UNITED NATIONS UNIVERSITY
Fisheries Training Programme

unuftp.is   Final Project 2012

FISHERY BIOLOGY AND STOCK ASSESSMENT OF BLUESKIN SEABREAM (*Polysteganus coeruleopunctatus*) IN MOZAMBIQUE

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ABSTRACT

A revision and an update of some important aspects of the fisheries biology of blueskin seabream in Mozambique were made in this study. The principal objective was to assess the status of the stock of this relatively deep water species caught primarily by hook and line in Mozambican coastal waters. The exploitation of the resource showed to be highly variable in response with frequency of the fleet in relatively deep waters. It seems that depletion of the shallow water species is the driving factor for the increased fishing intensity over deepwater reefs observed in last two years. As such, catch of blueskin has increased from less than 20 tons per year to approximate 200 tons making blueskin the major demersal species caught in the semi-industrial and industrial line fishery in the last two years with 20% of the total catch. Biological evidences of the population indicate that blueskin is a hermaphrodite protogynous species. The sex ratio is biased in favour of females (1:3 M:F) and no males are found in the small size classes. The results show also that blueskin is a slow growing and long-lived species with the maximum age estimated at l22 years. Estimated von Bertalanffy parameters were L_{∞}= 40.8., k=0.104 and t_0=-1.64. The size at 50% maturity estimated was 22 cm and the corresponding age at maturity was 6 years appointing blueskin as a late maturity species. Both life span and size at maturity were much higher than estimated in previous studies. The reproduction and recruitment are continuous with fish in all maturity development stages being found throughout all year. The current instantaneous fishing mortality rate was estimated by a production model ($F_{current}$ = 0.15 year^{-1}) that is below the reference point $F_{0.1}$ (0.24 year^{-1}). The $F_{current}$ is likely estimated too low. The fishing effort in the last two years has already increased, more than threefold of the level observed from 2003 to 2010. A further increase it is not recommended. The uncertainties involved in the estimation of current *F* and the risk of growing overfishing in this species leads to necessity of assuming this more conservative position. A maximum effort should not exceed the actual 1500 fishing days for all operations in deep fishing grounds. Massive concentration of the effort in deep reefs in response to the depletion of shallow water species is not sustainable and may lead to negative impacts in both areas in a short midterm. So the managers must avoid it by promoting a redistribution of the fishing effort of the semi-industrial and industrial line fishery in a wide range area.

This paper should be cited as:
Mutombene, R. J. 2013. Fishery biology and stock assessment of Blueskin seabream (Polysteganus coeruleopunctatus) in Mozambique. United Nations University Fisheries Training Programme, Iceland [final project].
http://www.unuftp.is/static/fellows/document/Riu12prf.pdf

TALBE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The blueskin seabream (*Polysteganus coeruleopunctatus*), locally known in Mozambique as cachucho, is a demersal marine fish belonging to the Sparidae family normally found associated with rocky habitats predominantly at depths greater than 100 m (Smith and Heemstra 1986, Fisher *et al.* 1990, Mann 2000). It is a tropical species found along the western Indian Ocean, from the Red Sea to the southern coast of Natal in South Africa including the coast of Madagascar (Smith and Heemstra 1986).

In Mozambique blueskin represents a resource of great commercial value, sold in the main domestic urban markets like Maputo city, but also considerably exported to South Africa and Europe.

Target fishing for this species started around second half of the 1990s in the southern part of the country with the introduction of large industrial vessels to the line fishery[1]. Within this process, an experimental trap fishery (1997-2001) was also authorized, conditioned to operate at depths greater than 100 m which resulted in very notable contributions of blueskin to the overall landings (van der Elst *et al.* 2003, Torres *et al.* 2011). Since then, the blueskin has been considered an important component of the demersal fisheries in Mozambique where it is actually harvested by the semi-industrial and industrial line fishery fleet operating either in the region south of parallel 21°S, as well as in the central region (the Sofala Bank area) (IIP 2011, Fenessy *et al.* 2012).

Because of the multi-species character of the line fishery (more than 100 species landed) blueskin and other two shallow fish species belonging to the same family (*Chrysoblephus puniceus* and *Cheimerius nufar*) were adopted to be key indicators for the status of all demersal species of this fishery as they represent together 30-40% of the annual landings (van der Elst *et al*. 2003, Torres 2005). In that sense, the blueskin seabream is also a species of a great importance particularly from the management point of view of demersal fish resources exploited in Mozambique.

An effective management of these valuable demersal resources requires detailed biological information including the population dynamics on the species and the fisheries (Garratt 1984). In fact, in the last decade a great effort has been made by the Fisheries Research in Mozambique to produce scientific knowledge about the demersal line fish resources and their exploitation status that may be applied for a rational management. Good information has been produced and some studies of reference generated some important fisheries biological parameters of these species (Lichucha 2001, Fenessy *et al.* 2003, Van der Elst *et al.* 2003, Torres and Jakobsen 2007, Torres 2008, Fenessy *et al.* 2012). From the three species used as indicators through formal assessment models blueskin is still clearly the least studied (Mann 2000, SWIOFP 2009) because most attention were given to shallow species water which were traditionally target by line fishery for many years. There is a gap in terms of some critical biological information on the species (Mann 2000, SWIOFP 2009), and estimates of some biological parameters were only derived from a preliminary study on the species based on data collected during the implementation of trap fishery (1997-2001) (Fenessy *et al.* 2003). The recent assessments for line fishery that include this species (Torres and Jakobsen 2007, Fenessy

[1] Line fishery can be defined as an activity where fish are harvested using a hook and line but excludes the use of set longlines (Mann, 2000). Semi-industrial comprises motorized vessels with length ranging from 10 to 20 m. Industrial sector comprises vessels exceeding 20m in length.

et al. 2012) are based on these biological parameters from the preliminary study. Some of those parameters are considered questionable and others need to be updated just by take into account the change in fishing pattern that the species has subjected after the end of the trap fishery. An improved knowledge of the biological parameters of this species will allow a better estimate of the stock status and may lead to improved management actions (Cadima 2003).

The present study aims to update the fishery biology of blueskin seabream and assess the status of the species stock in Mozambique.
The specific objectives of this study are to:

- Analyse trends on catch, effort and CPUE of blueskin caught by the semi-industrial and industrial line fishery in Mozambique.
- Describe and analyse possible variations in size structure, sex ratio, length-weight relationship and size at maturity of blueskin;
- Determine the spawning season of the species;
- Determine the age and analyse the growth pattern of the species in order to obtain the growth parameters of von Bertalanffy (L_∞, k and t_0) for the species;
- Use population dynamics models to assess the status of the stock and generate biological reference points, emphasising on estimating maximum sustainable yield and optimum effort level;
- Based on the results, propose measures that may be considered precautionary for resource management.

2 REVIEW OF BIOLOGY OF BLUESKIN

The blueskin (*Polysteganus coeruleopunctatus*) is a marine finfish belonging to the family Sparidae which can be easily recognized by its fairly large eye, red pink body and blue spots in the skin, well visible on live fish (Smith and Heemstra, 1986, Fenessy *et al.* 2003). It is a relatively deep-water demersal species found associated with reefs at depths below 80 m (Torres *et al.* 2011) but more predominant below 100 m (Smith and Heemstra 1986, Mann 2000). Mann (2000) suggested a vertical segregation between juveniles and adults of this species, with the juvenile fish found at depths of 60 to 100m while adults can occur from 66 to 405m.

There are some indications to suggest the blueskin to be a protogynous hermaphrodite species (Fenessy *et al.* 2003); a sequential hermaphrodite in which sex change occurs from female to male (Allops 2003). Spawning seems to occur throughout the year (Fenessy 2003, Torres 2011).

The maximum length of blueskin that has been reported in Mozambique is 60 cm (Fisher *et al.* 1990) and 65 cm (Mann 2000). In Tanzanian waters the maximum length reported was 50 cm (Bianchi 1895). Preliminary results achieved by Fenessy *et al.* (2003) suggest that blueskin is a relatively slow growing and late maturing species.

Although interest in this species has increased in the past decade there are some critical aspects of the biology of the species that need to be better understood especially age and growth (Mann 2000, Fenessy *et al.* 2003). This is critical because fish species that grow slowly and mature late are often vulnerable to over fishing (Coleman 2000). Accurate estimates of length or age at maturity are critical for the conservation of exploited fish stocks. Age at maturity is particularly important, as it strongly influences population model estimates of sustainable harvest rates (Clark 1991). The growth rates of a fish population are essential components in the assessment of exploited population dynamics (Campana 2001) because von Bertalanffy growth parameters (L_∞, k and t_0) are inputs into many assessment methods.

Also, most of the information available for blueskin was derived from data obtained prior to year 2000 (Fenessy *et al.* 2003, Torres *et al*. 2011). Since it is known that fisheries can change the parameters of exploited populations (size at maturity, maximum length) (Stokes and Law 2000, Ernande *et al.* 2003) the evolution of these parameters should be monitored. Many of them are useful indicators of the health of the stock and can be used to avoid risk of overexploitation (Begg *et al.* 1999).

3 REVIEW OF EXPLOITATION OF BLUESKIN IN MOZAMBIQUE

Exploitation of blueskin in Mozambique is primarily associated with the semi-industrial and industrial line fishery which can be classified as a commercial-formal[2] segment that is authorized to harvest marine fish using primarily hook and line (Table 1). It is a multispecies fishery with catches comprising of about 100 species, mainly demersal reef-fishes.

Table 1. Summarized description of fisheries segments that potentially exploited blueskin in Mozambique, (trap fishery was terminated in 2002).

Fishery type	Sector	Vessel length	Number vessels	Crew	Gear	Comments
Line fishery	Semi-industrial	10-20m (Port-based)	30	10-15	Rod + line (manual)	Iced catch
	Industrial	>20m (Port-based)	2	15-25	Rod + line (manual)	Frozen catch; quota controlled
Trap fishery	Industrial	>20m (Port-based)	-	10-20	Traps (longline traps)	Experimental (1997-2001)

This fishery started with a few semi-industrial vessels during the 1980s and expanded quickly at the beginning of 1990s with historical peak of catches recorded in 1993 and 1994 as result of the rapid increase in effort (Lichucha 2001, Torres 2005, Torres and Jakobsen 2007, SWIOFP 2009). At that time the operations were mainly confined in the Southern region, between Ponta Závora (24° 30’S) and Ponta de Ouro (26° 52’S), focusing on shallow water demersal species like the seabreams *Chrysoblephus puniceus* and *Cheimerius nufar*, and groupers (Serranidae) (Lichucha 2001, Torres 2005, Torres and Jacobsen 2007, SWIOFP 2009). The concentration of the effort of the semi-industrial fleet in the shallow fishing grounds promoted a progressive decrease in abundance of main shallow water demersal reef fish (Torres *et al.* 2011). This lead the authorities to stimulate the introduction of large industrial vessels to the line fishery in 1997 as an initiative to promote the expansion of the fishery to deep water fishing grounds (Torres *et al.* 2011). This initiative was also accompanied by an attempt to diversify the fishing methods resulting in the authorization of an experimental trap fishery. In 1997 two vessels were involved in this fishery but from 1998 only one vessel operated with traps (Torres *et al.* 2011).
The trap fishery was licenced to operate at depths greater than 100 m and blueskin was the main species caught by this fishery (Torres *et al.* 2011). Both an assessment of the line fishery

[2] As opposite to artisanal fisheries which are highly informal

in 2000 conducted by *Instituto Nacional de Investigação Pesqueira* IIP (Van der Elst *et al.* 2003) and the specific study conducted by Torres *et. al* (2011) describe in detail the implementation of this fishery. Despite being implemented by only one vessel the number of traps used per trip increased progressively from 25 traps in 1997 to 300 traps in 1999. Because of this increase of effort, the annual trap catches increased from 30 tons in 2007 to 300 tons in 2001, more than 50% of line fishery catch level in 2001 (Torres and Jakobsen 2007). An increase in frequency of the operation of this fishery at depths less than 100 m, were also noted, resulting in a progressive decrease of blueskin in the trap catches and an increase of relatively shallow water species like *C. puniceus* and *C. nufar*. In 1997 blueskin represented 70% of the trap catches in weight but in subsequent years (1998, 1999 and 2000) the contribution was 50%, 30% and 22% respectively (Van der Elst *et al.* 2003, Torres *et al.* 2011).

In general, it seems that the introduction of those large vessels including the trap fishery only increased the pressure on the shallow water recourses in the southern region leading to an "economic overexploitation" (Van der Elst *et al.* 2003). Consequently, many vessels left the fishery and others shifted the operations to the north, expanding effectively the line fishery to the Sofala Bank area. The trap fishery was terminated in 2002 and a maximum of 25 boats were declared as limit for the management region south of 21°S.

Line fishery can also include the artisanal and recreational sectors (Lichucha 2001, Van der Elst *et al.* 2003, Fenessy *et al.* 2012). However, it is unlikely that these two sectors are catching the blueskin as they are normally confined to the inshore and shallow water fishing grounds. For the artisanal sector the operation range is limited mainly by the capacity of the vessels with many using paddle or sail; only a few are engine powered (Lichucha 2001, IDPPE 2007, Fenessy *et al.* 2012). For the recreational sector there are some restrictions in terms of number of fish taken per day, particularly for demersal fishes. For blueskin only four fish can be taken per fisher per day (Decree 51/99). In fact, this sector is primarily targeting pelagic game fish although demersal fish are also taken (Fenessy *et al.* 2012). Furthermore, great part of the practitioners operates from the shore (without boat).

According to Fenessy *et al.* (2003) blueskin was also taken as by-catch in the industrial deep water trawl fishery (200-700 m depth) but there is no evaluation of the impact of this fishery on this species and this study will not deal with that subject.

4 METHODS

4.1 Area of study

The study was conducted in southern and central Mozambique coastal regions, within the continental shelf, where the semi-industrial and industrial line fish vessels based in Maputo, Inhambane, Vilankulos and Beira harbours normally operate (Figure 1). This includes areas where the substrate is predominantly hard (reef) in bathymetric depths between 25 to 200 m. For purposes of management of the semi-industrial and industrial line fishery, the Mozambican coast has been subdivided into two areas; the south of parallel 21°S region and the north of 21°S region (Figure 1). In the northern 21°S the semi-industrial and industrial line fishery has been confined to the Sofala Bank area (21°S-18°S) with no fleet operating northern of 18°S parallel. Despite this formal division, the analysis made for blueskin in the present study considered the entire line fishery area as unit.

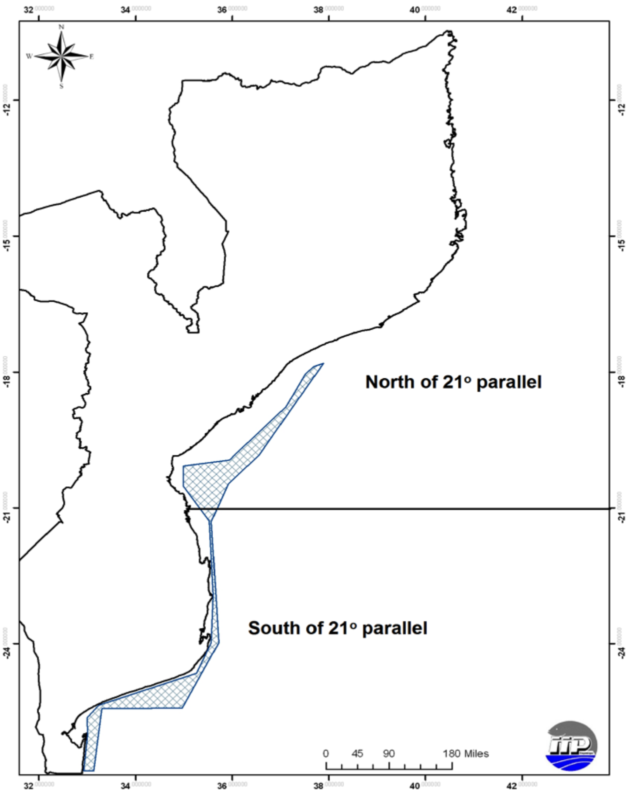

Figure 1. Semi-industrial and Industrial line fishery operation area in Mozambique (blue area) divided into the two recognised management areas.

4.2 Data collection

The present study used data collected through sampling on board of semi-industrial and industrial line fishing vessels between 2003 and 2012. The data included catch and effort (in fishing days, but also used the depths where individual fish was caught) as well as biological data (length, sex and maturity stages).

Additional sampling was made in 2011 and 2012 for collection of otoliths and other data. An attempt was made to sample at least 30 specimens per month, from caches of commercial vessels operating in the southern region. Sampling was relatively irregular but 7 months were covered and a total of 240 fish were sampled. Each fish was measured both fork and total lengths using a measuring board with an accuracy of 0.5 cm and weighted using a balance with a precision of grams. Sex and stage of gonadal tissue maturation was identified macroscopically for each fish, assuming the classification adapted from Fenessy *et al*. (2003) as displayed in Table 2. The pair of otoliths (Sagittal) of each fish were extracted, washed in running water for removal of secular membranes, dried and stored in envelopes for later determination of age.

Table 2. Description of macroscopic gonad stages of *Polysteganus coeruleopunctatus*. Adapted from Fenessy *et al.* (2003).

Stage	**Condition**	**Female**	**Male**
1	Inactive/ Immature	Ovaries with no development, round in cross-section and translucent yellow.	Testes are thin and off-white in colour.
2	Active	Ovaries are swollen and yellow-orange in colour, with eggs just visible	Testes are white and small amounts of sperm are visible if the gonad is cut and squeezed.
3	Ripe	Ovaries are yellow-orange, swollen and extend most of the body cavity. Eggs are clearly visible and hydrated eggs may occur in very ripe ovaries. Ovarian blood vessels may be numerous.	Testes are white, large and sperm is easily extruded from the sperm duct.
4	Spent	Ovaries very flaccid, reddish in colour Few residual eggs may be present	Testes empty, flaccid, of pale yellow colour

4.3 Laboratory analysis

Otoliths of blueskin are thick and opaque, so for ageing they needed first to be sectioned. A protocol on otolith preparation (sectioning process) was adopted after some trials on 43 otoliths of blueskin at the Marine Research Institute (MRI) Iceland (Appendix I).

After sectioning, a photo of each otolith was taken using a digital camera (DFC 295) under a microscopy (Leica M165 C) with transmitted light. The interface software Leica application suite V4 was employed for that. Then the translucent zones were counted by displaying the photos in Image J software. The number of translucent zones represent the age of the fish. For evaluation of the precision of the age determination, two readers conducted the first reading together on 50 otoliths assuming this as a trial event. After three weeks the two readers conducted independent readings on the same otoliths. The collection and fish numbers were the only identifiable information used in the readings. Given that the first reading was a trial, only the second and third readings were used in the reading agreement analysis. This was similar to the methodology adopted by other authors (Brouwer and Griffiths 2004, Anderson *et al.* 2009).

4.4 Data and Statistical analysis

4.4.1 Effort, Catch and CPUE

Trend in the fishing effort, catches, and CPUE of blueskin was analysed by plotting the annual historical data from on-board sampling between 2003 and 2012. The statistical program SPSS 20.0 was used to do the analysis between the depth and total amount of blueskin landed.

4.4.2 Size structure and Sex ratio

The size structure was analysed using the statistical program *R* by plotting the histogram of annual distributions of the lengths of males and females, and for both sexes combined. A t-test was used to compare the average annual sizes of males and females. Non parametric Wilcoxon test was used to assess if the sex ratio was significantly different from 1:1.

4.4.3 Length-weight relationship

The *R* program was also used to study the length-weight relationship of blueskin. This was determinate for males and females combined, based on a non-linear least-squares method on the following equation:

$$(1)\ W = aL^{b},$$

Where:
W= weight (g),
L= total length (cm),
a = a constant,
b= growth exponent.

Allometric growth was assessed based on the value of exponent *b* which denotes the relative change in proportion of body mass compared to the length during the growth of the organism. When b=3, increase in weight is isometric. When the value of *b* is other than 3, weight increase is allometric, positive allometric if b>3 (the fish grows faster in weight than in length) and negative allometric if b<3(the fish grows faster in length than in weight) (Karachle and Stergiou 2012).

4.4.4 Spawning season

The period of reproductive activity was determined by assessing the state of development of the gonads on a monthly basis. It was done by analysing the monthly proportion of females at different stages of maturation.

4.4.5 Length at maturity

The length at maturity curve was analysed in the *R* statistical program using the data form 2011 and 2012. Only females and immature fish data were used for this analysis. This was based on the suspicious that the species is hermaphrodite protogynous and on fact that is difficult to distinguee macroscopically if immature fish are male or female.
The size at 50% maturity was determined by examining the relative monthly proportions of mature (which included active, ripe and spent stages) fish and immature fish, and fitting a logistic curve;

$$(2)\ Y = 1/1 + \exp(-(X_{mid} - X_{0.5})/\delta)$$ (Butterworth *et al*. 1989)

Where:

Y = proportion of mature fish in length class X
X_{mid} = is the midpoint of the class interval at length X
$X_{0.5}$ = length at 50% maturity
δ = is a constant of the length of the maturity ogive.

4.4.6 Age and Growth

Precision of age reading was assessed using three variants: average percentage error (APE) (Beamish and Fournier, 1981), coefficient of variation (CV) and index of precision (D) (Chang, 1982).
These were calculated as:

(3) $$\mathrm{APE}_j = 100\% \times \frac{1}{R}\sum_{i=1}^{R}\frac{|x_{ij} - x_j|}{X_j}$$ (4) $$\mathrm{CV}_j = 100\% \times \frac{\sqrt{\sum_{i=1}^{R}\frac{(X_{ij} - X_j)^2}{R-1}}}{X_j}$$ (5) $$\mathrm{D}_j = \frac{\mathrm{CV}_j}{\sqrt{R}}$$

Where:
Xij = is *i*th age determination of the *j*th fish
Xj = is the average age for the *j*th fish
R= is the number of times each fish is aged

The present study assumed that one opaque band and one translucent band is laid down per year as has been adopted in other studies for Sparid species including blueskin (Fenessy *et al. 2003*), the congeneric *P. undulosus* (Chale-Matsau 2001), C. *puniceus* (Lichucha 2001) and *C. nufar* (Torres 2008).

Growth was investigated by fitting the von Bertalanffy growth function to size at age data using standard nonlinear optimization methods in *R* program. The von Bertalanffy growth function is defined as follows;

$$(6)\ L_{(t)} = L_\infty (1 - e^{-K(t - t0)}).$$

Where:
$L_{(t)}$ = the length of the fish at age *t*
t_0 = the hypothetical age of the fish when *L* is equal to zero
L_∞ = the asymptotic average maximum length
K = instantaneous growth rate (the rate at which the $L_{(t)}$ approaches L_∞)

4.4.7 Population dynamic

To conduct a formal stock assessment, it is necessary, to model the dynamic behaviour of the exploited stock. One objective is to describe how the stock has responded to varied fishing pressure. By studying the impacts on a stock of different levels of fishing intensity it is possible to assess its productivity (Haddon 2001). In the present study the biomass production model was used and yield-per-recruit analysis was made.

Estimative of Mortality rates

The instantaneous rates of mortality (*M* and *Z*) was analysed in the FAO statistical program FiSAT II (version 1.2.2).

The instantaneous natural mortality rate (*M*) was estimated using the empirical Equation of Pauly;

$$(7)\ \mathrm{Ln}(M) = -0.0066 - 0.279\ln(L_\infty) + 0.6543\ln(K) + 0.4634\ln T$$

Where:
L_∞ = the asymptotic average maximum length (cm)
K = VBGF instantaneous growth rate ($year^{-1}$)
T = mean environmental temperature over the range of the species (°C)

A mean environmental temperature (T) 20° C was taken in this study.

Other independent estimate of *M* was obtained from the Rikhter and Efanov equation, which requires an estimate of the age at 50% maturity ($t_{mat50\%}$).

$$(8)\quad M = \frac{1.521}{(t_{mat\,50\%})^{0.720}} - 0.155$$

The instantaneous rate of total mortality (*Z*) was estimated using the linearized length-converted catch curve. This method uses the von Bertalanffy growth equation to convert the length composition of the catch into ages (Sparre and Venema 1998). Only data of length composition of 2011 and 2012 were used for this analysis. In FiSAT II, the natural logarithm of the number of fish in each age class was plotted against the corresponding age and *Z* was estimated from the descending slope of the best fitted line using least square linear regression.

The actual instantaneous rate of fishing mortality (*F*) was calculated by subtracting the natural mortality rate (*M*) from the total mortality rate (*Z*);

$$(9)\ F = Z - M$$

The exploitation rate (*E*) was calculated as the proportion of the fishing mortality relative to total mortality;

$$(10)\ E = F/Z)$$

Biomass production model

The statistical program R was used to model the biomass, recruitment, exploitation ratio, yield and Index of abundance of blueskin during the period 2003 to 2012, in the Mozambique.

The input data into the model was catch and CPUE obtained for the semi-industrial and industrial line fishery. The model's predictions of annual catches (yield) and CPUE (index of abundance) was then compared to the observed data. The model incorporated recruitment, natural mortality and weighting correction factors.

The estimation of annual biomass for blueskin was based on the model of population number:

$$(11)\ N_{y+1} = N_y + R_y - C_y$$

Where:
R_y = recruitment in year y,
N_y = number of fish that survive in year y
Cy = catch in the corresponding year.

Biomass was then calculated by:

$$(12)\ By = \sum (N_{ay} * W_a)$$

Where:
N_{ay} = number of fish in a particular age (a) in year (y)
W_a = mean weight of fish at age a.

Yield per recruit and Spawning stock per recruit

Yield per recruit and spawning stock per recruit was estimated for different levels of fishing mortality using R program (Stefansson 2011a).

$$(13)\ \frac{Y}{R} = \sum \frac{F_a}{Z_a}(1 - e^{-Z_a}) w_a e^{-\sum_{a'<a} Z_{a'}}$$

From the yield per recruit curve the reference points F_{max} and $F_{.01}$ can be estimated. F_{max} corresponds to the level of fishing mortality that produce the maximum yield per recruit.

When fishing mortality is increased from zero, the catches increase dramatically, as implied by a steep slope of the yield-per-recruit curve at the origin. As F increases, the slope gets reduced, until it becomes zero at $F = F_{max}$ (Stefansson 2011b). The fishing mortality at which the slope of the Y/R-curve has become one tenth of the slope at the origin is denoted $F_{0.1}$ (Stefansson 2011b). At this fishing mortality the marginal gain in yield is only 10% of the initial marginal gain when fishing is started. The $F_{0.1}$ fishing mortality may be thought of as a simple approximation to the economically optimal point on the curve (Stefansson 2011b). So, $F_{0.1}$ indicates an approximate level of fishing mortality that will result in maximum economic yield.

The spawning stock biomass was used in this study in the same way as yield per recruit according the procedures described by Stefansson (2011b).

The corresponding values of biomass when the fishing mortality is F_{max} and $F_{0.1}$ were estimated from the spawning biomass per recruit curve. These values of stock biomass are denoted as B_{max} and $B_{0.1}$ respectively.

5 RESULTS

5.1 Effort, Catch and CPUE from 2003-2012

The overall effort of the semi-industrial and industrial fleet has been increasing continuously, more than doubling from 2003 to 2012 (Figure 2). Although the preference appears to be for shallow fishing grounds (25- 75 m) there is some year that occurs a considerable increase in the frequency of the fleet in the mid-deep reefs (>75 m), as was the case of last two years (Figure 2).

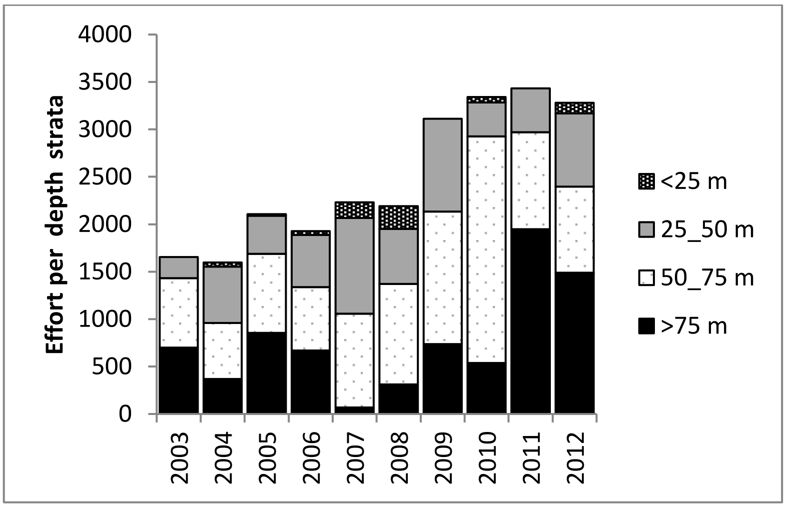

Figure 2. Distribution of the effort (in fishing days) of semi-industrial and industrial line fishery in different deep strata the by depth strata.

Because blueskin is known to occur only at depths greater 70-80 m, the effort considered for the analysis in this study was the partial effort in fishing days that the fleet spends at mid-deep reefs. From 2003 to 2010 the average effort observed over blueskin target depths was around 530 boat days, but in 2011 and 2012 the pressure on the mid-deep reefs rose to around triple of that (Figures 2 and 3).

Total catch of blueskin landed in 2003 was around 117 tons, but in subsequent years the catches were low (Figures 3). From 2006 to 2010 the average catch was less than 20 tons per year. However, in 2011 total catch of the species increased tremendously reaching 263 tons (Figure 3).

The highest CPUE was observed in 2003. Since then it has been following the same trend of catches and effort, with fluctuations throughout the time series (Figure 3).

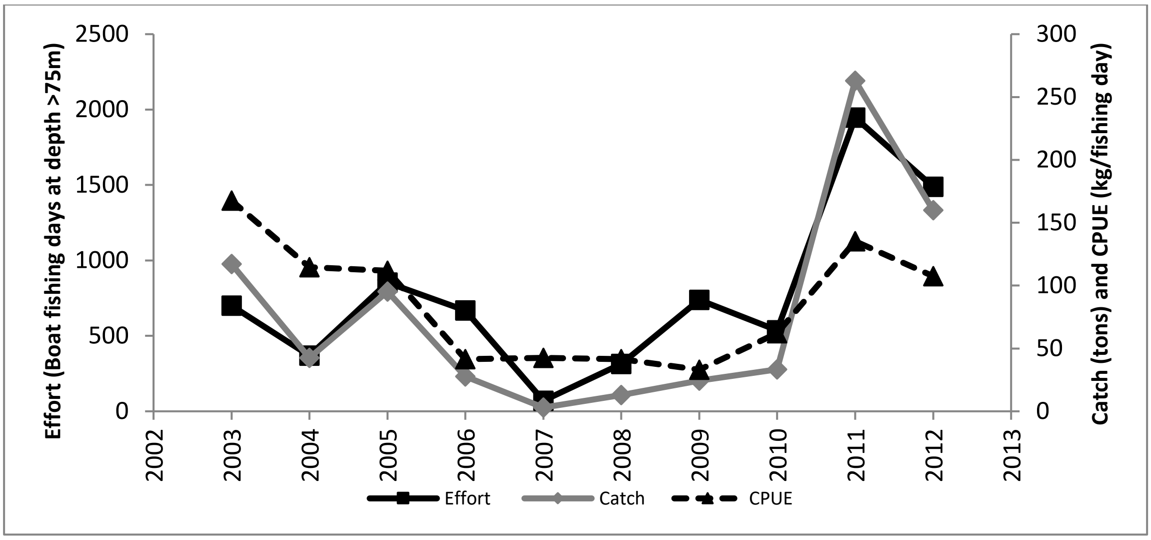

Figure 3. Annual catches of blueskin (tons), effort (boat fishing days at depth greater than 75m) and CPUE (kg of blueskin per boat fishing day at depth >75m).

5.2 Size structure and Sex ratio

The average annual length of blueskin caught in 2003-2012 ranges from 26cm to 33cm (Table 3). The year 2007 was omitted from the analysis because of very low sampling size.

Table 3. Average annual fork length of blueskin landed from 2003 to 2012.

Year	2003	2004	2005	2006	2008	2009	2010	2011	2012	Overall data
Average Length (cm)	28.1	32.7	29.6	27.8	26.7	28.3	26.2	28.6	31.1	29.3
+SD (±)	4.0	6.2	5.6	4.2	3.5	6.4	3.4	4.3	4.3	4.9
N	1701	1256	2013	2022	421	442	264	5097	3614	16830

The summary of annual the length statistics for each sex is presented in table 4. The annual average length of males was significantly greater than females ($p<0.01$, $t=4.682$, $n=10$). The sex ratio obtained for blueskin throughout the period of study was significantly different 1:1 ($p<0.01$, $Z=-2.934$). It was consistently greater than 1:2 (male:female). Based on the data of the overall period a sex ratio of 1:2.8 (male:female) was found (Table 4).

Table 4. Average fork length of males and females (fork length) and sex ratio of blueskin landed from 2003 to 2012.

Year	Males			Females			(M:F) Sex ratio
	Average length (cm)	SD (±)	N	Average length (cm)	SD (±)	N	
2003	31.2	3.8	384	27.0	3.4	1009	1: 2.6
2004	39.0	5.8	262	31.2	5.1	941	1: 3.6
2005	33.5	4.9	586	28.0	5.1	1424	1: 2.4
2006	32.0	4.0	430	26.6	3.5	1582	1: 3.7
2008	30.4	3.1	108	25.4	2.6	313	1: 2.9
2009	32.0	4.7	116	27.0	6.5	326	1: 2.8
2010	29.4	2.3	77	24.9	2.9	187	1: 2.4
2011	33.5	2.9	1211	27.0	3.4	3866	1: 3.2
2012	34.4	3.9	1193	29.4	3.5	2403	1: 2
Overall data	33.5	4.3	4367	27.8	4.2	12051	1: 2.8

In general, the main landed lengths range from 20 to 40 cm (Figure 4). It was found consistently females in small length classes and males in the larger length classes (Figure 4).

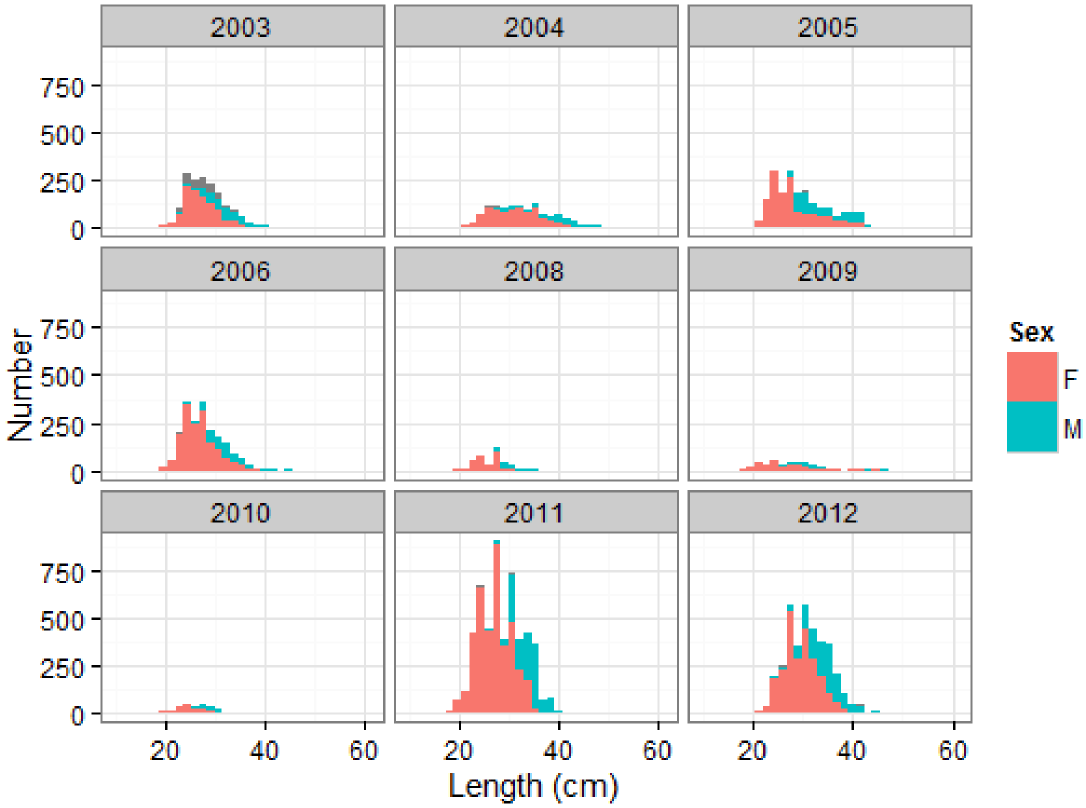

Figure 4. Annual length distribution of males and females of blueskin harvested by semi-industrial and industrial line fishery from 2003 to 2012.

Using the overall data of the decade it was found 75% of the landed females ranging from 20 to 30 cm and 23% ranging from 30 to 40 cm. Oppositely, for males 26% were ranging from 20 to 30 cm and 67% ranging from 30 to 40 cm (Figure 5).

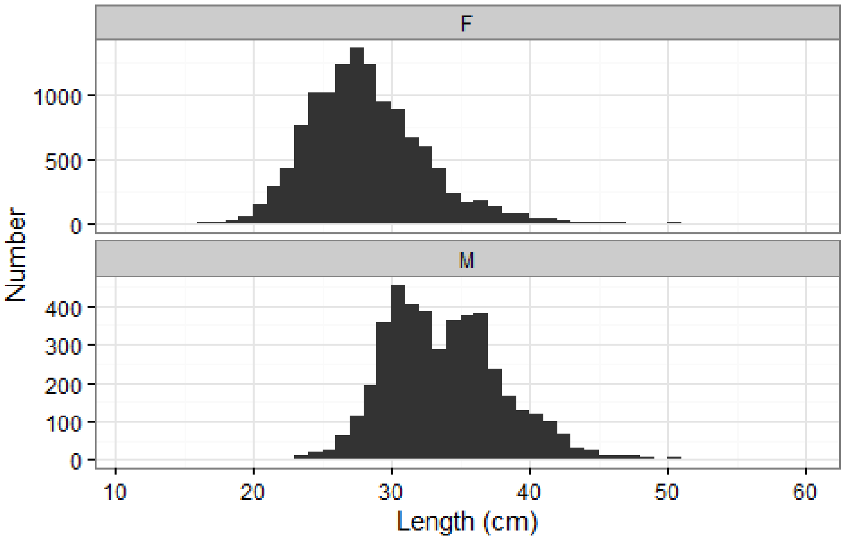

Figure 5. Overall male (n=4371) and female (n=12060) length distribution from data collect from 2003 to 2012.

5.3 Length-Weight relationship

The length-weight curves for males and females were similar (Figure 6) so it was decided to make the analyses considering all sex data combined.

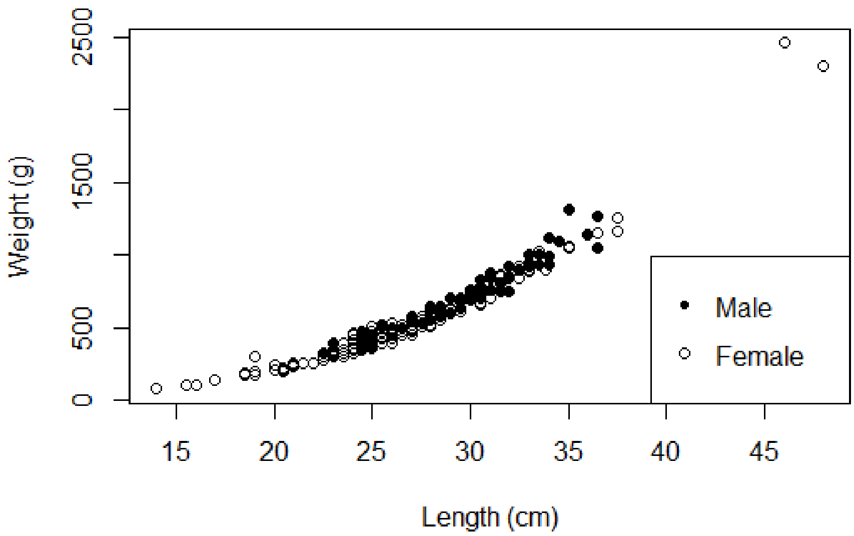

Figure 6. Length-Weight relation for females (n=172) and males (n=63) of blueskin based on data collected in the years 2011 and 2012.

Plotting males and females together, the relation between the body size and weight can be described as W (g) = $0.047*L^{2.826}$ (cm) ($p<0.01$, $R^2=0.972$) (Figure 7).
The value of *b* below to 3 suggests a slightly negative allometric variation of the proportion of body mass comparatively to size.

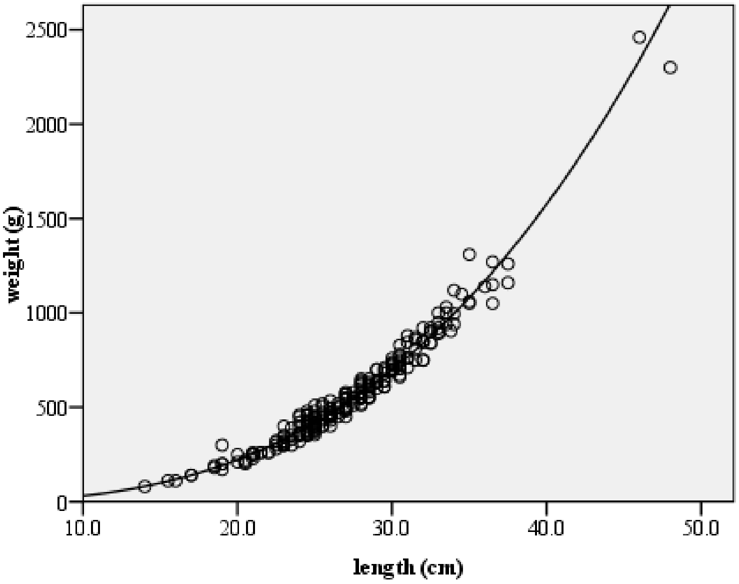

Figure 7. Length-Weight relation for blueskin (combined sexes) (n=235) caught by semi-industrial and industrial line fishery in the years 2011 and 2012.

5.4 Spawning season

The plot of relative monthly occurrence of reproductive stages in landed fish shows that all stages can potentially be found during any period of the year (Figure 8). Some years presented a low number of samples and it was preferred to omit them but the same pattern was observed even in those years.

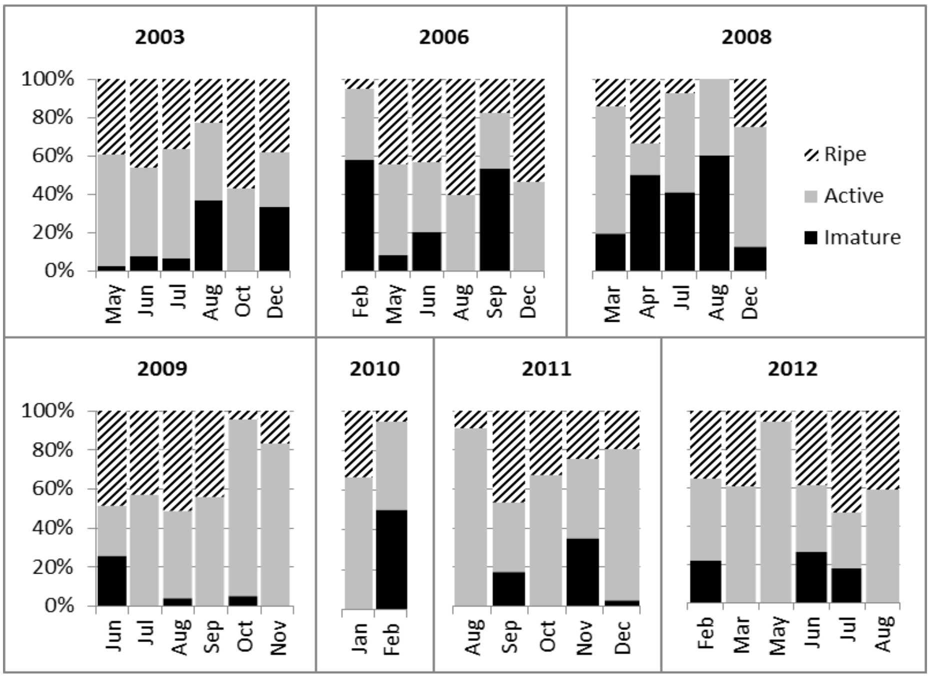

Figure 8. Monthly proportion of gonad state of blueskin based on data collected in the years 2003, 2006, 2008-2012.

5.5 Size at maturity

Size at 50% maturity for females of blueskin was estimated as 21.7cm (Figure 9).

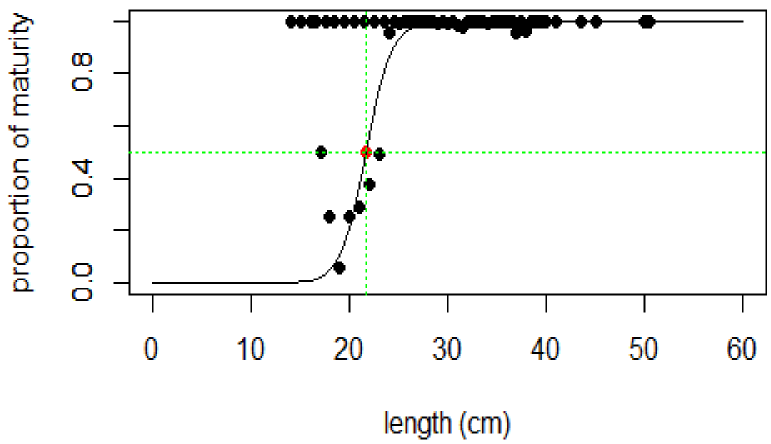

Figure 9. Size at 50% maturity for females sampled during 2011 and 2012 (n=6267).

5.6 Age and Growth

From a total of 241 sectioned otoliths, only six were discarded because of lacking a visible pattern. Figure 10 shows sectioned otoliths of blueskin with the translucent rings counted.

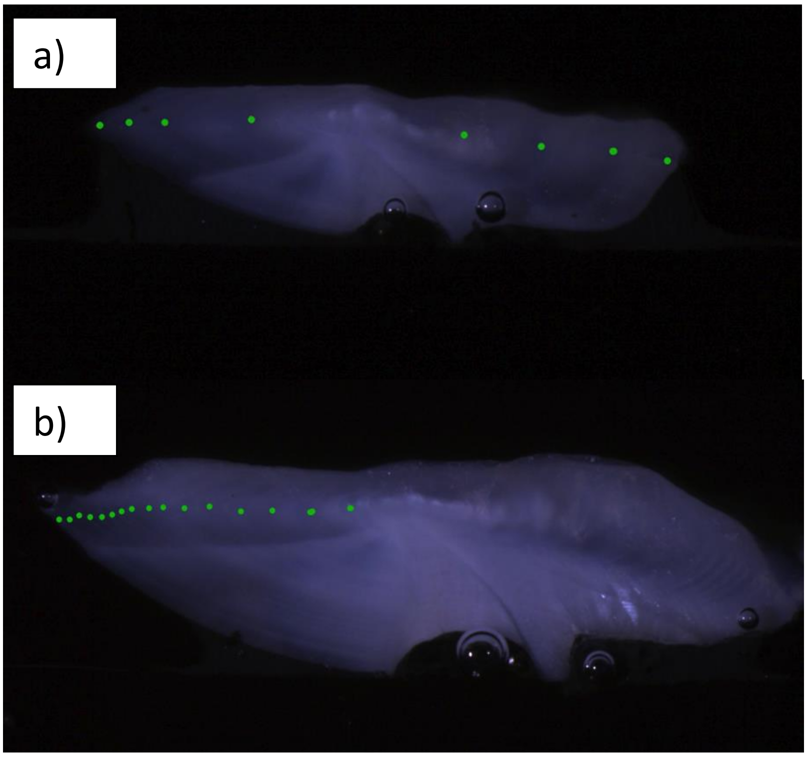

Figure 10. Sectioned otoliths of *P. coeruleopunctatus* with translucent zones counted. It was estimated 4 and 16 years for the otoliths *a*, *b* respectively**.**

The average percentage error (APE) value calculated for the two sets of age determination was found to be 1.68% while the coefficient of variation (CV) was 2.37%. Because there were only two readings the precision index D was also 1.68 as the APE (Chang 1982). These results indicate good agreement between readings (see *Table 2* in Appendix II).

The estimated ages for sampled fishes ranged from 3 to 22 years (Table 3 and 4 in the Appendix II). The range of the fork length for those fishes was 14 to 48cm (Table 3 and 4 in the Appendix II).

Because the von Bertalanffy growth curve was strongly influenced by the last two observations (FL=46 and 48 cm) it was decided to exclude them in the estimation of growth parameters (Table 5, Figure 11). The estimated von Bertalanffy growth parameters were L_∞=40.8cm, K=0.104 year $^{-1}$ and t_0=-1.64 year.

Table 5. Observed mean length at age (cm FL) and expected lengths derived from the von Bertalanffy growth parameters for *P. coeruleopunctatus* in Mozambique.

Age	Mean length at age ± SD (Observed)	Expected Length	*N*
3	14.75 (±1.06)	15.58	2
4	16.67 (±0.58)	18.06	3
5	20.12 (±1.28)	20.30	13
6	22.26 (±1.27)	22.32	21
7	24.94 (±0.84)	24.14	39
8	25.5 (±1.13)	25.78	31
9	27.31 (±1.15)	27.26	27
10	28.25 (±0.99)	28.60	20
11	29.31 (±1.68)	29.80	21
12	30.68 (±1.17)	30.88	17
13	32.09 (±1.48)	31.86	14
14	32.09 (±1.74)	32.74	11
15	34.44 (±2.03)	33.54	8
16	34.0 (±1.15)	34.25	4
17	37.5	34.90	1
18	37.5	35.48	1

The von Bertalanffy growth curve of blueskin can then be defined by the function; $L_{(t)}$= 40.8 cm FL/ (1-exp (-0.104 year $^{-1}$ (t+1.64 years) (Figure 11).

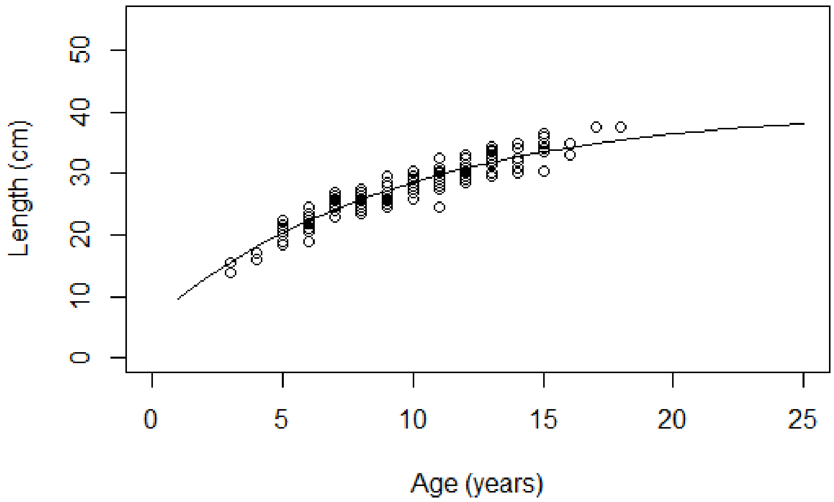

Figure 11. The von Bertalanffy growth curves for blueskin, *P. coeruleopunctatus*, from Mozambique.

5.7 Population dynamic

5.7.1 Mortality rates

Using Pauli's equation (chapter 4.4.7.1) assuming an environmental temperature of 20°C the instantaneous rate of natural mortality (*M*) for blueskin was estimated to be 0.32 year^{-1}. By using Rikhter and Efanov equation (chapter 4.4.7.1) the value of *M* was estimated as 0.26 year^{-1}.

Catch curve analysis on FiSAT II, estimated instantaneous rate of total mortality (*Z*) as 0.35 year^{-1} (r=0.97) (Figure 12).

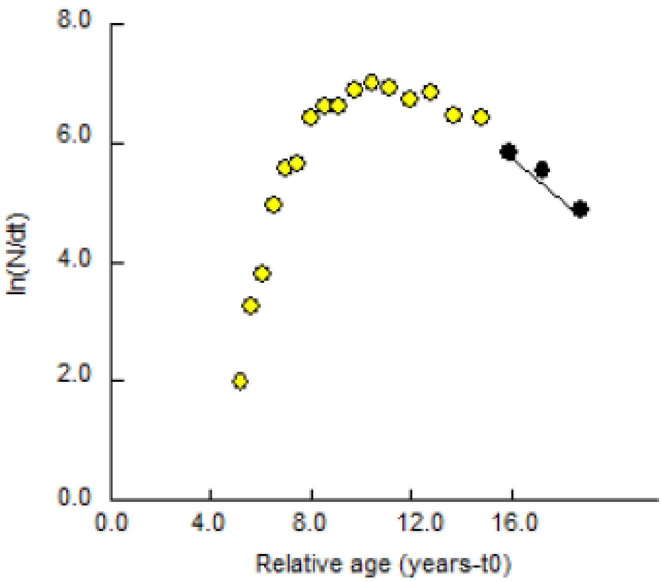

Figure 12. Linearized length-converted catch curve based on length composition data for blueskin.

By using the equation F=Z-M, the estimated instantaneous rate of fishing mortality based on Pauli's natural mortality was close to zero (0.032) meaning that there is practically no blueskin fishery. It is rather unrealistic. Assuming the natural mortality estimated based on Rikhter and Efanov equation the estimated value of F was 0.09 year^{-1}. Based on this last result an exploitation ratio *E*= 0.26 was estimated.

5.7.2 Biomass production model

The current fishing mortality rate (*F*) was estimated to be 0.15 year^{-1} by a biomass production model (Figure 13). The estimated *F* by the model is above to the value of *F* calculated using *M* estimated by the Rikhter and Efanov equation and *Z* from catch curve. The value of *F* ($F_{current}$=0.15) estimated by the biomass model was adopted for further analysis.

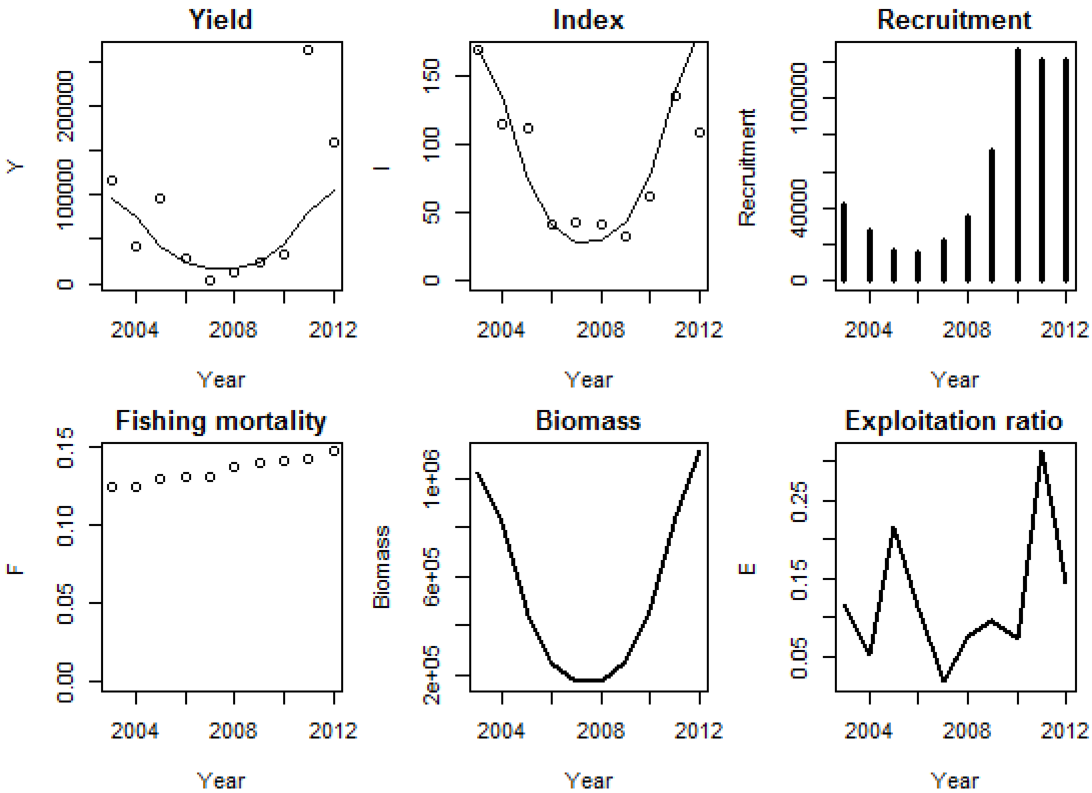

Figure 13. Yield, Index of abundance, recruitment, fishing mortality, biomass, explotation ratio resulting from the biomass prodution model for blueskin.

Figure 13 shows that the model doesn't fit well to the data. The estimated yield fits poorly at the end of the time series and so does the index of abundance in the last year. The yield was estimated much low in the last two years and index of abundance was estimated much higher than the value observed in 2012. Therefore, the estimated fishing mortality is most likely too low. However, there is a trend of increase of fishing effort during the years (Figure 13) like it has been observed.

5.7.3 Yield per recruit and Spawning biomass per recruit

Table 6 summarizes the input parameters utilised in the per recruit analyses. The estimated fishing mortality from the biomass production model ($F_{current}$ = 0.15 $year^{-1}$) was used for purposes of comparison only with the output reference points from the yield per recruit and biomass per recruit in order to assess the status of the stock.

Table 6. Values of estimated biological parameters for blueskin used for per recruit analyses.

Parameter	Estimated value
L_∞	40.8 cm
K	0.104 $year^{-1}$
t_0	-1.64 year
A	0.047
B	2.826
t_c	7 years
t_m	6 years
M	0.26 $year^{-1}$

From the yield per recruit curve F_{max} was estimated to be 0.41 $year^{-1}$ and $F_{0.1}$ as 0.22 $year^{-1}$ (Figure 14) (values scaled to the maximum yield per recruit and virgin biomass). The fishing mortality estimated by the biomass production is lower than F_{max} and $F_{0.1}$ (Figure 14).

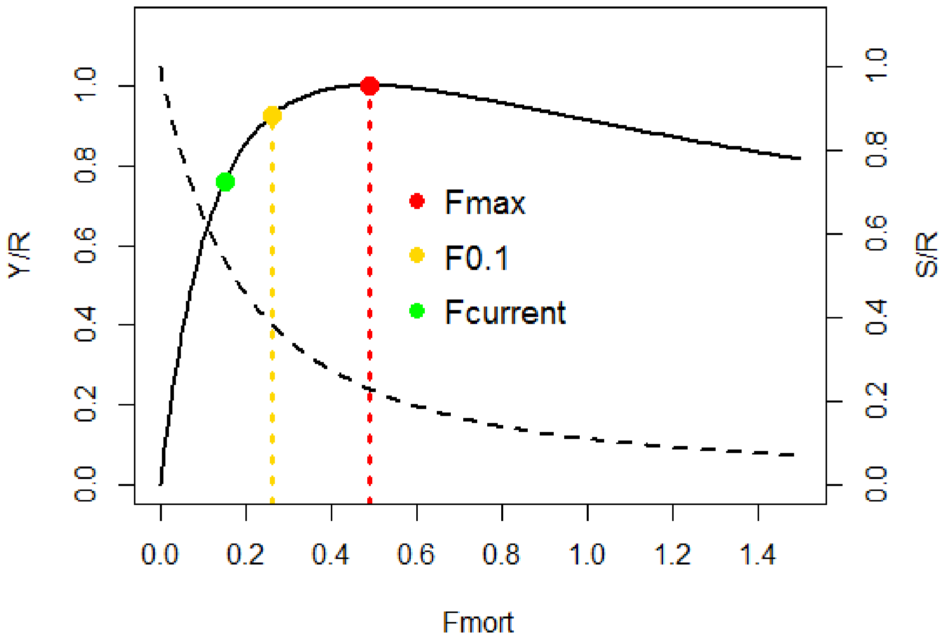

Figure 14. Yield per recruit (Y/R) and spawning biomass per recruit (S/R) curves for blueskin caught by semi-industrial and industrial line fishery in Mozambique. The values in the *y* axis corresponds the proportion of Y/R and S/R in relation to the maximum yield per recruit and virgin biomass respectively.

The maximum yield per recruit is obtained when the biomass is reduced to 24% of the virgin biomass (unexploited level) (Figure 14). This value of biomass that correspond the maximum Y/R is called $B_{max.}$

The yield per recruit that correspond to $F_{0.1}$ is obtained when the biomass is reduced to 40% of the virgin biomass. This value of biomass is called $B_{0.1}$ and the correspondent yield is $Y_{0.1.}$

6 DISCUSSION

6.1 Effort, Catch and CPUE

Since the experimental trap fishery of blueskin discontinued in 2002 the species has primarily been harvested by the semi-industrial and industrial line fish fleets.

Although the preference is for shallow reef species, the fishery has at times target mid-deep reefs below to 75 m. In fact, this has been partially the cause of good catches of blueskin in some years followed by years in which the species is poorly represented in the overall catch of the line fishery because blueskin only occurs from depths greater than 80 m. No catch of blueskin was recorded in depths shallower than 70m. These observations suggest that variation of the blueskin catches in Mozambique may not only be explained by variation of the stock abundance but also by the change of fishing grounds by the line fishing fleet.

The depth dependence of blueskin catches was also reported by Torres *et al.* (2003) during the implementation of trap fishery. According to the authors the reduced effort in deep waters observed from 1997 to 1999 was the main cause for the declining in catches of blueskin. However, the authors did not consider the question why the trap fishery moved from the deep waters into shallower waters during that time. Two explanations are possible: (1) blueskin abundance could have declined as a result of increased numbers of traps deployed per trip and also (2) the possibility of the vessel deliberately has decided to diversify the catches including the attractive valuable shallow seabreams and groupers. Other speculative cause may be the economic inefficiency of operating in the relatively deep water reefs that is considerable further off the coast. The continental shelf in the southern and central region is relatively wide meaning that the investment to target on deep water species like blueskin is higher than that made for the same value shallow water demersal species.

In recent two years a significant increase on targeting blueskin by the line fish fleet resulted in an increase of the contribution of the species to the overall catch of the line fishery in Mozambique (see figures 2 and 3). This shift of the effort to deeper waters was probable caused by the presumed depletion of the main shallow water resources, like *C. puniceus* and *C. nufar*, in the southern region, as appointed by the last assessments of line fishery (Torres and Jakobsen 2007, Fenessy *et al.* 2012).

Blueskin occurs both in the southern and northern region, while the other more desired endemic seabreams *C. puniceus* and *C. nufar* only occur south of parallel 21. The expansion of the fleet towards north may have increase the proportion of blueskin in the overall catch comparatively to those endemic species.

The highest CPUE for blueskin (in the last decade) was observed in 2003 after the trap fishery was closed. The notable increased effort in 2011 was followed by considerable increase in

CPUE (Figure 3). However, it must be noted that in 2011 the effort was more than double of that observed in 2003 but the CPUE obtained in 2011 was below the one in 2003.

6.2 Size structure and Sex ratio

Most of blueskin catch in the line fishery range from 20-40cm. It is unlikely that this is a reflection of the gear selectivity as line fishery operates with multi-hook size. Fishes below to 15 cm are often caught in the line fishery but it is a common practice for crew to keep the small fishes for themselves. Once harvested, this portion is kept separate from the main catches and it is not officially declared. This makes it difficult to get a proper sample during the landings and even on board. This represents a potential problem in terms of management of this resource because catches of juveniles is associated with risk of growth overfishing (Jennings *et al.* 2001) if they are taken in large quantities. Fishes larger than 40 cm are normally poorly represented in the catches of the line fishery. This observation raises the hypothesis of vertical size segregation for this species, with the larger individuals occurring in deeper waters as suggested by Mann (2000). According with the author, the adults occur in a large depth range between 66 to 405m while the Juveniles only occur in a short depth range between 60 and 100 m. Operations at depths greater than 200 m are not very usual in the line fishery and it is unlikely that the fishery has a potential to operate deeper as the gear is manually operated (retrieved).

The annual mean length of the fish landed during the last decade has been fluctuating but not showing a clear trend. It ranges from 26 to 32.7 cm and was not significantly different from the mean lengths found in 1997, 1998 and 1999 (27.7, 31.5 and 28 cm respectively) in trap catches (Torres *et al.* 2011).

The size distributions by sex of blueskin landed from 2003 to 2012 show a clear predominance of females in low size classes and males in large sizes classes (Figures 4 and 5). The annual average sizes of males are greater than females. These results are similar to those found by Fenessy *et al.* (2003) during the period 1997 to 2000 for blueskin obtained from the trap fishery. This is also similar to the results obtained by Torres and Jakobsen (2007) with data from the semi-industrial and industrial line fishery from 2001 to 2006. Such difference between the size distributions of females and male is expected in protogynous hermaphrodite species (Allops 2003). Fenessy *et al.* (2003) observed this for blueskin and it has been observed in for other species of the Sparidae family as well (Garratt 1994 and Lichucha 2001). In protogynous populations the sex ratio commonly biased towards females (Allsop, 2003). In the present study the sex ratio was consistently above 1:2 (male:female) similarly to the results obtained during 1997 to 2000 by Fenessy *et al.* (2003).

Protogynous sex-changing fish present a challenge for management because size selective fisheries can dramatically reduce reproductive rates (Alonzo and Mangel 2004). Size or age-selective fisheries can impact a species through a decrease in spawning stock biomass, in general and through the removal of highly fecund larger and older individuals, in particular (Alonzo and Mangel 2004) leading for a recruitment overfishing. In protogynous species, fisheries that preferentially remove large males can change the operational sex ratio possible causing sperm limitation and decreased larval production (Alonzo and Mangel 2004). So the fact that blueskin is a protogynous must be taken into account in the management of this resource too avoid the increased risk of recruitment overfishing.

6.3 Length-Weight relationship

The relationship between fork length and weight for this species shows that growth in weight is negatively allometric (*b*<3). This implies the fish becomes more slender as it becomes longer (Karachle and Stergiou 2012).

A negative allometric relation of body mass with length was also found by Fenessy *et al.* (2012) (b=2.57) which supports the conclusions of the allometric analyses of this study.

The negative allometry was also found previously in other two common seabreams in Mozambique marine waters, *C. puniceus* (Lichucha 2001) and *C. nufar* (Torres 2008).

The Length-Weight- relationship (LWR) is a useful tool in fishery assessment, which helps in predicting weight from length required in yield assessment. The coefficient *a* and exponent *b* of LWR are input parameters in many stock assessment models like in the yield per recruit. With LWR also morphometric comparisons can be made between species and populations (Lleonard *et al.* 2000). Blueskin is known to be widely distributed and LWR can be used as an indicator to assess the homogeneity of populations of different areas. In Mozambique many demersal fish of commercial value (including the other two common seabream) have their distribution limited south of parallel 21. It would be interesting to compare the morphometric parameter between the fish harvested in the southern region with those found in Sofala Bank area and in the northern section of the cost (above the Sofala Bank region).

6.4 Spawning season

In the present study ripe fish were found throuthout all year, with a montly proportion ranging from 30-50% of the total fish landed (Figure 8). This suggests that reprodution in blueskin is continuous. This fits to the result from Fenessy *et al.* (2003).

Species with short spawning seasons that form large aggregations are considered more susceptible to severe overexploitation than those with longer window of opportunity for spawning in numerous smaller aggregations (Coleman *et al.* 2000).

The fact that blueskin spawns throughout all year suggests that this species can be more resilient to local fisheries than other species that present a clear distinguished spawning season. The commercially extinct *P. undulosus* was found to spawn between September and November (Ahrens 1964, Penney *et al*. 1989 cited by Mann 2000). The spawning season for *C. nufar* in Southern Mozambique extends from May to October (Torres 2008) while for *C. puniceus* spawning takes place from August to November (Lichucha 2001).

As immature fish can be found throughout the year in large quantities (Figure 8) it may suggest that the recruitment to the exploitable phase is continuous.

6.5 Size at maturity

Size at maturity (L50) was estimated as 21.7 cm fork length and corresponding age at maturity was 6.3 years. Fenessy *et al.* (2003) estimated the size at 50% maturity as 22.7 cm based on data from females sampled in 1999 and 2000, which is similar to the findings of the present study. However, the age at maturity differed markedly between these two studies. Fenessy *et al.* (2003) estimated this parameter as 2.7 years. So the present study suggests that the blueskin mature later than it was previously determined. The congeneric species *Polysteganus undulosus* which is commercially extinct was also proved to be a late mature species with age at 50% mature estimated as 8.8 years (Chale-Matsau *et al.* 2001).

For *C. nufar* length at maturity was 22.5 cm corresponding age at maturity of 2 years (Torres 2008). For *C. puniceus* length at maturity was estimated 24 cm corresponding age of 1.5 years. Despite the three most caught Sparids in Mozambique mature at proximate lengths it is clearly seen that blueskin takes more than triple of the time to attain that size comparatively to others. According to Coleman *et al*. (2000) late maturing species are particularly vulnerable because the risk of growth overfishing is much higher in such species. It is known that small fishes (<15 cm) are significant in the catches, however not quantified in the line fishery in Mozambique. This is a potential risk particularly for species like blueskin that are late maturing.

Accurate estimates of length or age at maturity are critical for the conservation of exploited fish stocks. Age at maturity is particularly important, as it strongly influences population model estimates of sustainable harvest rates (Clark 1991).

6.6 Age and Growth

Although alternating opaque and translucent rings were observed in a high percentage of the sectioned otoliths, it was realized that the large size fish are quite difficult to read due stacking of the outer rings. However, older fish were poorly represented in the sample which may have contributed to high level of precision found in this study (APE =1.68%) (Table 2 in Appendix II). Fenessy *et al*. (2003) found a very high APE (23%) which may be because of aging larger size fish otoliths that are most difficult to count. The stacking of the outer rings was appointed as the main difficulty in ageing otoliths of older fish also in that study (Fenessy *et al*. 2003). Also in a congeneric species *P. undulosus* the phenomenon of staking in the margin of the otoliths were observed making edges sometimes difficult to interpret (Chale-Matsau 2001). The APE was 18.23 indicating also a poor precision for ageing that southern Africa species (Chale-Matsau 2001).

In species which pattern of rings are not very clear the percentage of agreement can also differ from one study to another depending on the way that readings are made. In the Fenessy *et al.* (2003) study, otoliths were read three times by one reader and once by another reader having a total of four age estimates for calculation of the APE. The present study used only two estimates (one reading per each reader) after a first common reading. This methodology may have contributed for the high agreement found in this study. The determination of age in a long lived Sparid *Argyrozona argyrozona* based in quite similar methodology show a low APE 1.8% indicating good precision of age estimation between the two readers (Brouwer and Griffiths 2004). Also the technology involving in the otolith preparation (See Appendix I) may had influenced for the high agreement found in this study, perhaps by making the rings more distinguishable.

The results of the present study show that blueskin is long lived species with the maximum age assumed to be at least 22 years. Fenessy *et al*. (2003) found the older fish age 17 year and in this study the oldest aged was 22 years. Such differences may be explained by age reading difficulties that are found in blueskin. The stacking of the marginal rings can lead to the underestimation of the ages of older fish. This assumption is supported by the high APE found in the Fenessy *et al*. (2003) preliminary study. As the results of both life span and age at maturity are much higher than those found in the preview study it is strongly recommended to adopt the new estimated population parameters in stock assessment of the species, as a precautionary measure. For the foreseeable future the processes of age estimation in fishes will remain an element of subjectivity that will contribute various degrees of error to all age determination (Campana *et al*. 1995). There are many instances in which ageing error, often undestimation of the age, has contributed to the serious overexploitation of a population or species (Campana 2001).

The commercially extinct *P. undulosus* was found recently (2000) to have a life span (20 years) greater than previously estimated (13 years in 1964) (Chale-Matsau *et al*. 2001). For *A. argyrozona* the maximum age obtained from whole otoliths was 16 years while that obtained from seccioned otoliths was 27 years (Brouwer and Griffiths 2004). These two examples demonstrate clearly that the underestimation of the age in Sparids is quite common. Many studies have reported Sparids to be generally long-lived with some species found to live 30 - 40 years (Mann 2000).

The estimated growth parameters of the von Bertalanffy growth equation were L_{∞}=40.8 cm, K=0.104 year $^{-1}$ and t_0=-1.64 year. The value of *K* (parameter of the curvature) denotes how fast the fish approach its average maximum length (L_{∞}). For slow growing species the value of *K* is low and the curve is thus relatively flat meaning that the fish takes many years to reach L_{∞}, while for fast growing short-lived species the value of *K* is relatively high (Sparre and Venema 1998). The estimated value of *K* for blueskin was low indicating blueskin as a slow growing species. This can be seen by the flat growth curve presented in Figure 11. In general species with low K have longer life spans, greater age (size) at maturity, lower reproductive output (Jennings *et al.* 2001).

There were very few large and small fishes in the sample used for the analysis of growth. According to Haddon (2001) the lack of data points for younger and older fish can distort or bias all von Bertalanffy growth parameters (Haddon, 2001). The L_{∞} and t_0 parameters are at the extremes of the curve and this is where data tend to be least adequate (Haddon 2001). However, virtually every fishery papers concerned with growth uses the von Bertalanffy growth equation even in situations with little data are available for younger and older fish (Haddon 2001).

6.7 Population dynamic

6.7.1 Estimate of mortality rates

The natural mortality estimated based on Pauli's equation (0.32 year^{-1}), was slightly higher than one estimated using Rikhter and Efanov equation (0.26 year^{-1}). Despite both values are acceptable for slow growing sparids (Mann 2000) the value estimated from Rikhter and Efanov was preferred in this study. The value estimated from Rikhter and Efanov equation was similar to the natural mortality used in the previous study of blueskin; also *M*=0.26 year^{-1} (Fenessy *et al.* 2003). This value was also similar to that estimated for the Sparidae *C. puniceus M*=0.27 other important sparid caught in the line fishery in Mozambique (Lichucha 2001).

Using the biomass production model the estimated value of F_{curent} (F=0.15) was found to be slightly higher than the value of *F* calculated assuming *M* estimated thought Rikhter and Efanov equation and *Z* from catch curve analysis. Higher value of *F* means that more conservative management advices are needed. For assessment of the status of the stock it was thus decided to use the F estimated from biomass production model F=0.15 year^{-1} (which is though likely too low.

6.7.2 Biomass production model

The biomass production model was used to get the historic variation of the blueskin stock and harvesting. There is a trend of increasing in the rate of fishing mortality. However, the prediction of the model doesn't match with the observed data good enough, especially in the last years. It is likely that the estimated actual rate of fishing mortality is too low.

The biomass and recruitment has varied a lot during the time series but such magnitude of variation predicted by the model is not assumed to be realistic. This is associated with inaccuracy of the input data. This problem was also detected in the last two assessments of the line fishery (Torres and Jakobsen 2007, Fenessy *et al.* 2012); poor fitting between the predicted and observed CPUE. The surplus production model, only requires catch and effort information – but the data need to be reasonably accurate, which seems not to be the case in Mozambique line fishery; with reports of under-reporting of the production (Fenessy 2012).

The fact that the fishing effort was low until 2010 could lead to mask the effects on the high fishing effort observed in 2011 and 2012 (Figure 14). This may be possible because of the delay of the effects of high fishing pressure in the long lived species population. Note that age at full recruitment (t_c) was estimated to be approximate seven years for blueskin. If the increase of the effort is reducing a lot the spawning biomass in the last two years, it means that a bad recruitment caused by that high fishing pressure will be visible not before the next six years.

6.7.3 Yield per recruit and Spawning biomass per recruit

The Target Reference Points (TRP) are defined as the level of fishing mortality or of the biomass, which permit a long-term sustainable exploitation of the stocks, with the best possible catch (Cadima 2003). For this reason, these points are also designated as Reference Points for Management. The most commonly used TRP are the target fishing mortalities F_{max} and $F_{0.1}$ which are estimated from the yield per recruit analysis. However, it must be stated that yield per recruit analysis by itself does not say anything about the sustainability of the predicted F values (Haddon 2001). The optimum target fishing mortality derivate from the yield per recruit should reflect this fact (Haddon 2001).

The F_{max} was adopted as long-term objective of management by the majority of the International Fisheries Commissions (1950-1970) (Cadima 2003). Actually $F_{0.1}$ is preferred to F_{max} as a target point by resource managers, and it was adopted in the 80's, as a long-term objective by many International Fisheries Commissions (Cadima 2003). Empirical evidences indicate that, in part because of uncertainties inherent in in equilibrium YPR analysis, F_{max} tend to be too high and leads to stock declines (Haddon 2001). So using a lower value of F is likely to be more appropriate.

The advantages of using $F_{0.1}$ instead of F_{max} is supported in the economic point of view meaning that $F_{0.1}$ indicates an approximation of the fishing mortality that will result in maximum economic yield (Stefansson 2011b). In other hand the fact that $B_{0.1}$ is always larger than B_{max} suggests that the fishing level $F_{0.1}$ is preferable to F_{max} as TRP (Cadima 2003). Although the production per recruit at $F_{0.1}$ is always smaller than maximum yield per recruit in practice, the difference is not large. For a small loss in yield, one often gains a great deal in stock resilience to poor recruitment years and other sources of uncertainty (Haddon 2001).

$F_{0.1}$ should be preferred as a target management reference point for blueskin than F_{max}. However, the input parameters for yield per recruit calculations have changed from the last assessment made, so the $F_{0.1}$ and F_{max} should be considered with precaution. There is a necessity of have same reservations in adopt it even the value of $F_{0.1}$ was a management objective for blueskin also because of the uncertainties involved in determination of F_{curent} which is likely to be underestimated.

Taking into account that the effort in deep reefs has already increased more than triple when compared to the mean value of 2003 to 2010 (530 fishing days/year) it is recommended as a precautionary measure that the total fishing effort should not exceed the level observed in 2012 (1500 days).

Note that this study focuses on the deep reefs so the effort used was the partial effort that the fleet spent in deep waters. Thus, reduction of the effort in this case must mean redistributions of the fishing effort between the fishing grounds taking into to account the depth strata. Considering that the most of attractive shallow water line fish in the southern 21°S are presenting signals of depletion (Fenessy *et al.* 2012) and that in the last two years there was a shifting of the effort to deep reefs it means that the blueskin stock can contribute to the recovery of the shallow water species if the management takes into account the rational redistribution of the fishing effort between shallow and deep water fishing grounds. Massive concentration of the effort in one fishing ground in response to the depletion of other one is not sustainable and may lead to negative impacts in both areas in a short-mid-term.

7 CONCLUSIONS

- The harvesting of blueskin is strongly influenced by the dynamics of the line fishing fleet. Increased fishing in deeper waters in the last two years has resulted in high contributions of this species to the overall landing of the line fishery.

- The effort over blueskin target depths in the last two years was more than threefold of the average level observed from 2003 to 2010. This shifting of fishing effort deeper is likely to be motivated by the depletion of shallower demersal species in the southern region.

- All the biological evidences of the population structure point to the possibility of blueskin to be a hermaphrodite protogynous species. This makes this species particularly sensitive to the selective fisheries because the rapid remove of large males can imbalance the operational sex ratio, possible causing sperm limitation and decreased larval production.

- Blueskin is a slow growing and late maturing species which mean that the population is very susceptible to growth overfishing if many small size individuals are taken in large quantities.

- The reproduction and recruitment is continuous with fish in all maturity development stages being found throughout all year. Comparing with the other two common sparids species caught in the line fishery, this can be seen as a compensative advantage in terms of vulnerability to fishing pressure during the spawning season.

- The current *F* estimated from a biomass production model is below the target fishing reference point $F_{0.1}$ derived from the yield per recruit curve, using estimated input parameters from this study, which differs from older studies. However, assuming that effort has already increased three times in the last two years and taking into consideration the uncertainties involved in the estimation of current *F* and the risk of growing overfishing that this species may be subjected (with juveniles taken but bot quantified) there is a need of more conservative measure meaning that at least the actual fishing effort should not be increased.

8 RECOMMENDATIONS

- Despite that the blueskin has primarily been harvested by semi-industrial and industrial line fishery it is known that it is also taken as by-catch in the deep water trawl fishery. It is recommended that a study will be done to evaluate the impact of the deep water trawl fishery on the blueskin.

- The use of otoliths is recommended for ageing of blueskin and similar species. A basic protocol for sectioning and reading of otoliths is found in this study. However, this needs a laboratory to be equipped with the respective ageing equipment in Mozambique.

- Studies of blueskin in the future need to benefit from more specimens collected at varying sizes (including very small and large fish), seasons or months, locations (South of parallel 21, Sofala Bank region and northern of Sofala Bank). Furthermore, monthly samples would also assist in validating if each *annuli* is deposited annually.

- It is recommended to conduct an independent survey to assess the relative abundance and size distribution between different deep strata in all vertical ranges of the species.

- A special attention must be taken in the management of this species because many small fishes are caught in the line fishery but not quantified. It is possible that juveniles of this species form a significant proportion of this non quantified catches, especially in the last two years. The management of this species must pass for the resolution of the problem of non-sampling small size fishes in the semi-industrial and industrial line fishery and by ensuring that large amount of juveniles is not fished.

- Because of the reproductive pattern (protogynous) of the species, an appropriate management should insure the maintenance of the size structure and operational sex ratio of the population.

- $F_{0.1}$ should be adopted as the acceptable Target Fishing Reference Point for blueskin and other related deep reef species in Mozambique instead of $F_{max.}$

- As a precautionary measure the total fishing effort in deep reefs should not exceed the level observed in 2012 (1500 days) until a further assessment has been done in the next 4-5 years.

- Concentration of the effort in deep reefs in response to the depletion of shallow water species is not sustainable and may lead to negative impacts in both areas in a short-mid-term. So it must be avoided by the managers by promoting a redistribution of the fishing effort in a wide range area.

ACKNOWLEDGMENTS

This project will be submitted as my MSc Thesis in Aquatic Biology and Coastal Ecosystems at Eduardo Mondlane University (UEM), Mozambique. So first I express my deep gratefulness to the United Nations University Fisheries Training Programme (UNU-FTP) to give me the opportunity to materialise this study. I am thankful for all the support given during these six months and for the much I have learned during the training course.

Particular thanks go to my supervisor, Ms. Ásta Gudmundsdóttir for the guidance and support given during the elaboration of my final project. Also I thank Dr. Gudmundur Thordarson for the support given in using *R* program for some statistical analysis, Dr. Tumi Tomasson (UNU-FTP Director) and Dr. Thor Asgeirsson (UNU-FTP deputy Director) for their guidance and criticism during elaboration of this paper.

An extensive thanks go to Dr. Adriano Macia from UEM for the assistance during the elaboration of the protocol for this study and for incentives me to participate on this course.
I wish to thank also the IIP Directorate, particularly the IIP Director, Dr. Paula Santana Afonso, for giving me the opportunity to attend this training program. To Dr. Isabel Chauca and Dr. Augusto Dimande for they recommendation letters and incentives to participate in this training program. To Dr. Osvaldo Chacate for all moral and technical support provided during the last six months.

I would like address a special thanks to the IIP staff involved in the line fishery monitoring program particularly to samplers Mr. José Cuna and Mr. Isaias Tembe who collected great part of the data used in this study on-board of line fish vessels. One special thanks also to all the suport provided by the Ageing Division Staff of MRI during the preparation and reading of the otoliths in particular to Ms. Gróa Pétursdóttir and Mr. Páll Valgeirsson.

I thank the support and friendship of all my UNU-FTP fellows and particularly the help of my specialization line colleagues (Marine and Inland-waters Resources Monitoring and Management).

Finally, I would like to thank my family for all support, incentives and comprehension during these six months. *Candace*, I love you my daughter.

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APPENDICES

Appendix I

Preparation and Sectioning of Otoliths of *P. coeruleopunctatus*

The otoliths of blueskin are thick and opaque (see figure I), so for ageing they needed first to be sectioned. To ensure consistent otolith sections for growth measurements, the otoliths were prepared using standardized procedures.

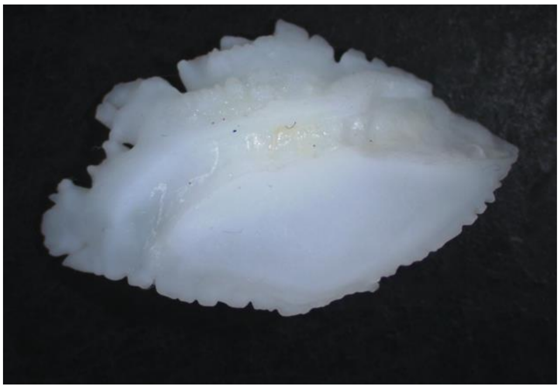

Figure 1. Sagittal otolith of *P.coeruleopunctatus* with the proximal surface facing up and the anterior part of the otolith to the left.

For sectioning, otoliths were embedded in black polyester resin. The resin formula consisted of: 550 ml CrysticC moulding resin (#SBCRYSTICC), 1.0 ml accelerator, 12.5 ml consolidator/hardener, and black pigment past colour (#SBPP0630BK). A metal frame, especially made for embedding otoliths was used. It has a scale from 1 – 20, and in the box is a layer of black polyester resin. A total of 100 otoliths can be placed on the layer of resin in the metal frame so that there are five otoliths in each row. After arranging the first row of otoliths, the gear is automatically moved 1 cm to begin the next row (figures II and III).

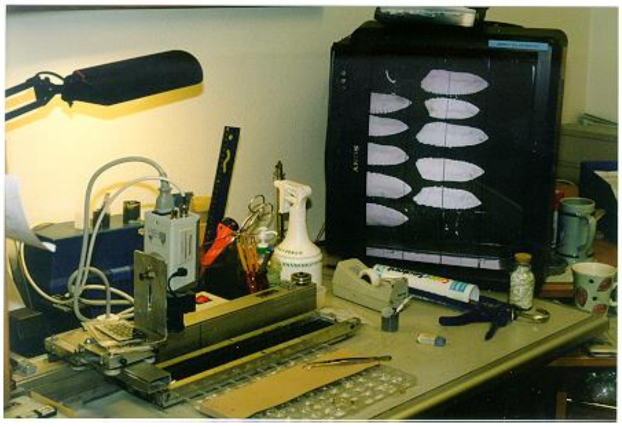

Figure 2. Arranging the otoliths, a screen is used to place them in the correct position for sectioning.

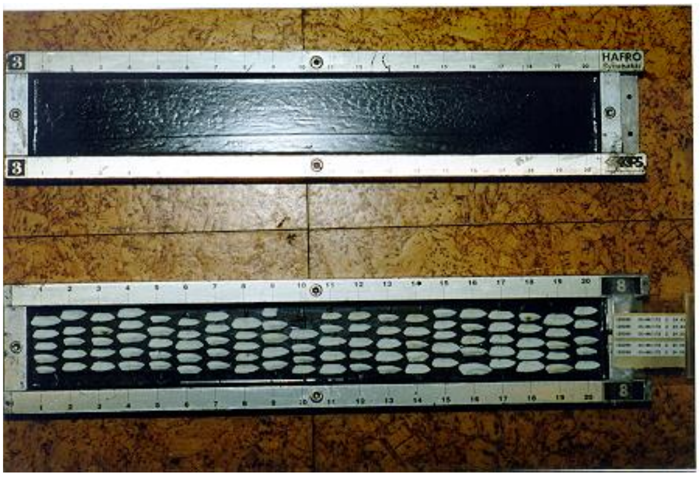

Figure 3. A total of 100 otoliths can be placed on the layer of black polyester resin in the metal frame.

After the otoliths have been placed they are covered with the black polyester resin and stored in a fume hood for 12 hours for the resin to harden. The otoliths are then ready for sectioning. Sections were obtained by cutting the block with a diamond grit blade into 20 sections. To ensure precision this process is automatically steered with software. The 20 otolith sections were organized on microscope glass slides in groups of 5 slices, with 5 otoliths on each slide (figure IV). One block, a sample of 100 otoliths, can be put on 4 microscope slides. Clear resin was pored over the slices, then a thin piece of glass was put on top and the slides stored in a fume hood overnight. Finally, after cleaning all excess glue from the slide, the sectioned otoliths were ready for analysis. The alternated growth rings can be counted under a microscopy with transmitted light. Either the left or right otolith from each sagittal pair should be used as no consistent differences have been detected between left and right otoliths.

Figure 4. After the cutting of the black polyester resin block with 100 otoliths; the 20 sections of otoliths (5 x 20) are organized on 4 microscope slides; 25 otoliths in 5 rows on each microscope glass.

Appendix II

Table 1. Annual effort allocated to depths greater than 75m *vs* proportion of blueskin in overall catches of the semi-industrial and industrial line fishery.

Year	Fishing days at depths >75m	% of blueskin weight in overall catch
2003	700	22
2004	370	9
2005	854	16
2006	669	4
2007	70	0.1
2008	313	2
2009	738	3
2010	537	4
2011	1947	32
2012	1488	21

Table 2. Estimative of precision of age readings between two readers.

Fish No. (i)	Reader 1	Reader 2	APE(i)	CV(i)	D(i)
1	3	3	0.0	0.0	0.0
2	3	3	0.0	0.0	0.0
3	5	5	0.0	0.0	0.0
4	6	6	0.0	0.0	0.0
5	7	8	0.0667	0.0943	0.0667
6	8	8	0.0	0.0	0.0
7	8	9	0.0588	0.0832	0.0588
8	11	10	0.0476	0.0673	0.0476
9	11	10	0.0476	0.0673	0.0476
10	15	15	0.0	0.0	0.0
11	3	3	0.0	0.0	0.0
12	5	5	0.0	0.0	0.0
13	5	5	0.0	0.0	0.0
14	6	6	0.0	0.0	0.0
15	8	8	0.0	0.0	0.0
16	8	6	0.1429	0.2020	0.1429
17	7	7	0.0	0.0	0.0
18	13	12	0.0400	0.0566	0.0400
19	11	11	0.0	0.0	0.0
20	16	16	0.0	0.0	0.0
21	6	6	0.0	0.0	0.0
22	5	5	0.0	0.0	0.0
23	6	6	0.0	0.0	0.0

24	7	7	0.0	0.0	0.0
25	6	6	0.0	0.0	0.0
26	6	6	0.0	0.0	0.0
27	6	6	0.0	0.0	0.0
28	9	9	0.0	0.0	0.0
29	10	10	0.0	0.0	0.0
30	10	10	0.0	0.0	0.0
31	5	5	0.0	0.0	0.0
32	4	4	0.0	0.0	0.0
33	9	9	0.0	0.0	0.0
34	6	6	0.0	0.0	0.0
35	8	7	0.0667	0.0943	0.0667
36	10	10	0.0	0.0	0.0
37	8	9	0.0588	0.0832	0.0588
38	17	16	0.0303	0.0429	0.0303
39	21	22	0.0233	0.0329	0.0233
40	17	16	0.0303	0.0429	0.0303
41	5	5	0.0	0.0	0.0
42	4	4	0.0	0.0	0.0
43	8	8	0.0	0.0	0.0
44	10	10	0.0	0.0	0.0
45	7	7	0.0	0.0	0.0
46	16	15	0.0323	0.0456	0.0323
47	12	12	0.0	0.0	0.0
48	17	15	0.0625	0.0884	0.0625
49	12	10	0.0909	0.1286	0.0909
50	12	13	0.0400	0.0566	0.0400
Average			0.0168	0.0237	0.0168
*100%			**1.68**	**2.37**	**1.68**

Table 3. Observed age-length key (ALK) for blueskin based in 2 cm length class data. Data inside the table are number of fish.

	Age (years)																				
Length (cm)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	**Total**
14	1																				1
16	1	1																			2
18		2																			2
20			7	1																	8
22			5	7																	12
24			1	12	6	6															25
26				1	31	17	4	1	1												55
28					2	8	18	9	5												42
30							5	9	9	5	3	3									34
32								1	5	10	5	3	1								25
34									1	2	5	4	3	2							17
36											1	1	2	2							6
38													2		1	1					4
40																					0
42																					0
44																					0
46																				1	1
48																			1		1
N	2	3	13	21	39	31	27	20	21	17	14	11	8	4	1	1	0	0	1	1	**235**

Table 4. Observed mean length at age (cm FL) for *P. coeruleopunctatus* in Mozambique.

Age	Mean length at age ± SD (Observed)	*N*
3	14.75 (±1.06)	2
4	16.67 (±0.58)	3
5	20.12 (±1.28)	13
6	22.26 (±1.27)	21
7	24.94 (±0.84)	39
8	25.5 (±1.13)	31
9	27.31 (±1.15)	27
10	28.25 (±0.99)	20
11	29.31 (±1.68)	21
12	30.68 (±1.17)	17
13	32.09 (±1.48)	14
14	32.09 (±1.74)	11
15	34.44 (±2.03)	8
16	34.0 (±1.15)	4
17	37.5	1
18	37.5	1
21	48.0	1
22	46.0	1