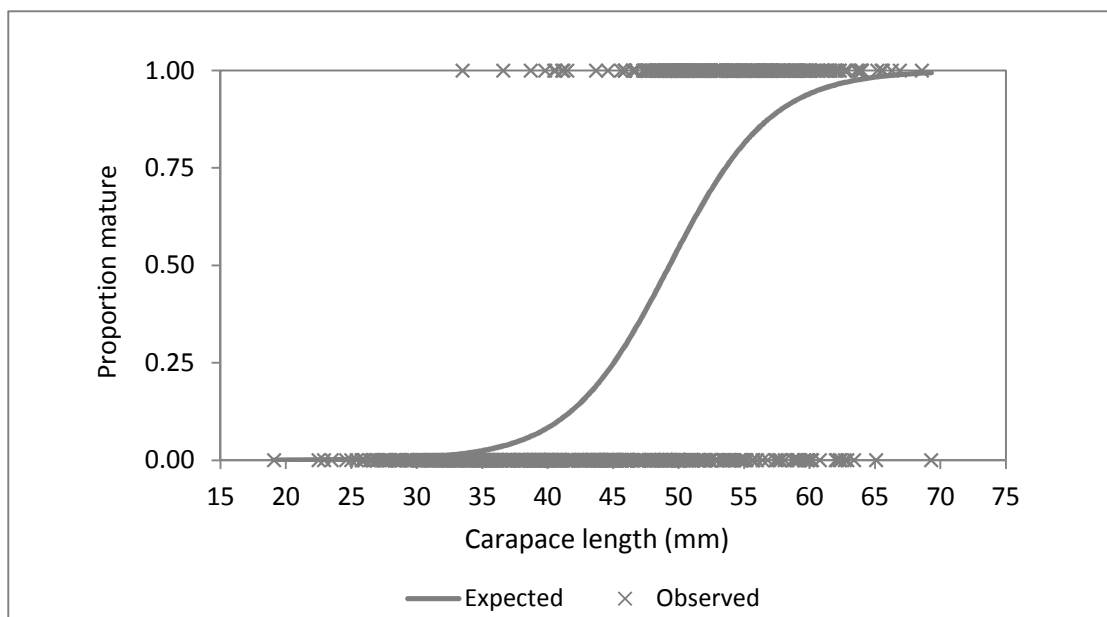


Figure 3.8. Size at maturity ogive for female *M. mozambicus*.

Growth

The length-frequency distributions of male and female *M. mozambicus* within individual months were statistically similar (Table 3.4). Based on this result, males and females were pooled to give a single length-frequency distribution per month; this aggregation resulted in more consistent trends (Figure 3.9). The identification of modes within the oldest and youngest size/age groups was complex, due to their low representation in the samples. However, modes (or distinct cohorts) were identified within each month, and the progression of cohorts was traced over time (Figure 3.9). A single dominant peak was identified in each month, except in March, when two prominent peaks were identified. Subsequent examination showed that these two peaks were attributable to the male and female length-frequency data, and consequently a single cohort was designated based on the mean CLs of the two sexes.

Table 3.4. Pearson's χ^2 tests of independence of monthly length-frequency distributions of male and female *M. mozambicus*.

Month	χ^2	df	p-value
Dec	11.6	6	0.072
Feb	4.85	5	0.434
May	11	6	0.090
Aug	2.28	5	0.809
Nov	2.65	4	0.618
Mar	5.68	4	0.224

A total of five cohorts were identified from the data with a minimum mean modal size of 22 mm CL and reaching a maximum of 64 mm CL before dissipating. Only two cohorts were used to fit the von Bertalanffy growth formula (VBGF) as they best represented the data and could easily be distinguished from the other cohorts (Figure 3.10).

When fitting the von Bertalanffy growth functions the asymptotic length (L_{∞}) was set to 76.4 mm, equivalent to + 5% of the maximum CL recorded in samples; this was done for both methods used. The Fabens method provided an estimate of 0.45 year^{-1} for K, and the VBGF method, in which the birth month was assumed to be May, based on biological characteristics, provided an estimate of 0.48 year^{-1} (Figure 3.11). Although the two methods provided similar growth rates, they have different assumptions and are therefore not directly comparable.

Length weight relationships

The log-transformed linear regression of CL and whole weight showed that males and females were not significantly different ($p = 0.078$). This can be clearly seen in Figure 3.12, with males and females having similar length-weight curves, and corresponds well with the growth data, described above. The implication is that a single conversion factor can be used to convert length measurements of samples measured on field trips to individual weights, irrespective of sex.

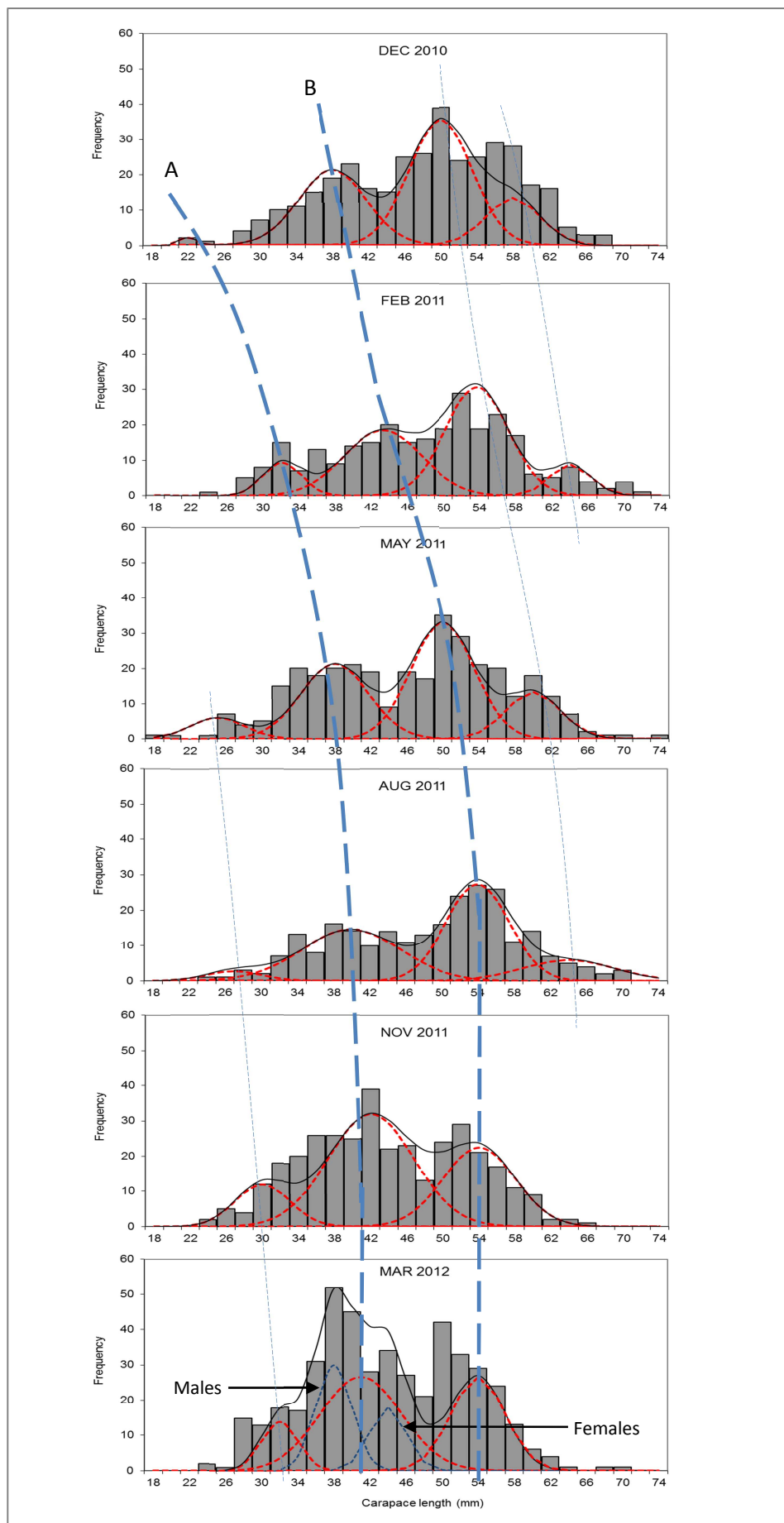


Figure 3.9. Monthly modal peaks of *M. mozambicus*. March had two peaks caused by a variation in the size-frequencies of males and females, separately, therefore the mean of the two peaks was determined. A and B indicate cohorts used in fitting the VBGF. The mean modal sizes (mm CL, continuous and dashed red and blue lines) used to fit the VBGF and Fabens method are also shown in the figure.

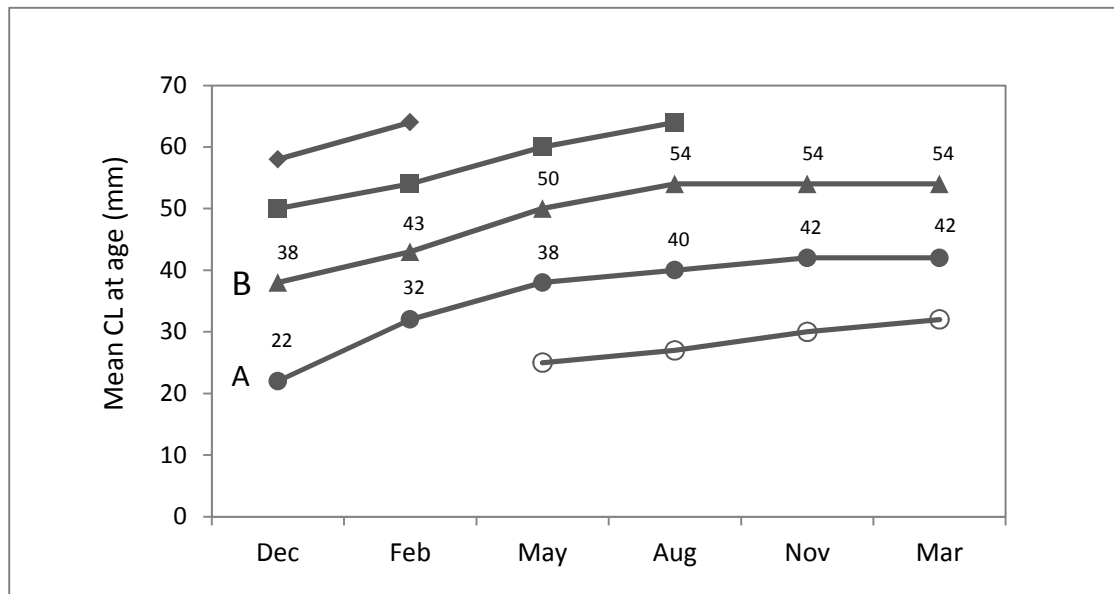


Figure 3.10. Mean CL for combined sexes of *M. mozambicus* cohorts over the sampling period. Although 5 cohorts are represented, only A and B were used in the analysis and fitting of the VBGF, their mean values are shown.

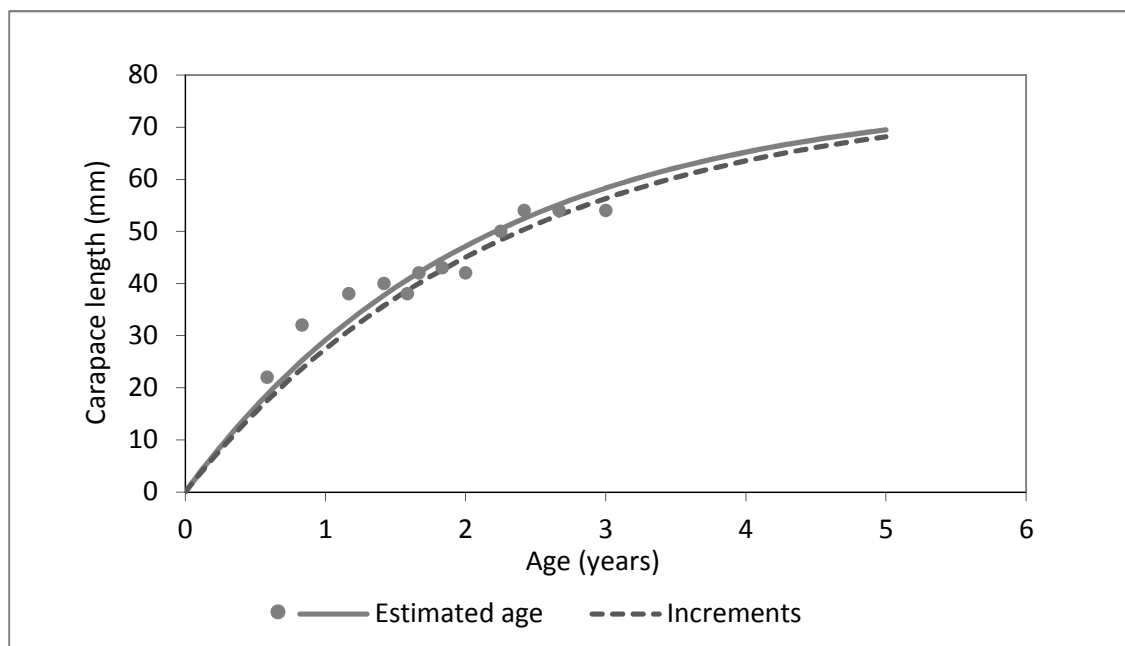


Figure 3.11. Von Bertalanffy growth curves for *M. mozambicus* sexes combined; fitted using increments and estimated age.

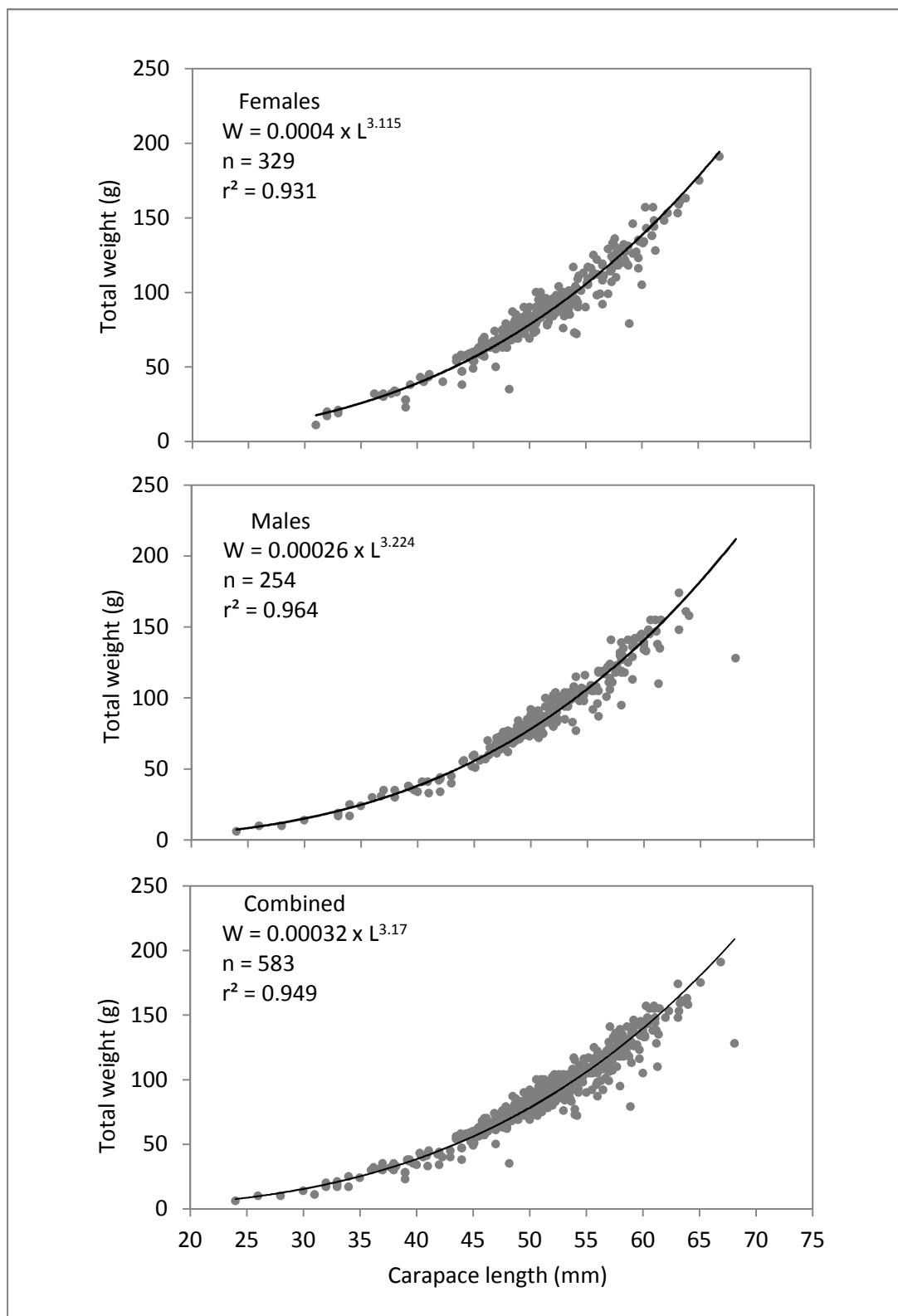


Figure 3.12. Relationship between carapace length and whole weight of *M. mozambicus* females, males and sexes combined, showing the exponential equation.

3.3 – *Haliporoides triarthrus*

CPUE

Haliporoides triarthrus was a highly targeted species present in 85.05% of trawls made between 1988 and 2010. The total catch over the 23 year period was 2 946.22 t at an average of 128.1 ± 47.53 t/year, and an average nominal CPUE of 14.15 ± 19.0 kg/hr.

The GLM used to investigate the CPUE of *H. triarthrus* is summarised in Table 3.2. The significant explanatory variables were year, month, depth and vessel. The first sub-model (presence/absence, binomial model) showed a relatively constant probability of capture between 1988 and 2006, fluctuating around a mean of -4.82 (see Table 3.2). However, the probability of capture increased substantially in 2007, and remained at this higher level for the remainder of the time series. By month, the probability of capturing *H. triarthrus* was highest between June and August and lower during the rest of the year, with a lowest point in May. By depth, the probability increased between 100 and 399 m, reaching a maximum in the 400 to 499 m depth range. As depth increased further the probability started to decline. No probability trend could be identified by vessel, although the vessel coefficient can conceptually be affected by several factors, such as vessel engine power, gear configuration, the time each vessel spent trawling and experience level of the skipper. The same explanatory variables were significant in the gamma model of positive catches (see Table 3.2).

The product of the binomial and gamma model outputs provided the standardised CPUE for *H. triarthrus*. The standardised CPUE correlated well with the trends in nominal CPUE for all three explanatory variables (Figure 3.13). The standardised CPUE was initially low in 1988, but increased to a peak of 23.64 kg/hr in 1990 (Figure 3.13a). Over the same period there was a rise in effort (see Figure 3.2), which peaked in 1989 and subsequently followed a general decreasing trend until 1997. The CPUE also declined during this period and was recorded at its lowest level in 1997 (11.3 kg/hr). The standardised CPUE then increased slightly during 1999 and 2000, but between 2001 and 2008 it increased substantially, and was recorded at over three times the value of 1997, at 34.21 kg/hr. However, it declined to only half of this by 2010, at 15.97 kg/hr. Over the same period the effort fluctuated, but generally decreased between 2001 and 2008, before doubling in 2009 and 2010 (see Figure 3.2). There was a well-defined monthly trend in the standardised CPUE, increasing from

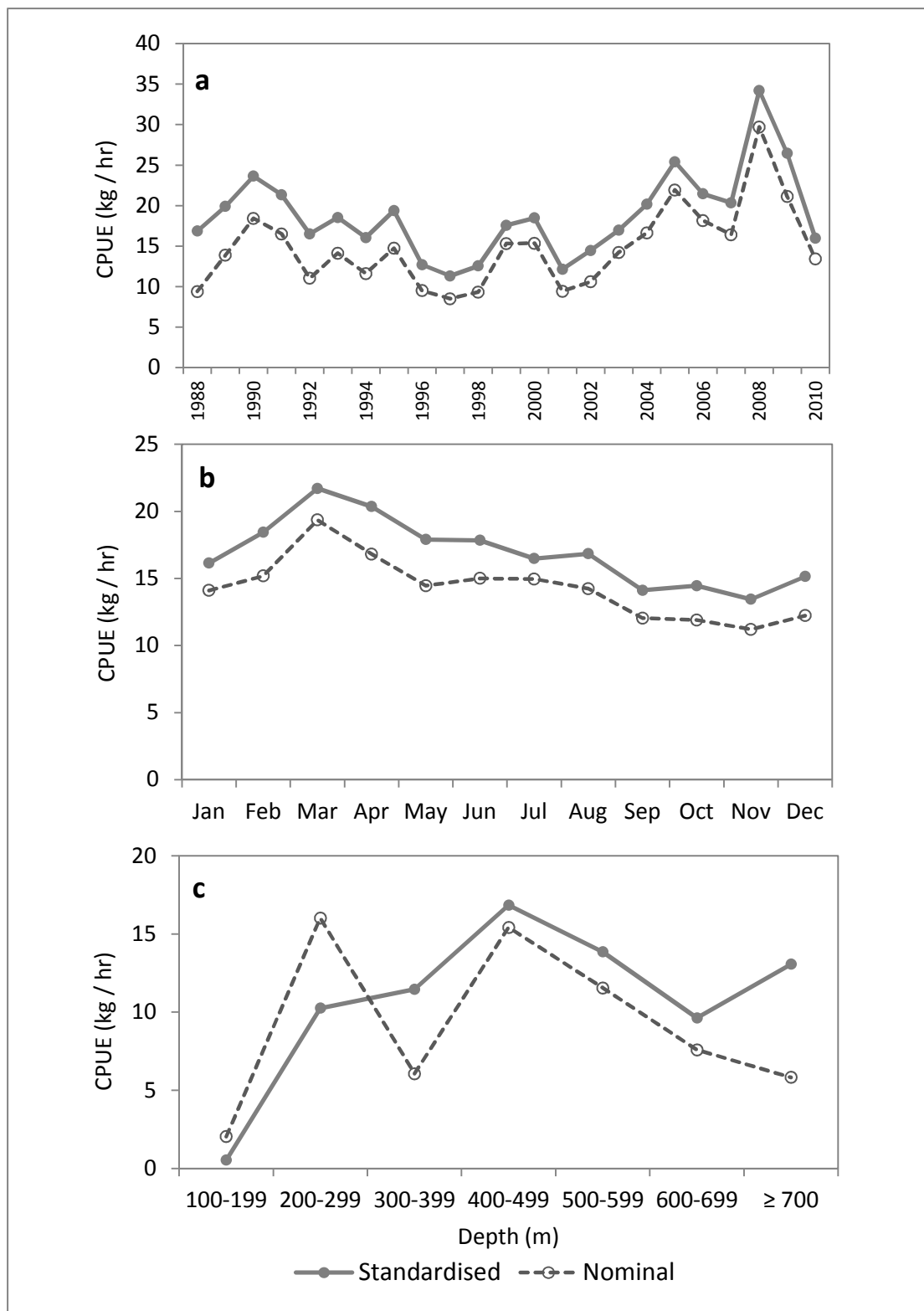


Figure 3.13. Nominal and standardised (based on final delta model) CPUE (kg/hr) of *H. triarthrus* by a) year, b) month and c) depth.

January to a peak in March, and followed by a gradual decline up to November (Figure 3.13b). The standardised CPUE was low (0.53 kg/hr) in the 100 to 199 m depth range and increased to around 10 kg/hr between 200 and 399 m (Figure 3.13c). The highest CPUE was between 400 and 499 m, at 16.85 kg/hr. As depth increased below 500 m the CPUE declined, although below 700 m the standardised CPUE increased again; this trend was not observed in the nominal CPUE, and was based on few data. The fishing effort followed a similar trend, increasing to a peak between 400 and 499 m and then declining to almost zero below 600 m (see Figure 3.2).

Size

The CL of sampled *H. triarthrus* ranged between 13 and 59.8 mm and on average males (26.77 ± 0.07 mm) were significantly smaller than females (29.04 ± 0.1 mm; t-test, $p < 0.0001$) (Figure 3.14). The GLM confirmed that sex was significant in explaining variations in CL, and also predicted that females would be larger than males (Figure 3.15a). Month and depth were also significant explanatory variables of CL (Table 3.5). The standardised CL by month showed that larger individuals were caught in March and November and smaller ones in December and February, although the size difference between the two extremes was only 6 mm (Figure 3.15b). By depth, the CL increased slightly from 400 to 474 m, after which it declined again (Figure 3.15c), but again the data only covered a narrow depth range.

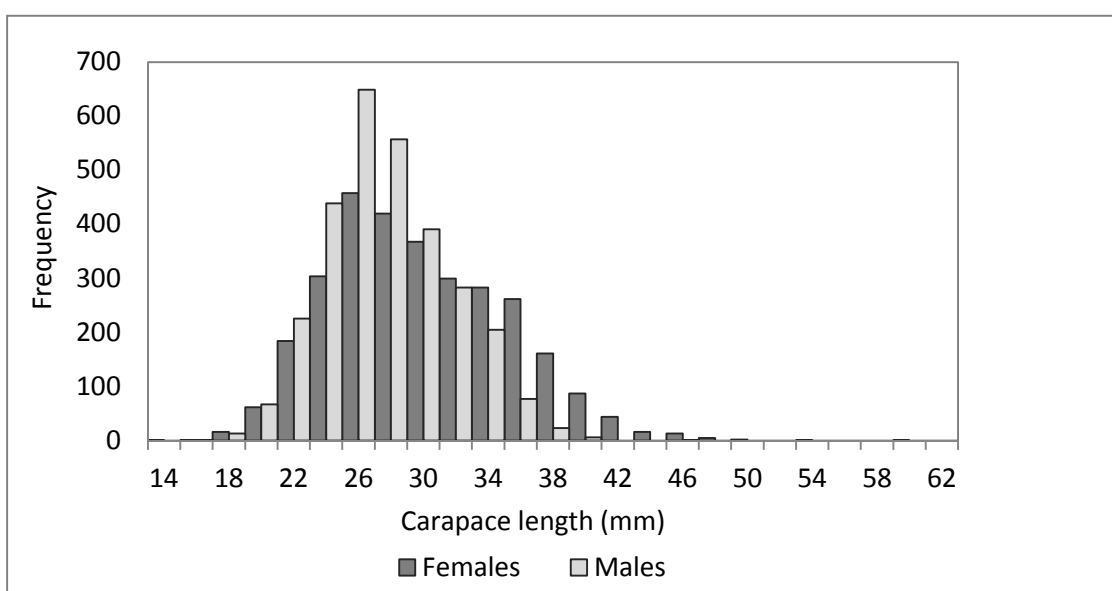


Figure 3.14. Length-frequency histogram of male ($n = 2938$) and female ($n = 2989$) *H. triarthrus*.

Table 3.5. Coefficients (\pm SE) of parameters tested in the final GLMs describing the size and sex ratio of *H. triarthrus*. $p < 0.0001$ indicated by ***.

MODEL	Size		Sex Ratio	
Error	Gaussian		Binomial	
Link	Log		Logit	
n	5927		5927	
AIC	33770		7863.7	
Residual deviance	4332640		366.9	
Df	10		7	
Chisq (P)	0		< 0.00001	
Explanatory variable	Estimate	SE	Estimate	SE
Feb	3.258 ***	0.005	3.140 ***	0.206
Mar	3.415 ***	0.006	2.678 ***	0.190
May	3.306 ***	0.005	2.888 ***	0.177
Aug	3.392 ***	0.006	3.109 ***	0.214
Nov	3.466 ***	0.007	2.913 ***	0.198
Dec	3.300 ***	0.006	2.722 ***	0.229
400-424 m	0	0		
425-449 m	0.028 ***	0.005		
450-474 m	0.064 ***	0.006		
≥ 475 m	0.017	0.011		
Female	0	0		
Male	-0.065 ***	0.004		
Length			-0.105 ***	0.007

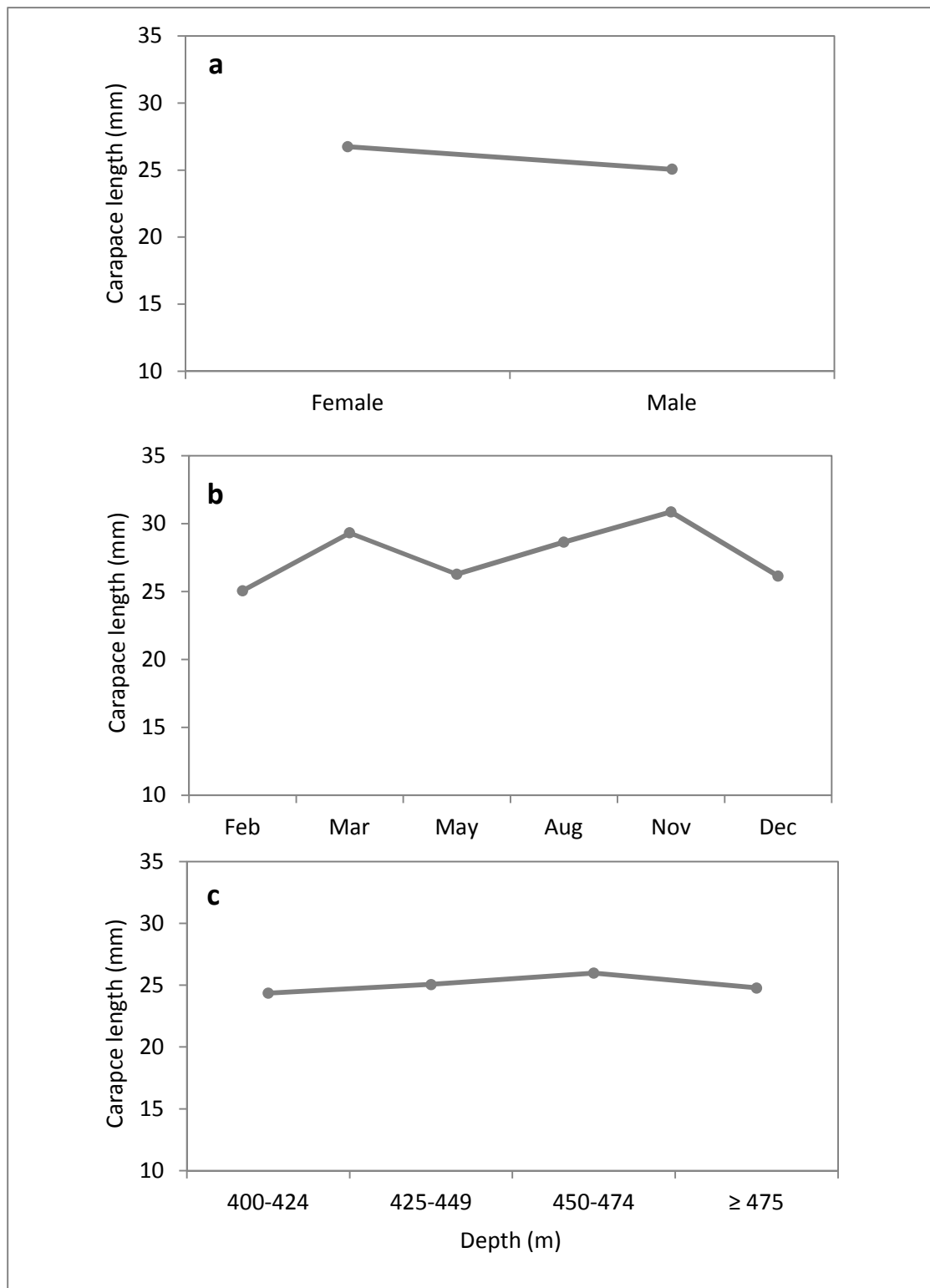


Figure 3.15. Standardised carapace lengths of *H. triarthrus* by a) sex, b) month and c) depth.

Sex ratio

Over the sampling period 2 938 males and 2 989 females were sampled with the overall sex ratio skewed very slightly in favor of females (1 : 1.002). The GLM found month and length to be significant explanatory variables (Table 3.5). By month the probability of capturing a male was greater in March and August, whereas females were more common in November and December (Figure 3.16a). The probability of capturing a male was high in the smaller size classes, but decreased as CL increased (Figure 3.16b). The CL at which the probability of capturing either a male or female was 0.5 was 27.4 mm and this result corresponds with those of the size-based GLM in which the females were found to be larger than the males.

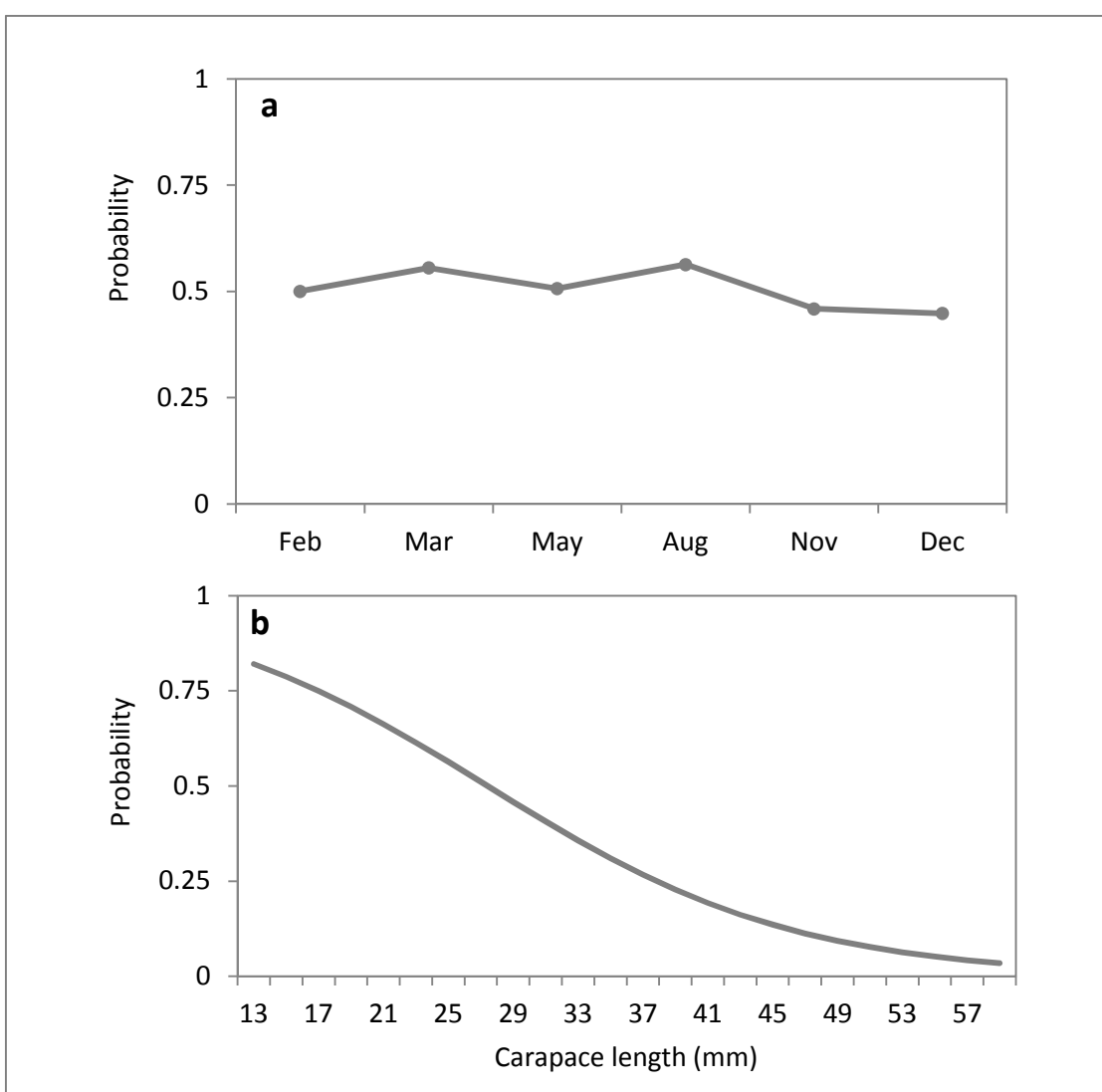


Figure 3.16. Probability of capturing a male *H. triarthrus* by a) month and b) carapace length.

Maturity

No reproductively active females were recorded throughout the sampling period.

Growth

The length-frequency distributions of *H. triarthrus* males and females within sampled months differed significantly (Table 3.6), and male and female growth were therefore analysed separately. The modes (cohorts) were easily identified for both sexes in all months sampled (Figure 3.17 and 3.18). The progression of the female cohorts was traced over time and the first cohort appeared in November/December and dissipated after approximately two years at a mean modal size of 39 mm CL (Figure 3.17). Male *H. triarthrus* cohorts appeared in monthly samples at similar times to females and could be easily traced over time (Figure 3.18). The mean cohort size of males, however, was smaller than that of the females, and the cohorts dissipated at a CL of 34 mm (Figure 3.19).

Table 3.6. Pearson's χ^2 tests of independence of monthly length-frequency distributions of male and female *H. triarthrus*.

Month	χ^2	df	p-value
Dec	74.2	3	< 0.0001
Feb	34.78	3	< 0.0001
May	43.4	3	< 0.0001
Aug	59.57	3	< 0.0001
Nov	6.86	2	0.032
Mar	62.96	3	< 0.0001

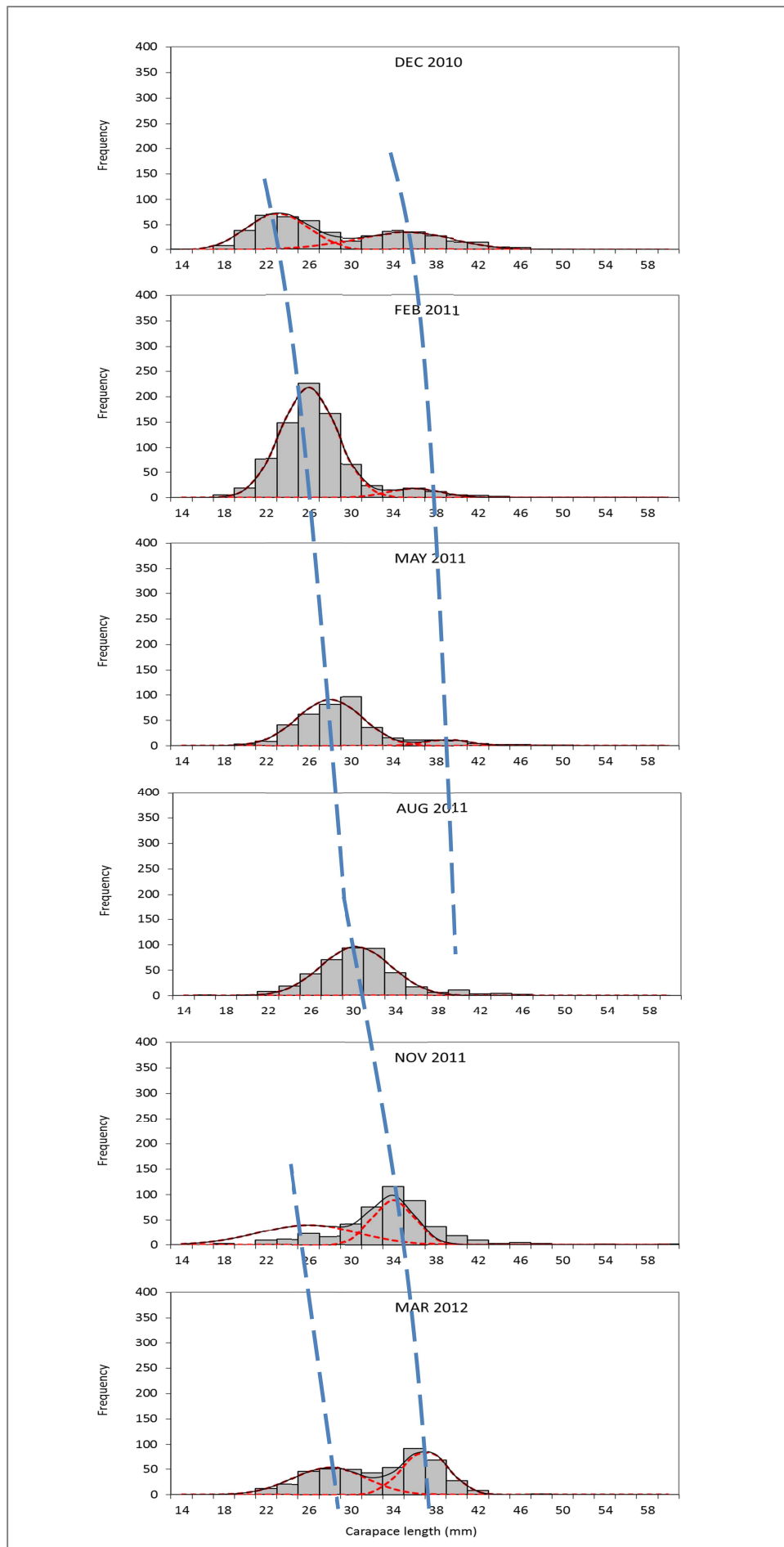


Figure 3.17. Monthly modal peaks of female *H. triarthrus*. The mean modal sizes (mm CL, continuous and dashed red and blue lines) used to fit the VBGF and Fabens method are also shown in the figure.

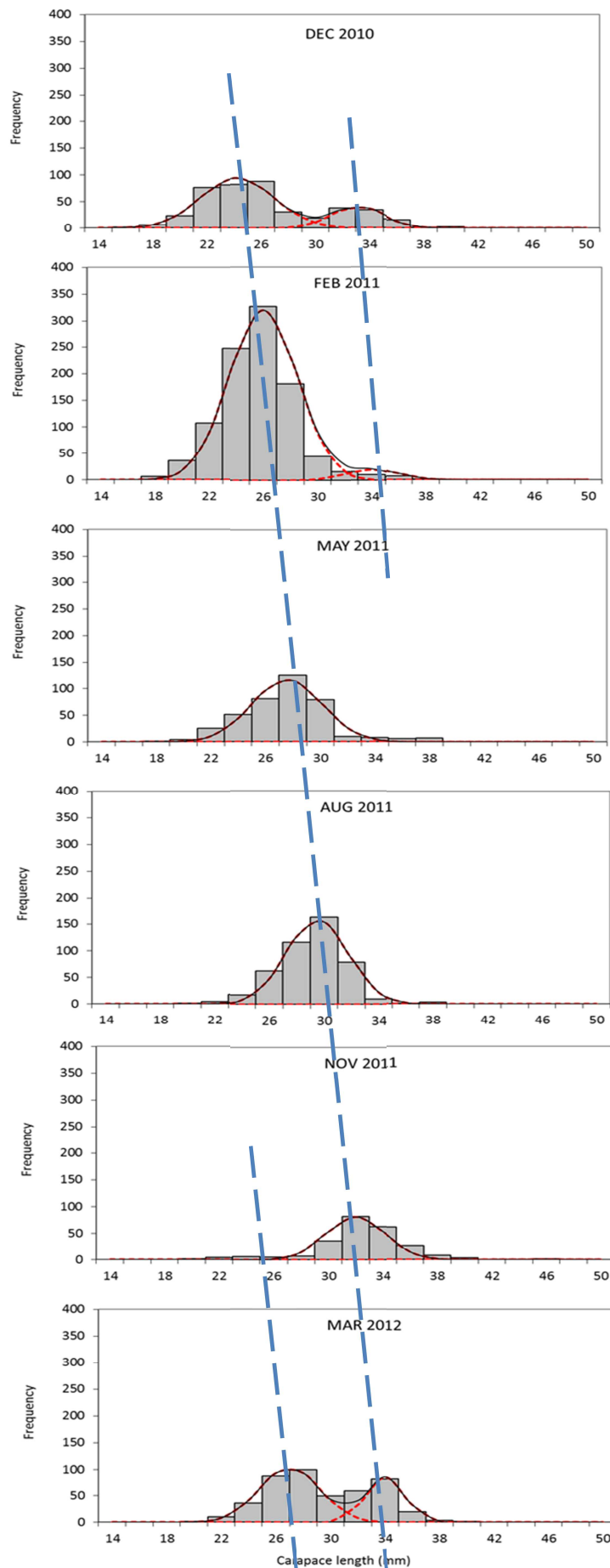


Figure 3.18. Monthly modal peaks of male *H. triarthrus*. The mean modal sizes (mm CL, continuous and dashed red and blue lines) used to fit the VBGF and Fabens method are also shown in the figure.

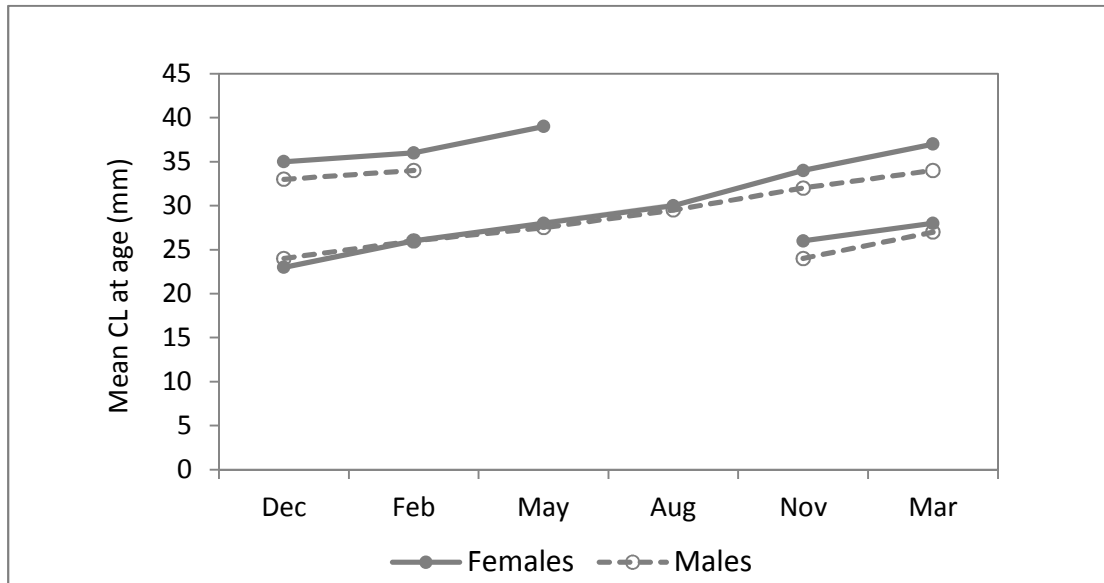


Figure 3.19. Mean CL of male and female *H. triarthrus* cohorts the over sampling period.

Due to the differences in length-frequency distributions, separate VBGF were also determined for females and males. When fitting the VBGF to data for females the asymptotic length was set to 62.9 mm CL, based on the maximum CL recorded in samples + 5%; this L_{∞} estimate was used in both methods. Fabens method for females provided an estimate of 0.3 year⁻¹ for K (Figure 3.20). When using an estimated age to fit the VBGF, and assuming March to be the birth month, the K value for females was calculated as 0.47 year⁻¹ (Figure 3.20).

The L_{∞} for males was estimated to be 46.6 mm CL (+ 5% of the maximum CL recorded in samples) and the Fabens method estimated K to be 0.5 year⁻¹ (Figure 3.21). The VBGF using March as the birth month estimated K to be 0.76 year⁻¹ (Figure 3.21).

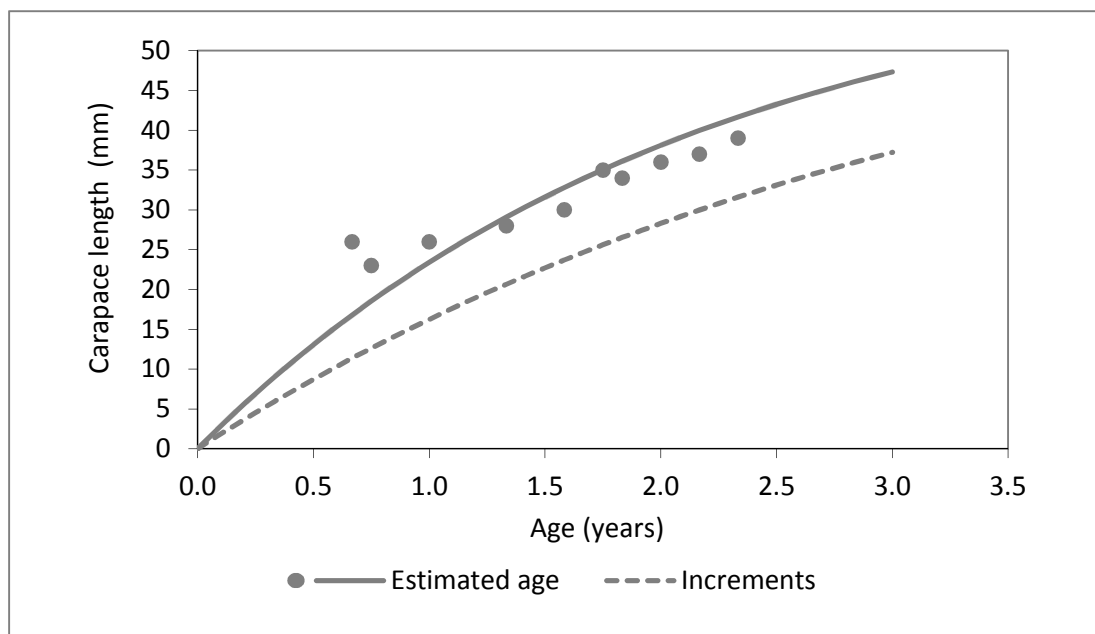


Figure 3.20. Von Bertalanffy growth curves for female *H. triarthrus*; fitted using increments and estimated age.

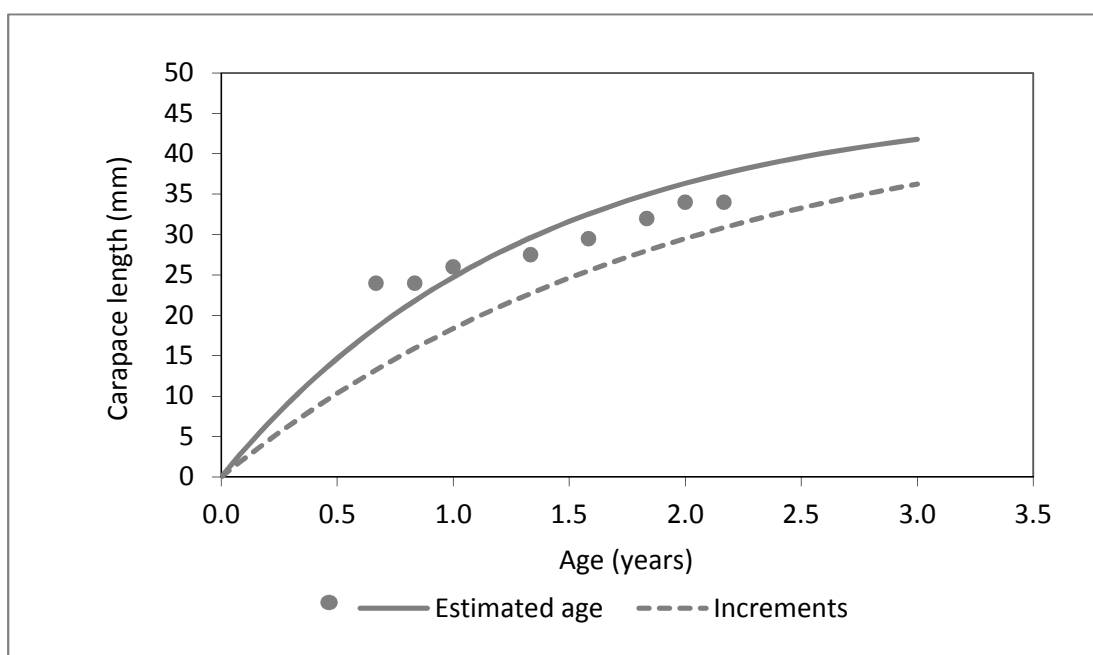


Figure 3.21. Von Bertalanffy growth curves for male *H. triarthrus*; fitted using increments and estimated age.

Length weight relationships

Multiple regression analysis of the log transformed data of CL and whole weight for males and females showed significant differences between the two sexes ($p = 0.0004$). Females

tend to become larger and attain a greater weight than the males (Figure 3.22) and this was validated in the growth curves and size data. The inference from this result is that sex-specific models might be useful for stock assessments of *H. triarthrus*.

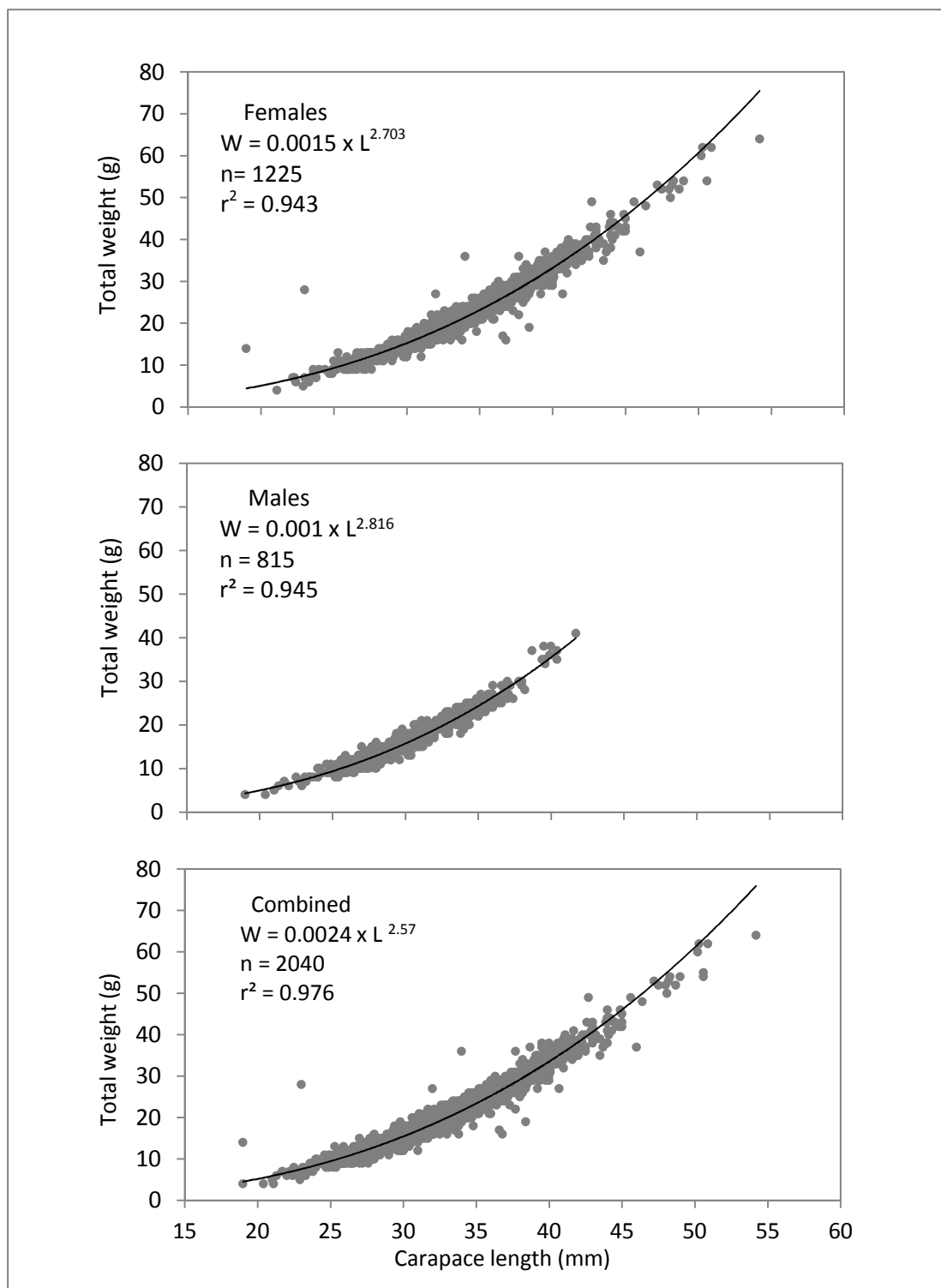


Figure 3.22. Relationship between carapace length and whole weight for *H. triarthrus* females, males and sexes combined, including the exponential equations.

Chapter 4 – DISCUSSION

4.1 – General

The deep-water crustacean trawl fishery off eastern South Africa is a longstanding commercial fishery that has been active since the 1970's. Logbook data of fishing effort and catches by species (or species category) have been collected by the Department of Agriculture, Forestry and Fisheries (DAFF) since 1988; these data now comprise a valuable 25-year time-series of information that can be used to establish long-term trends in fisheries abundance and species composition. To date, the database has been under-utilized.

The deep-water fishery has remained relatively stable over time; the trawlable area is limited by a narrowing of the continental shelf in the north and south and as such the fishing grounds are relatively small (approximately 1 750 km²), and the target species (mainly *M. mozambicus* and *H. triarthrus*) have remained the same over the past two decades. Fishing effort has evolved from many vessels (up to 12 in 1988) operating on a part-time basis during the 1980's and 1990's to a few (only 3 in 2009) that appear to have specialised in a niche fishery (the vessels do not participate in other fisheries). The same vessels have been in operation over the past decade, with only minor changes in technology, gear configuration and occasionally the replacement of a skipper. The relatively small fishing grounds, coupled with few operational changes in the fishery make the time-series data even more valuable, because trends in species distribution, abundance and composition can easily be separated from fisheries-induced effects on catch rates.

Initial observations from the time-series were that more *H. triarthrus* was caught than *M. mozambicus*, with deep-water lobster and red crab only occasionally targeted and caught in far smaller quantities. Crustacean target species made up approximately 18% (by weight) of the total catch, with the remainder comprising a variety of teleosts, elasmobranchs, cephalopods and other invertebrates – these were described by Fennessy & Groeneveld (1997) and Persad (2005). The non-crustacean by-catch species were either retained (approximately 12% by weight), or discarded (70%) if considered of low commercial value.

In multi-species trawl fisheries, skippers are often able to target the most valuable aggregations of species, based on knowledge of species distributions (Watson et al., 1993; Groeneveld & Melville-Smith, 1995). Targeting practices may affect abundance estimates of a specific species if it is only sparsely distributed in an area (specific depth or bottom type) that is preferentially trawled to catch another target species; in that case its abundance might be underestimated (Baelde, 1991). In the present study, however, both *H. triarthrus* and *M. mozambicus* were primary target species over a long time period and in a relatively restricted trawling area, and it was therefore assumed that bias emanating from targeting practices would be mitigated by the large amount of trawl data covering all parts of the fishing grounds, and that it could be adequately addressed within the framework of the GLMs.

The management strategy for the deep-water crustacean trawl fishery off eastern South Africa has not changed much over the past two decades, and is not based on output controls, such as a total allowable catch (TAC), or the biological characteristics of *H. triarthrus* or *M. mozambicus* (the most frequently targeted species), nor on restrictions on the capture of any of the by-catch species (DAFF, 2012). The total allowable effort (TAE) of the deep-water trawl fishery is controlled by the number of fishing permits allocated; however, there are more permits (for 7 vessels) than the number of active vessels (generally 3 or 4), and the TAE is therefore not effective. The mesh size on the trawl nets may not be smaller than 50 mm, measured from centre knot to centre knot, stretched (DAFF, 2012). Despite steps by DAFF to introduce an EAF (Ecosystems Approach to Fisheries) approach in South African fisheries (see Cochrane et al., 2004), the management *status quo* has remained in the deep-water crustacean trawl fishery, mainly because basic fisheries and biological analyses to assess sustainability and ecosystems effects have not been done.

Catch per unit effort (CPUE) data as an index of abundance have been widely used in fisheries, under the assumption that they are directly proportional to each other (Richards & Schnute, 1986; Hilborn & Walters, 1992). However, the relationship can be influenced by several factors, such as the behaviour of the target species, i.e. schooling species or not (Hilborn & Walters, 1992), spatio-temporal distribution of fishing fleets (Sbrana et al., 2003), fishing power and gear interactions (Hilborn & Walters, 1992), and effort (gear) saturation effects (Groeneveld et al., 2003). Where possible, the likely bias of the CPUE/abundance relationship should be quantified and used to adjust or standardize indices of relative

abundance (Maunder & Punt, 2004). In the present study generalised linear models (GLM) were used to quantify the effects of year, month, depth, and fishing vessel on long-term CPUE trends (Maunder & Punt, 2004), and to subsequently standardize abundance indices.

Gear selectivity can bias the collection of biological data (such as size composition or sex ratio information) if the entire population is not adequately sampled. Gear selectivity can be partially mitigated by collecting as many samples as possible from a wide spatial and temporal scale, and by using appropriate models to infer population structure (Maunder & Punt, 2004). Nevertheless, if some life stages occur outside the sampled range, or are not at all selected by the gear, placing any amount of certainty on their distribution and characteristics remains speculative.

4.2 – *Metanephrops mozambicus*

CPUE

Metanephrops mozambicus was not present in every trawl; this is not uncommon in multi-species fisheries where fishers can alternate between target species (in this case mainly *M. mozambicus* and *H. triarthrus*) with different spatial distributions (Pennington, 1996; Punt et al., 2000). Factors assumed to have affected the selection of *M. mozambicus* by trawl gear were relative abundance patterns and targeting of species aggregations with the highest potential economic value (Groeneveld & Melville-Smith, 1995; Salthaug & Godo, 2001), and weather and currents on the fishing grounds also affected fishing strategy at times (K. Sorenson, experienced skipper from Spray Fishing, pers. comm.).

The probability of capturing *M. mozambicus* and the CPUE of this species has generally increased throughout the 23 year period covered in this study, and during the same time the number of vessels operating on the deep-water fishing grounds has decreased, from 12 vessels in 1989 to only 3 in 2009. Three factors (or a combination of them) might explain the inverse relationship between CPUE and fishing effort: reduced effort saturation; improved gear and technology; or a real increase in the abundance of *M. mozambicus*.

Intuitively, fewer fishing vessels on a spatially limited fishing ground would have better access to prime fishing areas than if there were more vessels competing for limited space. Effort or gear saturation has been shown to negatively bias the CPUE in a trap-fishery for

spiny lobster, because surplus traps were set in suboptimal areas, where lobster abundance was low (see Groeneveld et al., 2003). In the present study, a strong inverse relationship was shown between effort and CPUE i.e. when effort increased, CPUE decreased and vice versa. For example, in 1994 a prominent fishing company did not fish, and the CPUE increased substantially during that year. This should be interpreted as a reduction in effort saturation rather than a sudden recovery in stock abundance. A similar effect was shown for deep-water prawn *Parapenaeus longirostris* in the Mediterranean, where seasonal abundance estimates were affected by changes in fishing effort, and not by changes in population densities or biological aspects (Sbrana et al., 2003). Therefore, increases in CPUE in the deep-water trawl fishery when fewer vessels are active may signal reduced effort saturation, rather than increased abundance of *M. mozambicus* on fishing grounds.

Secondly, improved technology and knowledge of the fishing grounds may have enabled more effective targeting of *M. mozambicus*, resulting in an increase in CPUE in the latter years, independently of changes in abundance. Changes in technology (mainly positioning systems and plotters) have been shown to increase CPUE irrespective of abundance trends (Robins et al., 1998; Lynch & Garvey, 2005) and vessel power also affects CPUE (Salthaug & Godo, 2001). Whereas individual vessels were incorporated into the GLM to correct for their relative fishing power, time-dependent aspects such as increases in engine power over time, advances in electronic navigational equipment, and the increasing skills of skippers in finding concentrations of *M. mozambicus* could not be explicitly modelled because the relevant data were largely unavailable. This remains a priority for future study.

The third factor that might explain increased CPUE is an actual increase in the abundance of *M. mozambicus* over time (1989 – 1995; and 2003 to date). The initial catches of this species during the late 1980s were higher than at present, and may have been unsustainable, leading to reduced abundance at that time. Many lobster species, including the closely-related *N. norvegicus* exhibit density-dependent effects on population growth (Tuck et al., 1997; Wahle & Fogarty, 2006); i.e. at lower densities, individual and population growth rates may increase because of higher per capita resources, such as space and food. This effect may have driven a recovery in the stock during periods of reduced fishing effort.

Above-average recruitment in some years may also have contributed to the recovery of stocks, although no attempt has yet been made to identify stock-recruitment relationships,

nor to identify environmental factors that may affect recruitment success. As in most lobster species, *M. mozambicus* larvae are pelagic and are therefore dispersed by ocean currents before settling on the substratum (Berry, 1969; Cobb & Wahle, 1994; Cobb, 1997). The oceanic environment off eastern South Africa is dominated by the flow of the Agulhas Current, which intrudes onto the continental shelf at times (Lutjeharms, 2006), although the circulation of water masses over the Natal Bight is not well understood (Lutjeharms et al., 2000). However, the flow patterns of the Agulhas Current and their effects on the Natal Bight may indeed aid in larval retention of *M. mozambicus* and help maintain the stocks, as discussed below.

GLM results showed that, by month, the catch rates/abundance of *M. mozambicus* peaked in July. Whereas reduced effort saturation during winter months (when fewer vessels are active) may explain this trend, it is also possible that behavioural characteristics of *M. mozambicus* increase their catchability during this period. Seasonal variation in CPUE is common in *N. norvegicus* fisheries and is influenced mainly by burrowing and emergence behaviour (Bell et al. 2006). *N. norvegicus* spends the majority of its time within its burrow, and they are therefore only available to fishing gear when they emerge, as a response to changes in environmental conditions, the need to feed and reproduce (Chapman & Rice, 1971; Chapman, 1980; Abello et al., 2002; Smith et al., 2003; Bell et al., 2006). Berry (1969) and Tomalin et al. (1997) tentatively suggested that variations in CPUE of *M. mozambicus* may be related to its burrowing habits, and therefore catchability fluctuations.

The increased CPUE of *M. mozambicus* during the winter months suggests that they spend more time outside their burrows; this may indicate emergence in response to seasonal or diel patterns. Within the nephropid family, emergence and thus catchability in *N. norvegicus*, *N. australiensis* and *M. thomsoni* has been linked to changing light intensities (Ward & Davis, 1987; Matsuoka et al., 1992; Aguzzi et al., 2003; Bell et al., 2006). Aguzzi et al. (2003) also showed that the seasonal emergence of *N. norvegicus* may be controlled by diel light intensity transitions, particularly at sunset; this may also be the case for *M. mozambicus*, as they spend more time outside the burrows during winter as the transitions from day to night is not as abrupt as in summer. It should, however, be taken into consideration that the difference between winter and summer light intensity is much greater at high latitudes than in the sub-tropics, where *M. mozambicus* occurs. Consequently it is unlikely that light intensity plays as large a role for *M. mozambicus* as it

does for *N. norvegicus*. Other factors, such as emergence patterns of prey species are also thought to influence the timing of emergence *N. norvegicus* particularly in deeper water where light levels are extremely low (Aguzzi et al., 2003). The possibility that *M. mozambicus* may respond to small changes in light intensity, although unlikely, cannot be ruled out.

N. norvegicus spend more time in burrows during moulting, because they are then more vulnerable to predation and cannibalism (Bell et al., 2006). Moulting periods depended on age and sex, with mature *N. norvegicus* males moulting 1 to 2 times per year (late winter and late summer) and females once per year in late winter, after eggs have hatched (Bell et al., 2006). No clear moulting season was found in the current study, and it was often difficult to distinguish between an individual in moult and one damaged by the trawl gear (pers. obs.). However, Berry (1969) found that most male *M. mozambicus* moulted between December and March. The preponderance of males in catches in November (see Figure 3.4) fits this pattern well if it is assumed that males would be feeding most actively in November, just prior to their moult season in December to March. This pattern is common in crustaceans, and has been shown for crabs and spiny lobster (Lipcius & Herrnkind, 1982; O'Halloron & O'Dor, 1988).

The standardised CPUE of *M. mozambicus* was highest between 300 and 399 m depth, corresponding with the findings of Berry (1969) and Groeneveld & Melville-Smith (1995). The CPUE was somewhat lower between 400 and 499 m, but increased again between 500 to 599 m depth, suggesting that *M. mozambicus* abundance is vulnerable to increased fishing effort, which was highest between 400 and 499 m, where *H. triarthrus* was generally targeted. More frequent trawling in the 400 to 499 m depth range than between 300 and 399 m and between 500 and 599 m may have caused increased sediment disturbance there, a factor thought to influence the catchability of *N. norvegicus* (Maynou & Sardà, 2001). Tuck et al. (1998) found that tracks left in the sediment by trawl doors could remain up to 18 months and affected infauna, a factor that might influence burrowing species such as *M. mozambicus*; this disturbance factor was also suggested by Tomalin (1997) as a cause of depressed CPUE levels of this species in the 1990's off South Africa.

If post-trawl recovery of *M. mozambicus* is relatively slow, then the frequency of trawling over the same ground would influence CPUE; for instance, relative abundance at 400 to 499 m depth might appear lower than at other depths, because of relatively higher fishing effort

at this depth; i.e. there is not enough time between trawls for *M. mozambicus* densities to recover to the same extent as in areas less frequently trawled. The sharp decline in CPUE between 600 and 699 m depth (much lower fishing effort), confirmed that the deeper edge of the species distribution range (reported as approximately 500 m by Holthuis, 1991) had been reached. The increased CPUE at ≥ 700 m depth was assumed to be artefactual, as there is doubt that these reported depths are valid (K. Sorenson, experienced skipper from Spray Fishing, pers. comm.).

Size

The sampled size distribution of *M. mozambicus* was not considered to be representative of the entire population, because smaller size classes were absent from catches. Poulsen (1946) and Barnes & Bagenal (1951) found that small nephropids were free of barnacles, thus implying that they remained in their burrows for long periods. Similarly, Berry (1969) suggested that few small *M. mozambicus* were captured in trawls because they moulted more frequently than larger individuals and therefore remained in their burrows for longer periods.

The monthly variation in average size of *M. mozambicus* was negligible over the duration of the study; this confirmed a similar finding by Berry (1969). It is, however, quite possible that trends do actually exist (e.g. recruitment peaks or cohorts moving onto fishing grounds during certain months), but the data collected in this study were incapable of resolving these, because the catch of small individuals was too low.

The average CL of *M. mozambicus* decreased with increasing depth between 325 and ≥ 475 m, and similar trends were shown by Bailey et al. (1997) for the same species and for *N. norvegicus* (de Figueiredo & Thomas, 1967; Eiríksson, 1999). Bailey et al. (1997) proposed that trawl area may be a more important factor affecting CL than depth, and Tuck et al., (1997) and Eiríksson (1999) suggested that local environmental conditions, such as sediment characteristics, were responsible for trends in the CL of *N. norvegicus*. Possible changes in local conditions over the South African trawling grounds may therefore be responsible for the variation in CL, as opposed to the depth. De Figueiredo & Thomas (1967) proposed that fishing pressure reduced the mean CL of *N. norvegicus*, because trawl gear tends to capture larger individuals in the population, thus causing the mean CL to decrease. Fishing pressure is a likely cause for the CL decline over depth in *M. mozambicus*, because effort (and thus

fishing pressure) was much higher in the 400 to 499 m depth zone, where smaller individuals were found.

Sex ratio

Equal numbers of male and female *M. mozambicus* were recorded in the present study, except in November when males were significantly more prevalent. Berry (1969) found no significant variation in the sex ratio, with on average slightly more females captured than males. Variations in the sex ratio of *N. norvegicus* populations have been attributed to reproductive behavioural patterns of females and on average more males were more frequently captured (Barnes & Bagenal, 1951; Thomas, 1964; de Figueiredo & Thomas, 1967). The change in sex ratio of *M. mozambicus* from parity to substantially fewer females than males during November may be linked to the reproductive activities of females; as in *N. norvegicus* a proportionate decline of females in trawl catches during the reproductive season suggests either a migration of females off the fishing grounds, or that egg-bearing females remain in their burrows for longer periods (Thomas, 1964; Rice & Chapman, 1971). The suggestion by Berry (1969) that egg-bearing *M. mozambicus* females would have to spend more time outside their burrows to oxygenate eggs (thus making them more likely to be captured) is not necessarily correct, because other means of oxygenating eggs may exist. For example, female *N. norvegicus* burrows have two entrances which facilitates water flow over the eggs of sheltered females (Chapman & Rice, 1971; Rice & Chapman, 1971). The burrows and burrowing activity of *M. mozambicus* have not yet been described; this information might be highly useful in interpreting CPUE trends in this species.

Maturity – egg-bearing cycle and size at sexual maturity of females

Variation in the proportion of egg-bearing females captured over time was used as an indication of reproductive activity. The proportion of egg-bearers in the present study declined during March and May, which was thus assumed to be a hatching period (i.e. larvae are released into the water-column). The low proportions of egg-bearers persisted into August, followed by a spawning period between September and December, when numbers of egg-bearing females increased. Berry (1969) suggested a similar seasonal reproductive cycle for *M. mozambicus*, and both his study and the current one further agree that the reproductive cycle is annual off the South African coast. The reproductive cycle of the females was also apparent as a fluctuation in sex ratio (see above), when the probability of

capturing a female declined over the peak spawning period, as egg-bearing females are likely to shelter in burrows.

Although the incidence of egg-bearing defined a clear seasonal pattern, some females with eggs were found throughout the study period. This is not uncommon in crustaceans, and has been shown for *N. thomsoni* off Korea (Choi et al., 2008) and also for some *N. norvegicus* populations (Poulsen, 1946; Sardà, 1991; Bianchini et al., 1998; Bell et al., 2006).

Reproductive cycles of nephropids and other lobster species are generally synchronized by internal cues related to the physiology of the species (Raviv et al., 1995) and external factors such as fluctuations in temperature, light intensity, food availability or other factors (Bell et al., 2006; MacDiarmid & Sainte-Marie, 2006). Specific cues, or combinations thereof, are notoriously difficult to determine (Quackenbush, 1993). Lobster species have also been shown to detect and respond to environmental stimuli including salinity, osmolality and temperature (Childress & Jury, 2006) and slight changes in temperature or day length have been shown to induce reproductive behaviour (Quackenbush, 1993; MacDiarmid & Sainte-Marie, 2006). *Metanephrops mozambicus* lives in a fairly constant deep environment, in which ambient temperatures and light intensities fluctuate very little over the seasons (Berry, 1969; L. Guastella, University of Cape Town, unpublished data). Nevertheless, the reproductive cycle starts in early spring (September) – therefore some factor (or combination of factors) presumably triggers synchronous spawning. For instance, *M. mozambicus* may be responding to a combination of factors, such as day length increases changes in temperature or changes in current regimes. Although environmental changes (or cues) might be subtle at depths of 200 to 500 m, it may be all that is required to initiate the reproductive cycle.

In some lobster species migrations are a vital part of their life history strategy, which may require movement into different habitats associated with feeding, sheltering and the onset of reproduction (George, 2005; Childress & Jury, 2006). Egg-bearing female *M. mozambicus* were captured in greater numbers in shallower depths, suggesting a reproductive migration. Migratory behaviour of egg-bearing females to shallower depths has been documented for spiny lobster *Palinurus delagoae*, in the same area and depth range in which *M. mozambicus* occurs (Berry, 1972; Groeneveld et al., 2006) as well as for the deep-water crab *Geryon maritae* (Melville-Smith, 1987). Moving shallower might be a mechanism to release larvae in

a more suitable habitat, i.e. away from the core of the Agulhas current, which flows strongly over the deeper trawling grounds and may sweep larvae away from suitable adult habitats. Albeit located further south (southern Cape) than the target species in this study, at least two spiny lobster species have evolved counter-current migratory behaviour to maintain their populations below the Agulhas Current, where downstream dispersal of pelagic larvae may threaten geographic distribution patterns of adult populations (Groeneveld, 2002; Groeneveld & Branch, 2002).

Oceanic circulation over the deep-water trawling grounds in the Natal Bight are complex, consisting of at least four features (Lutjeharms, 2006): an up-welling cell in the north (Lutjeharms et al., 1989), general cyclonic circulation (Malan & Schumann, 1979), a lee eddy south of Durban (Schumann, 1982) and enhanced shear-edge features at the shelf edge (Lutjeharms, 2006). However, this circulation may offer opportunities for recruitment to the shelf region (Hutchings et al., 2002); specifically the cyclonic circulation which together with the up-welling cell could create the necessary conditions for pelagic larvae to be retained within the region (Lutjeharms et al., 2000; Hutchings et al., 2002). *M. mozambicus* larvae released into this system may therefore be retained in the vicinity of the adult populations, particularly if the larvae are able to orientate themselves in the water column. Chiswell & Booth (1999) showed that spiny lobster *Jasus edwardsii* larvae were able to swim and position themselves in the water column to take advantage of eddies and counter-currents systems in order to return to suitable adult habitats. The larvae of *N. norvegicus* in the western Irish Sea have been found to be retained over suitable sediments by a cyclonic near-surface gyre (Hill et al., 1996) and there are indications that similar mechanisms may be retaining larvae in other populations (Hill et al., 1997; Bell et al., 2006). These mechanisms, although not well understood, may be retaining *M. mozambicus* larvae in the Natal Bight.

The size at which 50% of female *M. mozambicus* achieved maturity (L_{50}) was estimated as 49.4 mm CL, compared to previous estimates of 47 mm (Berry 1969), 50 mm (Tomalin et al. 1997) and 51 mm (Bailey et al., 1997). All four studies relied on the presence of external eggs to determine maturation. However, the proportion of egg-bearers per 2 mm size category was used to fit logistic curves in the three earlier studies, whereas the present study determined the probability of egg-bearing for each individual based on the presence and absence of eggs of all females sampled, using a GLM approach. The latter method provides a better estimate of the length at maturity, which is unbiased by the selected size

category. Bell et al. (2006) summarised several studies which used different methods of determining the size at 50% maturity of *N. norvegicus*. These methods included ovarian maturation, presence/absence of spermatophores and ovigerous condition, all of which provided a range of different estimates for L_{50} . Thus the small discrepancies in L_{50} of *M. mozambicus* between the four studies can be ascribed to differences in methodology, rather than a shift in size at maturity over time.

Growth

Growth studies of crustaceans are inherently difficult because all hard structures that may have growth rings are lost at each moult, and growth is step-wise or discontinuous (Hillis, 1979; Wahle & Fogarty, 2006; Chang et al., 2012). Many factors may influence estimates of K and L_{∞} (Bell et al., 2006), which often remain uncertain, despite their importance in population modelling. The use of length-frequency data to determine growth rates, as in the present study, can be influenced by sampling artefacts such as a small sample size, or poor representation of smaller size classes due to gear selectivity (Castro, 1992; Mytilineou & Sardá, 1995; Mytilineou et al., 1998; Bell et al., 2006). It can also be affected by environmental and intrinsic factors, such as ambient temperature, food availability and quality, habitat suitability, density dependence, and fishing pressure (Tuck et al., 1997; Mytilineou et al., 1998; Wahle & Fogarty, 2006). All of these factors or a combination of them may affect the growth of *M. mozambicus*.

Growth rates in *Metanephrops* species have not been determined previously, and in this study were estimated using two methods. The first method (VBGF), has been extensively used to model crustacean growth, even though it assumes a continuous increase in size; furthermore it explicitly requires size-at-age information, which is generally not available for crustaceans (Wahle & Fogarty, 2006; Chang et al., 2012). These factors have been overcome by using tag-recovery data to estimate age based on moult increments and moulting frequencies. However, no tag-recapture data were available for *M. mozambicus*, and instead the age of monthly cohorts was estimated based on their progression over time. The method tends to represent the average growth of a population, irrespective of size (Pedraza-Gracia et al., 2012). Although not optimal, the VBGF used in this study was relatively easy to apply and is widely used in fisheries (Mytilineou et al., 1998; Bell et al., 2006).

The second method (Fabens), did not require age estimates and used changes in modal length frequencies in order to model growth. These data are more simply analysed with the use of computer programs, such as the adaptation of the MIX program used in this study; nevertheless, results may vary depending on the program used, based on the assumptions about the data (Macdonald & Pitcher, 1979; Mytilineou et al., 1998). The identification of the age groups, or cohorts is another factor affecting the outcome of a length-frequency analysis, because of the discontinuous growth of crustaceans the detection of modes is not always straight-forward (Chang et al., 2012).

Although no changes in monthly modes of *M. mozambicus* length-frequencies could be detected by Berry (1969) or Tomalin et al. (1997), changes were found in the present study, thus allowing for estimation of growth parameters. The VBGF and Fabens methods provided similar parameter estimates for K and L_{∞} , suggesting that the two growth curves are representative of the data. The growth rates of *M. mozambicus* and *N. norvegicus* are summarised below (Table 4.1). Although not directly comparable, it is clear that estimates vary considerably among areas and studies. This may be due to several factors affecting growth, including the analysis used and different environmental condition. Furthermore, it has been suggested that male and female *N. norvegicus* may grow at different rates after the onset of sexual maturity (Bell et al., 2006), although, as in the present study on *M. mozambicus*, Farmer (1974) found both sexes of *N. norvegicus* to grow at similar rates.

Table 4.1. Summary of growth findings for *M. mozambicus* and *N. norvegicus* from different regions, using different methods and programs.

Species/Region	Source	Method	Sex	L_{∞} (mm CL)	K
<i>M. mozambicus</i>	Current study	VBGF	Combined	76.4	0.48
(South Africa)	Current study	Fabens	Combined	76.4	0.45
<i>N. norvegicus</i> (Catalan Sea)	Mytilineou & Sardá, 1995	Length frequency (Bhattacharya's, FISHPARM and ELEFAN I)	Male and Female separate	63.6 - 96.6	0.06 - 0.09
<i>N. norvegicus</i> (Scotland)	Tuck et al., 1997	Length frequency (Multifan)	Male and Female separate	45.5 - 65.5	0.16 - 0.22
<i>N. norvegicus</i> (Atlantic)	Mytilineou et al., 1998	Length frequency (MIX and FISHPARM)	Male and Female separate	70.7 - 158.3	0.04 - 0.14

Length weight relationships

Commercial catches of *M. mozambicus* are generally packed as whole frozen animals, but they may also be processed as tails only, by removing the cephalothorax (pers. obs.). Conversion factors to whole landed mass are therefore required, both as a way to report total catches of the fishing fleet, and for data conversions for length-based population assessment models (see Hossain et al., 1987). Only CL to total weight relationships were determined in the present study, and no statistical difference could be found between the parameters for males and females.

Length and weight relationships calculated by Berry (1969) provided insights into CL to total length, CL to abdominal width, CL to tail weight and CL to total weight. The length-weight relationships were also examined by Ivanov & Krylov (1980), although they provided no interpretation of their results. Berry (1969) found that males became increasingly heavier than females as CL increased, and concluded that this was due to the increased size of the chelipeds, which became more robust in mature males, with similar findings were reported by Poulsen (1946) and Hossain et al. (1987) for *N. norvegicus*.

The difference between CL to whole weight ratios of male and female *M. mozambicus* in this study compared to those of Berry (1969) may be due to difficulties (in both studies) of recording accurate weights at sea; in both studies, samples were packed, frozen and analysed in a laboratory after surveys at sea had been completed. During packing and defrosting, individual langoustines tended to lose limbs and dehydrate, and therefore weights recorded may not have been as accurate as for fresh samples.

4.3 – *Haliporoides triarthrus*

CPUE

Haliporoides triarthrus was present in 85.05% of trawls, and on average, landed quantities were 2.5 times larger than that of *M. mozambicus*. Although *H. triarthrus* commands a much lower market price than *M. mozambicus* (Fennessy, 2001), the larger quantities captured makes this species the mainstay of the South African east coast trawl fishery.

Inter-annual fluctuations in the standardised CPUE of *H. triarthrus* over the 23 years studied were presumably affected by similar factors as described for *M. mozambicus* in Section 4.2, namely effort saturation, improved technology and changes in abundance. Although the two species were captured in the same trawls, their biology and behaviour differ greatly, and therefore it was expected that the relative influences of the three factors on inter-annual CPUE fluctuations would also differ between the two species.

The relationship between the CPUE and fishing effort did not appear to be as strongly linked in *H. triarthrus* as in *M. mozambicus*; for example, the large decline in effort during 1994, when a major fishing company did not operate, did not give rise to a substantial increase in CPUE, as was observed for *M. mozambicus*. Furthermore, the broad inter-annual trend in CPUE (general decline between 1990 and 1998; general increase between 2001 and 2008) does not correlate well with improved technology (sudden CPUE increase expected in years after a technological improvement) or with improved knowledge of fishing grounds by skippers (several long-term skippers have been active since the 1990's) (see Baelde, 1991; Fennessy, 2001). Nevertheless, the improved technology hypothesis cannot be ruled out at this point, and there is scope for time-series modelling that takes specific technological advances into account (see Robins et al., 1998). Unfortunately, this would require

knowledge on the timing of the introduction of such technology or gear improvements on individual vessels, which is not readily available.

Perry et al. (2000) suggested that the CPUE of caridean prawn *Pandalus jordani* was affected by behavioural responses and changes in distribution patterns on fishing grounds related to winds, tides and water mass shifts. In the current study, changes in the spatial distribution of *H. triarthrus* stocks could have caused below-average CPUE in some years, especially because the Agulhas Current, which dominates the seascape in this region, exhibits varying speed over the trawling grounds (Lutjeharms, 2006).

Haliporoides triarthrus is a short-lived and fast-growing species with a life span of probably only 2 to 3 years (Torstensen & Pacule, 1992). Its abundance on the fishing grounds is therefore likely to be more strongly linked to recruitment fluctuations and environmental variability than would be the case in long-lived species, such as *M. mozambicus* (Garcia, 1996). Weak or failed recruitment events in short-lived species may have deleterious effects on fisheries in subsequent years (King, 1995), as has been shown recently for shallow-water prawns of the east coast of South Africa. In that case, recruitment failure was caused by the closure of estuarine outlets to the sea; consequently juveniles in estuaries could not recruit to adult prawn populations on offshore fishing grounds on the Tugela Bank (see Turpie & Lamberth, 2010). Similarly, sardines (*Sardinops sagax*), which are short-lived, fast growing fish, exhibit large fluctuations in biomass as well as stock collapses; this has been related to successive years of poor recruitment and subsequent over fishing off the west coast of South Africa and off Japan (Watanabe et al., 1995; Beckley & van der Lingen, 1999).

The monthly trend in CPUE showed a distinct peak in March and April. This was unlikely to be a result of reduced fishing effort, which was lowest over the autumn/winter months (May – August). A similar March/April peak in CPUE was observed in Mozambique (de Freitas, 1985), and was attributed to increased targeting of *H. triarthrus* during those months. However, the fishing grounds off Mozambique are much larger with a greater depth range than off South Africa, and the Mozambican distributions of *H. triarthrus* and *M. mozambicus* are better defined, allowing for more specific targeting (de Freitas, 1985). The increased CPUE of *H. triarthrus* in March/April in the present study was not accompanied by a concurrent decrease in *M. mozambicus* CPUE, and thus there was no evidence of targeting effects on the CPUE trends.

The increased abundance of *H. triarthrus* in March/April was therefore interpreted as a reflection of underlying biological or behavioural responses, possibly a recruitment pulse. This is supported by a bimodal length-frequency distribution in March 2012, suggesting recent recruitment of a cohort to the fishing grounds. *H. triarthrus* does not inhabit burrows (de Freitas, 1985) and it is therefore unlikely that monthly abundance trends would have been skewed by burrowing behaviour, as suggested for reproductive *M. mozambicus* females (see section 4.2).

By depth, the standardised CPUE peaked between 400 and 499 m, thus confirming the *H. triarthrus* depth distributions found by earlier workers off eastern Africa (Holthuis, 1980; de Freitas, 1985). The 400 to 499 m depth range was preferentially targeted by trawlers, and it is possible that the high levels of disturbance by trawling might have reduced the abundance or catchability of larger slow-growing species (such as *M. mozambicus* and *P. delagoae*), leaving more space and food resources for faster-growing smaller species, such as *H. triarthrus* (Schratzberger et al., 2002).

Size

Female *H. triarthrus* were larger, on average, than males and this was also found by Berry et al. (1975) off South Africa as well as off Mozambique by de Freitas (1985), Torstensen & Pacule (1992), Sobrino et al. (2007) and Dias et al. (2009). Sexual dimorphism in size is common in penaeid prawns, and females generally attain a larger size than males (Baelde, 1994; Ohtomi & Irieda, 1997). Larger females than males were also found for the congeneric *H. sibogae* off eastern Australia (Baelde, 1994) and south western Japan (Ohtomi & Irieda, 1997), as well as the penaeid prawns *Aristeus antennatus* off Mozambique (Sobrino et al., 2009) and *Aristaeomorpha foliacea* from the Mediterranean Sea (Ragonese et al., 1994). Generally, sexual dimorphism is considered to be an adaptive life history trait (Fairbairn, 1990; Sardà et al., 1998), possibly to facilitate reproductive processes.

Sardà et al. (1995) proposed that the morphometry of smaller individuals, mainly males, of the deep-water prawn *A. antennatus* made them better suited to pelagic life. The hypothesis was that the morphometry allowed increased swimming ability which might confer a competitive advantage, because it would improve male access to widely-spread reproductive females (Berglund, 1981). Also, larger females of the caridean prawn genus *Palaemon* translated into increased fecundity (Berglund, 1981). Larger female *H. triarthrus*

are almost certainly more fecund than smaller individuals, however whether male individuals swim better than females because of their smaller size is speculative.

In this study, carapace length increased nominally over the narrow sampled depth range of 400 to ≥ 474 m sampled, however this trend may be more apparent over a greater depth range, or absent. A significant increase in CL over a depth range of 300 m was recorded for *A. antennatus* off Mozambique, but not for *A. virilis* (Sobrino et al., 2009). It has also been proposed that adult caridean prawns may attain larger sizes at greater depths, because lower predation in deeper waters would theoretically allow for a longer life span (King & Butler, 1985). Berry et al. (1975) proposed that *H. triarthrus* increased in size at deeper strata – the present study might have missed detecting this trend because no samples were collected >500 m depth.

Sex ratio

The sex ratio was close to parity over the duration of this study, with only slight (non-significant) variations from month to month. Berry et al. (1975) found the sex ratio to be near parity at depths up to about 450 m, but females were favoured as depth increased further. Similarly Dias et al. (2009) recorded a variation in the sex ratio of *H. triarthrus* off Mozambique, with an overall ratio of 0.7 : 1 (males to females), but as depth increased the ratio greatly favoured females (0.3 : 1). This increase in the proportion of females at deeper strata may have been size dependent; larger animals were found deeper and generally females were larger than males (Berry et al., 1975). Again, the narrow depth range sampled in the present study precludes conclusions on gradients across depth; this was also the case for the congeneric *H. sibogae* in Australia, in which the narrow depth range obscured temporal changes in sex ratio, which remained at approximately 50% (Baelde, 1992).

Small increases in the numbers of female *H. triarthrus* were recorded in November and December of this study. Conversely, increased numbers of females between July and August were related to the spawning period by de Freitas (1985). However, no correlation between sex ratio and the reproductive cycle could be found in the present study, as proposed by Berry et al. (1975) and de Freitas (1985).

Maturity – reproductive cycle

No reproductively active female *H. triarthrus* were recorded in samples taken during this study and in general very few have been recorded in South African waters by earlier studies (Berry et al., 1975; Tomalin et al., 1997; S. Fennessy, Oceanographic Research Institute, unpubl. data). Based on very few samples, Berry et al. (1975) found some degree of macroscopic ovarian activity throughout the year, with a peak in October and November (off South Africa) and in August and September (off Mozambique). De Freitas (1985, 1995), interpreting the findings of Berry et al. (1975), suggested that spawning occurred throughout the year, with a peak in winter months. Multiple spawning has also been proposed for the congeneric species *H. sibogae* off south eastern Australia (Baelde, 1992).

In contrast there is extensive reproductive activity off the Mozambique coast, with a large proportion of females captured showing signs of ovarian activity (de Freitas, 1995; D. Hayes, fisheries observer, Oceanographic Research Institute, pers. comm.). It therefore appears that the main breeding grounds of *H. triarthrus* are located off Mozambique, and that the South African population depends on a net import of larvae from further north. The question then arises whether the population off KZN is a sink (i.e. it does not contribute to the overall reproductive output of *H. triarthrus*, and relies solely on larvae originating from the much larger Mozambique populations), or whether it is also a source of reproductive adults to the upstream populations in Mozambique, through counter-current migrations of pre-reproductive cohorts.

A reproductive migration to breeding grounds off Mozambique was proposed by Berry et al. (1975) and de Freitas (1995), and similar long-distance migrations have also been shown for *H. sibogae* off south-eastern Australia, where prawns moved from southern recruitment grounds to northern spawning grounds (Baelde, 1992). In the Agulhas Current region, two spiny lobster species undertake long-distance counter-current migrations to position reproductive females upstream of post-larval recruitment hotspots: *Palinurus gilchristi* off southern South Africa (Groeneveld & Branch, 2002) and *Palinurus delagoae* off KwaZulu-Natal and southern Mozambique (Groeneveld, 2002). These examples suggest that a similar long-distance migration pattern for *H. triarthrus* is not unlikely, and a genetic population study is presently being conducted to assess metapopulation connectivity of *H. triarthrus* between South Africa and Mozambique (J. Groeneveld, Oceanographic Research Institute, pers. comm.). Alternatively, reproductively active female *H. triarthrus* off South Africa may

not be migrating north into Mozambique, but to nearby areas which are not trawled because of greater depth or unsuitable bottom types (also suggested by Berry et al., 1975).

Berry et al. (1975) determined the CL at which 50 % of female *H. triarthrus* matured (L_{50}) to be 41 to 42 mm in Mozambique and 49 to 50 mm in South Africa; de Freitas (1985) estimated L_{50} in Mozambique to be between 45 and 46 mm. The L_{50} was not estimated in the present study, because no mature females were captured despite the considerable sampling effort, albeit at a limited depth range. Nevertheless, the earlier L_{50} estimates for female *H. triarthrus* are considerably larger than for *H. sibogae* off Australia, a species with a smaller maximum size (30.8 mm CL; Baelde, 1992).

Growth

Despite possible bias due to sampling artefacts and gear selectivity (Pedraza-Gracia et al., 2012), analysis of length-frequency data has been used to estimate growth of several penaeid species, including *H. triarthrus* off South Africa and Mozambique (Berry et al., 1975; Torstensen & Pacule, 1992; Tomalin et al., 1997), *H. sibogae* off eastern Australia (Baelde, 1994) and off Japan (Ohtomi & Matsuoka, 1998) as well as for the penaeid *Solenocera melanthera* off southern Japan (Ohtomi & Irieda, 1997). These studies provided a good background against which the results from the present study could be compared.

Female *H. triarthrus* achieved a significantly larger size than males, and growth rates were therefore determined separately. As with *M. mozambicus*, two methods were used to estimate growth parameters: the first was the VBGF which requires size-at-age information (generally unavailable for crustaceans), but which was overcome by determining the age of cohorts traced over time. The VBGF furthermore excluded seasonal variation in growth and assumed a continuous trajectory; nevertheless, it was assumed to be a reliable approximation of growth in penaeids (Baelde, 1994).

The second method (Fabens method), relied on estimating changes in length frequencies between the different cohorts. Although these data could be simply interpreted using computer programs, the results depended on assumptions made, and bias could be introduced through the identification (or selection) of cohorts, a process which is affected by the discontinuous growth of crustaceans, and poor gear selectivity of the smallest age groups.

Both methods provided similar estimates of K and L_{∞} , and thus it was assumed that they were representative of the data. Growth rates of males were faster than for females, and females reached a larger asymptotic size. Similar results were found in three different studies of *H. triarthrus* off Mozambique, as summarised by Torstensen & Pacule (1992) and in studies on *H. sibogae* off Australia and Japan (Baelde, 1994; Ohtomi & Matsuoka, 1998), and in other penaeid populations such as *S. melanthero* from Japan (Ohtomi & Irieda, 1997) and *A. foliacea* from the Mediterranean (Ragonese et al., 1994).

Table 4.2. Grow rates of different penaeid prawn populations, determined using a variety of methods. (* total length).

Species/Region	Source	Method	Sex	L_{∞} (mm CL)	K
<i>H. triarthrus</i> (South Africa)	Current study	VBGF	Male	46.6	0.76
		Fabens	Male	46.6	0.5
		VBGF	Female	62.9	0.47
		Fabens	Female	62.9	0.3
<i>H. triarthrus</i> (South Africa)	Tomalin et al., (1997)	ELEFAN I	Male	41	0.65
			Female	51	0.71
<i>H. triarthrus</i> (Mozambique)	Torstensen & Pacule (1992)	ELEFAN I	Male	48	1.08
			Female	62.4	0.78
<i>H. sibogae</i> (Australia)	Baelde (1994)	MULTIFAN	Male	33.5	0.49
			Female	48.3	0.37
<i>H. sibogae</i> (Japan)	Ohtomi & Matsuoka (1998)	Pauly & Gaschukzt equations	Male	111.5*	1.74
			Female	130.8*	1.275

Although these studies all showed similar trends in growth, there are variations between them, with some predicting much faster growth rates than others. For *H. triarthrus* from the SWIO, there were large differences between the predicted values of the growth coefficient K for the various studies, with some nearly double that of others. Tomalin et al. (1997) was the only study that predicted faster growth in females (i.e. higher K value) than in males – all the others studies had a lower K for females. The results from the present study are similar to those of Torstensen & Pacule (1992), but predicted a slightly faster growth of both females and males.

Variations in growth rate parameters have also been shown for *H. sibogae* off Japan and Australia, where in general female growth was more variable than males (Baelde, 1994; Ohtomi & Matsuoka, 1998). Growth variability has been linked to both environmental factors (such as temperature changes) and changes that females undergo during the reproductive cycle (Hopkins & Nilssen, 1990; Bergstrom, 1992; Ragonese et al., 1994; Rasmussen & Tande, 1995; Ohtomi & Irieda, 1997). These effects have not yet been studied in relation to growth rates in *H. triarthrus*. Other factors which may impact on local growth rates are density dependence, recruitment patterns, food availability and predation (Bergstrom, 1992).

The model selected to estimate growth parameters can also instil further variation. Incorporating seasonal effects on growth of penaeid prawns resulted in better model fits than without them (Hopkins & Nilssen, 1990; Bergstrom, 1992; Ragonese et al., 1994), however, the simple VBGF used in this study did not account for seasonal variation in growth and this could further explain the higher growth rates found for female and male *H. triarthrus* off South Africa when compared to Mozambique, as Torstensen & Pacule (1992) incorporated the seasonal effects. Despite the different methods used, estimated growth curves and length-frequency data in the present study suggested a life span of approximately 2 to 3 years in *H. triarthrus*, which is similar to the results obtained by Torstensen & Pacule (1992) and for *H. sibogae* off Australia (Baelde, 1994).

Length weight relationships

Apart from the present study, parameters were determined for *H. triarthrus* off South Africa by Bailey et al. (1997), using data collected by Berry et al. (1975) as well as off Mozambique by Ivanov & Krylov (1980) and Berth et al. (1982). Parameters for *H. sibogae* off Australia have also been calculated and were reported by Bailey et al. (1997).

The differences found in growth between males and females were also obvious in the CL versus whole weight relationships. Females became larger and heavier than males, and similar results were obtained by Ivanov & Krylov (1980) and Berth et al. (1982). Ohtomi & Irieda (1997) determined the length-weight values for females to be nearly twice that of the males, however, it is interesting to note that males occurring off South Africa exhibited similar relationships between CL and whole weight to those found off Mozambique, and the same was true for females. Although environmental conditions at a local scale can influence

growth rates (and thus length weight relationships; Nair et al., 1984), it is also likely that the methods used can result in biased estimates: for instance, the samples in the present study were not analysed at sea because motion-compensated scales were unavailable, therefore frozen samples were used and these may influence weight measurements through loss of appendages and dehydration during the freezing process.

4.4 – Management of the fishery

The management of the deep-water crustacean trawl fishery off eastern South Africa has not changed much since its origin. Prior to 1983, 20 South African vessels were permitted to operate out of Durban harbour on a mixed permit system, allowing them to operate in South Africa and Mozambique. Four vessels fished in South Africa while the rest fished in Mozambique territorial waters. However, in 1983 there was a moratorium on all South African vessels operating in Mozambique, and faced with a possible rapid increase in effort along the eastern coast of South Africa, the then Department of Sea Fisheries reduced the number of permits for South African vessels to 10 (Sauer et al., 2003).

The main management focus for this fishery has since then remained the control of fishing effort, which is currently limited by the allocation of long-term fishing rights and permits (Appendix 1). Currently there are four long-term rights holders: Viking Fishing Co. (deep-sea) (PTY)LTD, Spray Fishing (PTY)LTD, Nathaz Fishing CC. and Hacky Fishing (PTY)LTD. Furthermore, the number of vessel permits have been reduced to seven, which are renewed on an annual basis. However, only two of these companies operate on a regular basis, utilising three vessel permits; as such there is a large amount of latent effort in this fishery. The latent effort is cause for some concern, because the status of the stocks remain unknown and additional vessels entering the fishery may potentially lead to over fishing.

There are however, no output controls for this fisher, with no regulations or restrictions on gear (besides minimum mesh size), landings (TAC) or on capture of by-catch species. This poses an environmental concern for the fishery as a whole, as it may be yielding unsustainable amounts of target species and/or by-catch species.

Skippers submit drag-sheets in logbooks to record catch and effort, as well as landing sheets upon discharge. This system effectively commenced in 1988 (Sauer et al., 2003), and whereas the long-term database is highly valuable as an indicator of relative abundance

trends, it has not been fully utilised, and to date no formal stock assessments have been undertaken. There are regulations in the permit conditions that allow for fisheries observers to be taken on-board fishing vessels (see Appendix 1), and although observers are frequently used to monitor the bycatch of the fishery, no long-term on-board biological sampling of target crustaceans has been undertaken. Potentially, observers would augment the catch and effort data, and collect much needed biological data on target and by-catch species.

The biological characteristics of deep-water species (e.g. growth rates, life span, fecundity) make them vulnerable to overexploitation and depletion; and the lack of life-history data on the two main target species (*M. mozambicus* and *H. triarthrus*) is a major concern for this fishery, as it can limit the implementation and further development of adequate management measures (Villalobos-Rojas & Wehrtmann, 2011).

It is recommended that a formal stock assessment of the two target species (*M. mozambicus* and *H. triarthrus*) be undertaken and that the management of this fishery be reviewed in terms of both the current input controls as well as the introduction of output controls, based on a stock assessment and biological characteristics of these two species.

Chapter 5 – CONCLUSIONS and FUTURE RESEARCH DIRECTION

Metanephrops mozambicus and *Haliporoides triarthrus* are the mainstay species of the deep-water crustacean trawl fishery off eastern South Africa, yet relatively little is known about their biology and the impact that trawl fishing has on their populations. They are captured simultaneously over a broad depth range, but are most abundant between 300 and 500 m. Although their distributions overlap, prawns and langoustines have fundamentally different life history strategies and biological characteristics, and therefore the effects of trawling on their respective populations differed substantially.

A general increase in the standardised CPUE of *M. mozambicus* over the 23 year study period was attributed to a combination of factors, including reduced effort saturation, improved technology and skipper experience, and an increase in abundance. The CPUE of *H. triarthrus* varied substantially more between years than for *M. mozambicus*, probably because it is a faster-growing short-lived species. The variations in the abundance of *H. triarthrus* were thought to be more dependent on shorter-term recruitment and growth fluctuations, although gear-effects could not be entirely disentangled.

Seasonal cycles of both species affected their availability to fishing gear. For instance, the burrowing behaviour of *M. mozambicus* reduced its availability to the fishery during certain months (May – August), when egg-bearing females spent more time in burrows. Based on the incidence of eggs, an annual reproductive cycle was proposed, with hatching occurring in March to May and spawning taking place in September to December. Females matured at 49.4 mm CL (L_{50}), similar to earlier estimates. No gravid female *H. triarthrus* were encountered, and few have previously been recorded off South Africa. Conversely, gravid females are often captured off Mozambique. A counter-current spawning migration was therefore hypothesized, to redress likely downstream dispersal of pelagic larvae.

Two methods were used to determine growth parameters from length-frequency data; estimates from the von Bertalanffy growth model for *M. mozambicus* provided a K value of 0.48 year⁻¹ and L_{∞} of 76.4 mm CL were as for *H. triarthrus* the K value of the males was 0.76 and 0.47 year⁻¹ for females with L_{∞} of 46.6 and 62.9 mm CL, respectively. Estimates from the Fabens method were K of 0.45 year⁻¹ and L_{∞} of 76.4 mm CL for *M. mozambicus* and for

male *H. triarthrus* K was 0.5 year^{-1} and L_{∞} of 46.6 mm CL and for females K was 0.3 year^{-1} and L_{∞} of 62.9 mm CL.

Limitations of this study were that biological data were only collected from a commercial fishing vessel during normal fishing operations; therefore only a narrow depth range was sampled and the minimum mesh size of trawl nets was 50 mm. A structured survey design covering a broad depth range and a smaller mesh size in trawl nets are required to fill the gaps (i.e. recruitment; reproduction; distribution patterns) that could not be addressed in the present study.

Stocks of both species are possibly shared with fisheries in Mozambique, and a genetic population analysis to assess connectivity is presently underway. If shared, then collaborative research projects with Mozambican scientists should be developed so that stock units can be investigated in their entirety.

Logbooks form the basis of a valuable long-term database of effort and catches by species for the fishery. This data could be improved by updating the systems used to record it, so that information from trawls (start and end position, depth and duration) and catches (weight per species) can be relayed to shore in realtime with greater accuracy and consistency; the ability of crews to correctly identify a broader range of species would help the management thereof. The placement of fisheries observers on board trawlers to collect biological information has augmented the logbook data; nevertheless, most data collections focussed on by-catches, and neglected key crustacean species. The observer programme should be strengthened, and collection of biological data of crustacean target species enhanced.

No formal stock assessment has yet been undertaken for *H. triarthrus* or *M. mozambicus* in South Africa, despite the large quantities of time-series data available. Formal assessments should be attempted to support management recommendations for the fishery.

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Appendix 1 – PERMIT CONDITIONS: KZN PRAWN TRAWL FISHERY

Permit Conditions: KwaZulu- Natal Prawn
Trawl Fishery

FISHING SEASON: 2012

DATE OF APPROVAL: JANUARY 2012



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Permit Conditions: KwaZulu- Natal Prawn
Trawl Fishery

FISHING SEASON: 2012

DATE OF APPROVAL: JANUARY 2012

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agriculture, forestry & fisheries

Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

TABLE OF CONTENTS

SECTION B

1.	APPLICABLE ACTS, POLICIES AND DELEGATIONS	3-4
2.	VALIDITY OF PERMIT	4-5
3.	FISHING AREAS	5-6
4.	NOTIFICATIONS	6-7
5.	EFFORT LIMITATIONS AND GEAR RESTRICTIONS	7
6.	CATCH CONTROLS AND LIMITATIONS	7-8
7.	HANDLING OF OVER/UNDER CATCHES AND PROHIBITED FISH SPECIES	8
8.	VESSEL SPECIFICATIONS	8
9.	VESSELS MONITORING SYSTEM	8-10
10.	LANDING OF FISH	10-11
11.	SUBMISSION OF INFORMATION	11-12
12.	RECORD KEEPING	12
13.	LEVIES	13-14
14.	VIOLATIONS	14-15
15.	CONSULTATION AND COMMUNICATION	16
16.	OBSERVER PROGRAMME	16
17.	PROCESSING AND SALE OF FISH	17
18.	TRANSFER OF FISHING RIGHTS	17
19.	TRANSPORTATION OF FISH	17
20.	FISHING PERFORMANCE MEASURING	17-18

1. APPLICABLE ACTS, POLICIES AND DELEGATIONS

1.1 This permit is issued subject to the provisions and regulations of the following laws but not limited to:

- (a) The Marine Living Resources Act, 1998 (Act No. 18 of 1998) (MLRA) and regulations promulgated thereunder;
- (b) The National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA), and regulations promulgated thereunder;
- (c) The National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) (NEMBA) and regulations promulgated thereunder;
- (d) The National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) (NEMPA) and regulations promulgated thereunder;
- (e) The National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) (NEMA:ICMA) and regulations promulgated thereunder;
- (f) The Sea Birds and Seals Protection Act, 1973 (Act No. 46 of 1973) (SBSPA) and regulations promulgated thereunder;
- (g) The Fire Arms Controls Act, 2000 (Act No. 60 of 2000) (FACA) and regulations promulgated thereunder;
- (h) The International Convention for the Prevention of Pollution from Ships Act, 1986 (Act No. 2 of 1986) (ICPPSA) and regulations promulgated thereunder;
- (i) South African Maritime Safety Authority Act, 1998 (Act 5 of 1998) (SAMSAA) and regulations promulgated thereunder;



- (j) The Animals Protection Act, 1962 (Act No. 71 of 1962) and the Regulations promulgated thereunder;
- (k) The Standards Act, 2008 (Act No. 8 of 2008) and the Regulations promulgated thereunder;
- (l) The National Regulator for Compulsory Specifications Act, 2008 (Act No. 5 of 2008) and the Regulations promulgated thereunder;
- (m) National Ports Authority Act, 2005 (Act No. 12 of 2005) and the Regulations promulgated thereunder; and
- (n) The Companies Act, 2008 (Act No. 71 of 2008) and the Regulations promulgated thereunder.

1.2 This permit is issued subject to the further provisions of the following policies:

- (a) General policy on the Allocation of Commercial Fishing Rights, 2005;
- (b) Policy for the Allocation of Commercial Fishing Rights in the KwaZulu Natal Prawn Fishery: 2005; and
- (c) Policy for the transfer of Commercial Fishing Rights: 2009.

1.3 The Director: Inshore Fisheries Management (IFM) shall be entitled to amend these permit conditions after consultation with the relevant stakeholders.

1.4 Any reference to the Permit Holder in these permit conditions includes the entity or person in whose name the commercial fishing right is allocated to ("the Right Holder") by the Minister or the delegated authority.

2. VALIDITY OF PERMIT

2.1 This permit shall be valid from the date of issue until **31 December 2012**.

- 2.2 This permit shall automatically expire and be invalid should:
- (a) the right be cancelled or revoked in terms of Section 28 of the MLRA;
 - (b) the fishing season terminates or ends; and
 - (c) the permit be revoked, cancelled or suspended in terms of section 28 of the MLRA.

3. **FISHING AREAS**

- 3.1 In terms of this permit, the authorised vessel may only engage in fishing in waters adjacent to the coastline of the Province of KwaZulu-Natal (KZN), defined as the area, from the high-water mark, between, as a northern boundary, a line (110° true bearing) drawn from the lighthouse at Ponta do Ouro (26° 51.4' S 32° 53.3' E), situated approximately one nautical mile south of Ponta do Ouro, as indicated on chart SAN 134, and; as a southern boundary, a line (130° true bearing) drawn from the mouth of the Mtamvuna River (31° 04.8' S 30° 11.6' E), as indicated on chart SAN 130.
- 3.2 Fishing is prohibited on the Tugela Bank, defined as the area within 7 nautical miles of the high-water mark, and between the northern boundary line (090° true bearing) drawn from the lighthouse at Cape St Lucia (28° 30.9' S 32° 24.0' E) and southern boundary, a similar line drawn from the mouth of the Mvoti River (29° 23.5' S 31° 20.1' E), from September to February.
- 3.3 Fishing is prohibited in the St Lucia Marine Protected Area, defined as the area between the high-water mark and a line three nautical miles seawards of the high-water mark and between the northern boundary, a line (090° true bearing), drawn from the beacon marked N3 (27°26'.837S; 032°42'.143E), situated approximately 11km to the north of the Ngoboseleni Stream at Sodwana Bay and, as southern boundary, a similar line drawn from the beacon marked N4 (28°08'.5S; 32°33'.75E), situated approximately 1km to the south of Cape Vidal.
- 3.4 Fishing is prohibited in the Maputaland Marine Protected Area, defined as the area between the high-water mark and a line three nautical miles seawards of the high-water



mark, and between, as a northern boundary, a line (090° true bearing, drawn from the beacon marked N7 (26°51' .6S; 32°53' .433E), situated at the South African-Mozambique border and, as southern boundary, a similar line drawn from the beacon marked N3 (27°26'.837S; 032°42' .143E), situated approximately 11 km north of the Ngoboseleni Stream at Sodwana Bay.

- 3.5 Permit Holders with inshore permits may fish on the Tugela Bank from 01 March 2012 to 31 August 2012.
- 3.6 Permit Holders with offshore permits may not fish the area within 7 nautical miles from the high-water mark, between the northern boundary, a line (090° true bearing) drawn from the lighthouse at Cape St Lucia (28° 30.9'S 32° 24.0' E) and, as a southern boundary, a similar line drawn from the lighthouse at Green Point (30°15.0'S 30° 46.8'E).
- 3.7 Fishing is prohibited within the 0.5 nautical miles of the high-water mark.

4. **NOTIFICATIONS**

- 4.1 The Permit Holder shall inform the Ezemvelo KZN Wildlife Officer in writing at least 24 hours prior to the intended time of landing of the following:
- (a) the vessel details;
 - (b) to which Right Holder(s) the catch is to be allocated/apportioned;
 - (c) the estimated total catch on board;
 - (d) the species of fish harvested;
 - (e) the estimated time of arrival; and
 - (f) the port of arrival.
- 4.2 The Ezemvelo KZN Wildlife must be notified by phone and fax at the following numbers:



Table1. Ezemvelo KZN Wildlife contact details

FISHERY CONTROL OFFICE	TELEPHONE NUMBER	FACSIMILE NUMBER	CELL NUMBER	CONTACT PERSON
Ezemvelo KZN Wildlife	031-2741176/60	031-2741174	0825592860/7	Benedict Nene

5. **EFFORT LIMITATIONS AND GEAR RESTRICTIONS**

The mesh size on trawl nets may not be less than 50 mm, measured center knot to center knot.

6. **CATCH CONTROLS AND LIMITATIONS**

- 6.1 Whilst operating in terms of the provisions of this permit, the Permit Holder may not activate any other fishing right allocated to it.
- 6.2 Any spotted grunter (*Pomadasys commersonii*) caught may not be sold. The catch of this species must be landed in a whole state and handed over to the appropriate Ezemvelo KZN Wildlife Officer.
- 6.3 The Permit Holder may only harvest the amount of fish allocated to it in terms of the total applied effort ("TAE") allocated to it under **Section A (the permit)**. Fishing over or under these limits will result in the initiation of proceedings under section 28 of the MLRA.
- 6.4 Should the Permit Holder fails to adhere to the above conditions, the Department will (with respect to paragraphs 10.1, 10.2 and 10.3) confiscate the unauthorised gear or fish, as the case may be. The Department will implement the provisions of section 28 of the Act in all cases where the above conditions are believed to have been breached.

- 6.5 The Permit Holder may be required to install experimental by-catch reduction devices (BRD) or undertake other measures to reduce by-catch.

7. HANDLING OF OVER/UNDER CATCHES AND PROHIBITED SPECIES

Not applicable in the KwaZulu-Natal Prawn Trawl Sector.

8. VESSELS SPECIFICATIONS

- 8.1 The letter "G" must be displayed on the vessel next to the area number.
- 8.2 The Permit Holder shall not use any fishing vessel unless it bears the registration letters and numbers assigned thereto by the Director-General. Such letters and numbers shall be painted in white on a black background or in black on a white background on both bows in characters not less than 15 cm in height, 10 cm in breadth (figure "1" excepted) and 2 cm in thickness (width of stroke). The space between adjacent letters and figures shall be between 2 cm and 5 cm.
- 8.3 Radio call signs must be clearly visible and displayed as stipulated in terms of regulation 78 promulgated under the MLRA.

9. VESSEL MONITORING SYSTEM (VMS)

- 9.1 The Permit Holder's nominated fishing vessel shall be fitted with a functional Vessel Monitoring System ("VMS") approved by the Chief Director: Monitoring, Control and Surveillance (MCS).
- 9.2 It is the responsibility of the Permit Holder to ensure that the VMS is fully operational and that the VMS continues to transmit to the Department's Operations Room. The Permit Holder shall establish that the VMS unit is functional by contacting the **Operations**



Room at the Branch: Fisheries Management on telephone numbers (021) - 402 3076 or (021) -402 3077, prior to sailing.

- 9.3 The VMS shall report a minimum of 4 times a day. Should the power supply to the satellite-tracking system be interrupted or the equipment not be operational for any reason whatsoever for a period of exceeding six hours, the nature of the problem shall be reported immediately by fax to the Department at **fax number (021) 425 6497**. Should the problem persist for more than 24 hours, the vessel shall immediately return to port to have the VMS equipment repaired.
- 9.4 Vessels fitted with Inmarsat C VMS units, wishing to switch their units off whilst alongside in port, shall only do so a minimum of six (6) hours prior to their estimated time of departure from port. Should the power supply be interrupted or the equipment become non-functional (for whatever reason), and the problem persists, the vessel shall return to port within twenty-four hours of being informed of the problem.
- 9.5 Vessels wishing to switch off their VMS units whilst alongside in port, shall do so only after a minimum of 6 (six) hours after berthing, and must switch on their units a minimum of 6 (six) hours prior to the estimated time of departure from port.
- 9.6 In cases where VMS units are non-functional due to "technical" problems, and such Permit Holders/ Right Holders/ Vessel Owners/ Skippers wish to proceed to sea without a VMS unit on board, an Application for an exemption to undertake fishing without a VMS unit must be completed. This form, together with a letter from the Company who undertook the repairs (which must include the fishing vessel's name, area number and estimated time that it will take to repair and re-install the unit), must be faxed to the Department's Customer Services Centre, fax number **(021) 402 3362**, for attention Assistant Director: Customer Services Centre.
- 9.7 Should the Permit Holder/ Right Holder/ Vessel Owner/ Skipper not adhere to the provisions of the above, the Department may detain the vessel once in port and implement proceedings under section 28 of the MLRA.



- 9.8 Only once written permission has been received from the Department (i.e. an exemption has been granted), may the vessel proceed to sea. The VMS exemption must be kept onboard the vessel for the duration of each trip undertaken within the period of validity of the exemption.
- 9.9 For each fishing trip undertaken during the exemption validity period, the Permit Holders/ Right Holders/ Vessel Owners/ Skippers of such vessels shall notify the Department's Operations Room on telephone numbers **(021) – 402 3076 or (021) – 402 3077** that they are proceeding to sea, and upon arrival back in port or launching site for the duration of the exemption.
- 9.10 The Permit Holder and/or the Vessel Owner and/or the Skipper must inform the Department's Operations VMS Room at **(021) 402 3077** before 16H00, that the vessel is laying over.

10. LANDING OF FISH

- 10.1 The Permit Holder shall inform the Ezemvelo KZN Wildlife Officer in writing at least 24 hours prior to the intended time of landing of the following:
- (a) The vessel details;
 - (b) To which Right Holder(s) the catch is to be allocated/apportioned;
 - (c) The estimated total catch on board;
 - (d) The species of fish harvested;
 - (e) The estimated time of arrival; and
 - (f) The port of arrival.
- 10.2 The above information must be copied to the Ezemvelo Wildlife at fax number (031) 274 1176.
- 10.3 The Permit Holder shall ensure that all fish is discharged from the vessel in accordance with the instructions of the Ezemvelo KZN Wildlife Officer.



- 10.4 Catches may only be landed at the ports of Durban and Richards Bay.
- 10.5 The total catch retained during a trip must be discharged at one point in the presence of an Ezemvelo KZN Wildlife Officer.
- 10.6 The catch shall be weighed with an approved mass meter in the presence of an Ezemvelo KZN Wildlife Officer. No part of the catch may be retained thereafter on-board the vessel.

11. SUBMISSION OF INFORMATION

- 11.1 The Permit Holder shall submit to the Department (Right Holder Information, Attention: Deputy Director: Large Crustacean Fisheries Management, Customer Services Centre, Ground Floor, Foretrust Building, Martin Hammerschlag Way, Foreshore, Cape Town or Private Bag x2, Roggebaai, 8012) notification of any change of contact details within 30 days of such change by completing the application form available at Customer Services Centre.

11.2. Catch Statistics

- 11.2.1 The Permit Holder shall submit to the Department on a monthly basis the following catch and effort data on the stipulated Drag Book OM/EN 26/6/15 and Landing Books OM/EN 26/6/13 and 26/6/14:

- (a) The quanta of fish harvested and landed;
- (b) The species of fish harvested and landed;
- (c) The details of the vessel(s) utilised;
- (d) Whether any fish harvested was for the account of a third party, the details of such harvest (quanta and species) and the third party;



11.2.2 The above details shall be recorded in the logbook and shall be signed by the Right Holder or its authorised representative. The duplicate copies shall be retained by the Permit Holder for a period of 12 months.

11.2.3 On completion of the offloading process, the mass of the applicable landing must be completed on the Landing Report, OM/EN 26/7/3, and certified as correct by both the Right Holder or a nominated representative of the Permit Holder and the Fishery Control Officer/ Marine Resources Monitor. The name of the Permit Holder must be reflected on the landing report.

11.2.4 The Permit Holder shall furnish the statistics as prescribed on the Drag Book and Landing Book of catches to the Department (Attention: Mr Neil van den Heever, Tel. (021) 402 3127), Postal Address: Private Bag X 2, Roggebaai, Foreshore, 8012, Cape Town; or at The Customer Services Centre, Ground Floor, Foretrust Building, Foreshore), The drag and landing sheets of a trip must be handed to the Ezemvelo KZN Wildlife Officer by the Permit Holder immediately after the discharge has taken place.

11.3 **Socio-Economic Information**

The Permit Holder shall provide, on request, any economic, socio-economic or financial information in the format as requested by the Department.

12. **RECORD KEEPING**

12.1 The Permit Holder shall store at his/her registered place of business the original permit issued to him/her over the duration of the right. The Permit Holder shall at all times have available a true certified copy of this permit on board the vessel utilised to harvest the KZN Prawn trawl.

12.2 The Permit Holder shall keep the second copy of all landings for a minimum period of sixty (60) months.



13. LEVIES

- 13.1 The Permit Holder shall pay the prescribed levies for the fish landed for prescribed species as stipulated in the Government Gazette No.33518 published on 10 September 2010.
- 13.2 The Permit Holder shall submit a levy declaration form by the last working day of the month following the harvesting periods stated below in paragraph 13.3.
- 13.3 All levies and fees shall be paid monthly in arrears and by the last working day of the month following the harvesting period stated below:
- (a) **1 January 2012 to 31 December 2012.**
- 13.4 Non-compliance will result in a 10% penalty being charged on the late submission of the prescribed levy declaration form.
- 13.5 The permit holder must submit together with all levy payments a levy declaration form including:-
- (a) A copy of the relevant 'catch discharge sheet' contained in the trawl fishing log that corresponds with that month's levies; and
- (b) In cases where a vessel is harvesting the allocation of more than one Permit Holder, a copy of the distribution of 'catch among rights allocations' sheet in the trawl fishing log.
- 13.6 The Department may refuse to issue fishing permits to Right Holders who have any levies or fees outstanding for a period in excess of 30 days, or may suspend the Right Holder's fishing permit until all outstanding levies have been paid to the Department.
- 13.7 A "NIL" return must be submitted for every month where no fish has been landed.



- 13.8 All declarations forms shall be submitted to the Directorate: Revenue Management by either of the following:

13.8.1 Facsimile – 086 613 6256

13.8.2 Electronic mail – revenue@daff.gov.za

13.8.3 Postage – Private Bag x2, Roggebaai, 8012

13.8.4 By hand – Department of Agriculture, Forestry and Fisheries, Branch: Fisheries Management, Customer Services Centre, Ground Floor, Martin Hammerschlag Way, Foretrust Building, Foreshore, 8001.

- 13.9 The information required in condition 13.5 shall be submitted when paying levies to the cashier at the Department of Agriculture, Forestry and Fisheries, Branch: Fisheries Management, Branch: Fisheries Management, Customer Services Centre, Ground Floor, Foretrust Building, Martin Hammerschlag Way, Foreshore, Cape Town. Alternatively, payment can be made via direct deposit at any First National Bank (FNB) branch or Electronic Funds Transfer (EFT) to the following banking details:

Branch code – 204109

Account name – Marine Living Resources Fund

Account number – 62123256382

Deposit reference -

The Permit Holder must use its Customer (Party) Number as a deposit reference. The Permit Holder must ensure that proof of the payment together with a levy declaration is faxed to 086 613 6256 or email to revenue@daff.gov.za.

14. VIOLATIONS

- 14.1 A breach of the provisions of the MLRA or these permit conditions by the Permit Holder, or its employees (whether permanent, full-time or part-time), its contractors, agents or advisers and the skipper of the vessel, may result in the initiation of legal proceedings (which may include section 28 proceedings or criminal proceedings).
- 14.2 A breach referred in paragraph 14.1 includes, but is not limited to:



- (a) failure to provide information to which the Department of Agriculture, Forestry and Fisheries ("the Department") is entitled to or to submit information which is not true or complete; or
- (b) failure to effectively utilise the permit.
- 14.3 The Permit Holder shall not land, sell, receive or process any fish taken by any means in contravention of the MLRA.
- 14.4 The Permit Holder shall not discard any waste material, garbage or pollutants into the sea or harbour or landing site. The Permit Holder shall safely store all inorganic waste material, garbage and pollutants on board the vessel. 14.5 The Permit Holder shall not transship any fish whether at sea or at the landing site.
- 14.6 The Permit Holder shall not simultaneously collect any other species, or engage in the execution of any other fishing right, when undertaking commercial fishing of KwaZulu Natal Prawn Trawl in terms of this permit.
- 14.7 The Permit Holder shall safely store all inorganic waste material, garbage and pollutants on board the vessel. Should the Permit Holder discard any waste material, garbage or pollutants into the sea, this permit will be suspended for a period determined by the Department and the Permit Holder shall take those steps considered necessary in terms of NEMA to remedy any pollution caused.
- 14.8 Any contravention shall immediately be reported telephonically to the Customer Services Centre at **(021) 402 3180/402 3443** and thereafter shall be faxed to **(021) 425 7324**, Attention: The Chief Director: Monitoring, Control and Surveillance (MCS).
- 14.9 The Department may refuse to issue a subsequent permit should the conditions stipulated in this permit not be adhered to.



15. CONSULTATION AND COMMUNICATION

- 15.1 The Department will prefer to consult and communicate with the recognised bodies and interested groups in terms of the MLRA and which are representative of Right Holders in this fishery.
- 15.2 Communication regarding all permits and licences shall be addressed to the Department's Customer Services Centre, Ground Floor, Foretrust Building, Foreshore, Cape Town. The Customer Services Centre may be contacted on **(021)402-3180/402-3443**.
- 15.3 The Chief Director: Marine Resources Management will consult with Permit Holders when conducting performance reviews to determine further criteria against which Permit Holders will be measured.

16. OBSERVER PROGRAMME

- 16.1 The Permit Holder shall, when requested by the Department or its agent, accommodate an Observer on board the Permit Holder's nominated vessel.
- 16.2 The Observer shall be fully accommodated on board the vessel and provided with food and facilities reserved for officers.
- 16.3 The Permit Holder shall bear the costs of the Observer deployment.
- 16.4 The Permit Holder shall allow the Observer unrestricted access to monitor fishing activity and compliance with permit conditions and all applicable laws.
- 16.5 Should the Department reasonably believe that an Observer is being prevented from carrying out his/her obligations in any way or threatened in any way while on board, the Department may implement proceedings under section 28 of the MLRA

17. PROCESSING AND SALE OF FISH

The Permit Holder shall issue an invoice to the purchaser indicating the particulars of the Fish Processing Establishment, Purchaser, Permit Holder, the whole mass of Prawns sold, the date of delivery, and a copy of this receipt shall be kept for a period of sixty (60) months at the registered place of business as indicated in this permit.

18. TRANSFER OF FISHING RIGHTS

18.1 The Permit Holder may only transfer the long-term commercial fishing right allocated to it in terms of section 21 of the MLRA read together with the Policy for the Transfer of Commercial Fishing Rights (Gazette No 32449).

18.2 Any transfer of shares or sale of shares and/or or membership interest that results in a change in control or ownership of the Permit Holder must be approved by the Department in terms of section 21.

18.3 Failure to comply with paragraph 18.1 and/or 18.2 may lead to the initiation of further legal proceedings including but not limited to proceedings in terms of section 28 of the MLRA.

19. TRANSPORTATION OF FISH

Not applicable in the KwaZulu-Natal Prawn Trawl Sector.

20. FISHING PERFORMANCE MEASURING

20.1 The Permit Holder shall be obliged to provide the Department with information required to carry out a performance measuring exercise, which may include but not limited to:



- (a) data regarding transformation levels;
- (b) sustainable fishing practices;
- (c) data regarding investments made in the fishery and jobs created and sustained;
and
- (d) data regarding compliance initiatives.


DIRECTOR: INSHORE FISHERIES MANAGEMENT (ACTING)

DATE: 18 January 2012

