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LIFE HISTORY AND STOCK ASSESSMENT OF THE AFRICAN HIND (*CEPHALOPHOLIS TAENIOPS)* (VALENCIENNES, 1828) IN SÃO VICENTE- SÃO NICOLAU INSULAR SHELF OF THE CAPE VERDE ARCHIPELAGO

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ABSTRACT

The African hind *Cephalopholis taeniops* (Valenciennes, 1828) is one of the most abundant and important demersal species caught in the Cape Verde archipelago. In this report, the life history parameters of *C. taeniops* are estimated and the status of the stock in the insular shelf from São Vicente to São Nicolau is assessed. Data were collected following a biological sampling scheme established in 1993. Following the changes in the gonadosomatic index it is concluded that the highest reproductive activity period extends from June to October. The maturity ogive is estimated and the mean length at sexual maturity was determined at 26.5 cm, which corresponds to a mean age of sexual maturity of 4.2 years. The weight-length relationship is estimated with α =0.0067 and β=3.2. Von Bertalanffy growth parameters are estimated using the Ford-Walford plot and the Macdonald and Pitcher method. For assessment purposes, the growth parameters L_∞= 62.9 cm, K=0.12 per year and t_0=-0.28, estimated using the Macdonald and Pitcher method, are used. The natural mortality is estimated to be *M*=0.34 by Pauly's empirical formula and *M*=0.38 by Rikhter and Efanov's formula, the last one being used in the assessment. Age-based assessment methods are applied. The cohort splitting is performed through least squares minimisation, following the Macdonald and Pitcher method of analysing distribution mixtures. A classic VPA and a simplified YpR and SSBpR model of Beverton and Holt were applied and tested for sensitivity using different scenarios of *M*-values. YpR management targets (F_{max} and $F_{0.1}$) were estimated. A yield forecast for 2001, assuming different values of *M*, was performed. Assuming the *M*=0.25 scenario as the most probable one, it is concluded that the fishing mortality since 1997 has been around the $F_{0.1}$ levels and no increases in fishing effort are recommended. This scenario predicts for 2001 a yield at F_{term} around 77 tons and a yield at $F_{0.1}$ around 74 tons. Finally, some changes are recommended in the sampling scheme in order to improve data collection and to create a basis for applying better and more reliable assessment models.

Key words: *Cephalopholis taeniops,* life history parameters, cohort splitting, age-based assessment, yield prediction, F_{term}, $F_{0.1}$.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Cape Verde archipelago is situated in the eastern Atlantic, between 14° 50'- 17° 20' N latitude and 22° 44'- 25° 30' W longitude, 375 miles to the west of Senegal and Mauritania (SEPA 1999). Formed by 10 islands and five islets originated by volcanic activity, the archipelago covers an area of 4,033 km^2 (Bravo de Laguna 1985). The Exclusive Economic Zone (EEZ) is relatively large (734,265 km^2), but the insular shelf to 200 m of depth is only around 5,934 km^2 (Bravo de Laguna 1985).

The climate is dry and tropical. There are two well defined seasons: a cold and dry season from December to June, with an average sea surface temperature (SST) of 21 - 22°C, and a warm and wet season from July to November, where the SST oscillates between 26 and 27°C (Almada 1993).

From surface to 50 m of depth, the seawater is warmer in the southeast of the archipelago, but the highest temperatures are found in the northern part, between 100 and200 m, especially in the well-known fishing grounds around Santo Antão, São Vicente, Santa Luzia and São Nicolau insular shelves. (Almada 1993) There are seasonal variations of the thermocline, which is located between 40 and 70 m of depth throughout the year (Diouf 1992).

Little is known about the temporal patterns of the primary productivity in the Cape Verde waters and the results from different studies are contradictory. From 1982-1984 the productivity was estimated to be 150-500 mgC/ m^2 per year, which is considered relatively high, with low seasonal variability (Diouf 1992). In 1997 the estimates of primary productivity were relatively low, varying between 0.1 to 0.46 mg of chlorophyll / M^{-3} (IPIMAR, INDP 1997).

Upwelling occurs around some of the main sea-mountains (Nova Holanda, João Valente and Noroeste de Santo Antão), and important fishing banks are located there (Almada 1993).

Due to the climatical influence of the Sahara, the lack of fresh water and the limited extension of the island shelf, biodiversity is lower than on the continental coast of Africa and marine resources are scarcer. Nevertheless, the existing resources form the basis of a relatively important socio-economic activity. In 2000 there were about 5,200 fishermen in Cape Verde (INDP 2001). For every fisherman there are four to five jobs in related areas, such as trade, supporting services and research (Cadima 2000). Therefore, in Cape Verde there are around 21-26,000 people (about 5-6% of the population) working in fisheries. The fishery is, at the same time, one of the most important sources of animal protein, fish being the staple food of the majority of Capeverdeans.

The estimated potential yield of the Cape Verde EEZ is between 32 to 37,000 tons (INDP 1999) and the most important fisheries resources include tuna and similar fishes, small pelagic coastal fishes, ground fishes and lobsters.

Cape Verde fisheries are divided into two main components: the artisanal (small-scale) and the industrial or semi-industrial fisheries. In 2000 the artisanal fisheries employed 70% of Capeverdean fishermen operating 1,257 outboard motor boats and

20 closed-deck boats (INDP 2001). Artisanal fishermen mainly target tuna and similar species, demersal fishes, coastal lobsters and small pelagic fishes. In 2000 the industrial or semi-industrial fleet was comprised of 55 vessels, mainly targeting tuna and deep-water lobster (INDP 2001).

About 1,000 tons of demersal fishes are landed annually by the artisanal fishermen, representing, on average, 18% of the total artisanal landings (Figure 1). There are many ground fish species in Capeverdean waters, which are traditionally exploited by artisanal fishermen, using mainly hook and line. Other types of fishing gears are of minor importance in the demersal fishery.

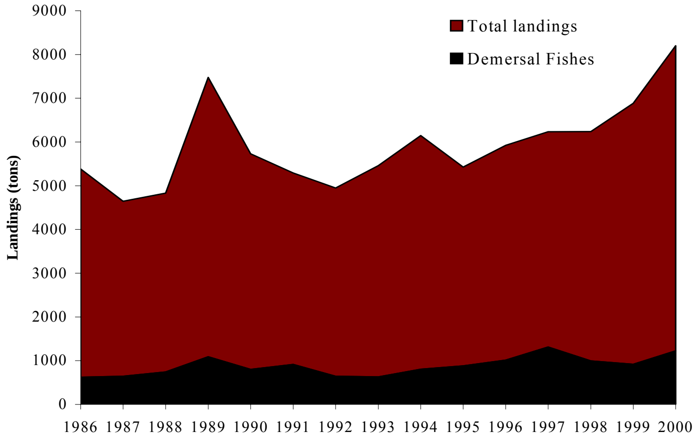


Figure 1: Demersal fish artisanal landings in comparison with the total artisanal landings from 1986 to 2000, Cape Verde archipelago (INDP 2001).

The African hind (*Cephalopholis taeniops)* (Valenciennes, 1828), locally known as "garoupa", is one of the main demersal fish species caught in the Cape Verde archipelago (Figure 1.2 A). Its distribution is restricted to the eastern Atlantic, from the western Sahara to Angola, including Cape Verde and the São Tomé e Príncipe Islands (Heemstra and Randall 1993). *C. taeniops* is a grouper, from the family SERRANIDAE, subfamily Epinephelinae. It is a predatory species, with solitary habits and is usually found over rocky bottoms, sometimes over sandy bottoms, in a depth range of 20 to200 m (Heemstra and Randall 1993). The maximum reported total length is 70 cm (Reiner 1996). *C. taeniops* is considered a protogynous hermaphrodite, in which mature fish function first as females and later change into males (Shapiro 1987). Very little has been published on its biology.

As a relatively important component of Capeverdean fisheries, *C. taeniops* is caught throughout the year and all over the archipelago by artisanal fishermen (Figure 2 B). It is caught mainly by handline, and sold in local markets. It has also been caught in experimental longline fisheries and sporadically in trawl. Artisanal fishermen have historically used the same size of hook (7 - 9) for catching this and other demersal fish species.

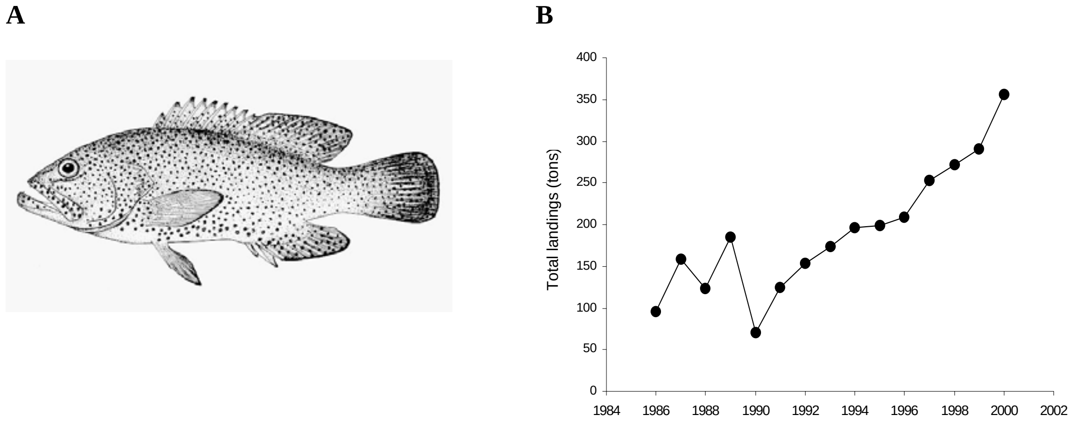


Figure 2: A) *Cephalopholis taeniops* (Valenciennes, 1828). B) *C. taeniops* total artisanal landings from 1986 to 2000, Cape Verde archipelago (Heemstra, P.C. and J.E. Randall, 1993).

Due to their importance to the artisanal fisheries in Cape Verde, a biological sampling scheme was implemented for a group of demersal species, aiming to determine the exploitation status of the stocks, in order to provide advice on their optimal exploitation and management. Since 1994, the effort has been concentrated in *C. taeniops* sampling because of its abundance throughout the year.

A stock assessment using available data is the basis of the present work. The specific objectives of this study are defined as follows:

a) To extract and summarise the biological information from the data for a better understanding of species biology, as a basis for stock assessment (estimation of basic life history parameters).

b) To assess the quality of the collected data and of the sampling scheme to determine the sources of errors, in order to suggest how to improve data collection and to determine what kind of analysis and assessment tools could be used in this particular situation.

c) To investigate the population dynamics using appropriate assessment models.

2 MATERIAL AND METHODS

2.1 Data and data collection

The data were collected following a biological sampling scheme, established in 1993 in the fisheries community of Salamansa (São Vicente Island). The sampling is performed once a week, in a landing site, and less frequently during bad weather conditions or during the tuna season. One of the arriving boats is chosen randomly and 30 individual *C. taeniops* are randomly selected for detailed biological sampling at the laboratory. The remaining catch of *C. taeniops* is measured. Length is expressed in terms of total length (TL) to the nearest centimetre. The fishing zone, the number of fishermen, the hours of fishing, an estimate of the total catch of the boat (all the species) and the hook size, are recorded on forms specially designed for this purpose.

At the laboratory, the 30 individuals are sampled. The individual TL to the nearest centimetre, using 1-cm length groups and the individual weights are recorded. Sex and maturity stages are determined macroscopically. Four stages of maturity are used: immature (1), maturing or developing (2), ripe, pre-spawning (3), and spawning, post-spawning (4). Finally, the gonad weight, in grams, is recorded.

In 1997 otoliths were collected from 321 individuals. They were analysed in the laboratories of the Marine Research Institute, Iceland, in 1998, in terms of age (number of annual rings) and size (diameter).

About 21,000 length measurements were recorded and almost 10,000 individuals were sampled in the laboratory during the period from 1993 - 2002.

The official landing statistics for the São Vicente and Sao Nicolau Islands are used in this work (Figure 3). The effort data were not used because they correspond to aggregated effort, aimed at both demersal (including *C. taeniops*) and tuna fish. A series of effective catch-per-unit of effort, expressed in kg/fisherman/hour of fishing, is available for the last five years, but it is still a short interval for use in surplus yield models or in tuning the data.

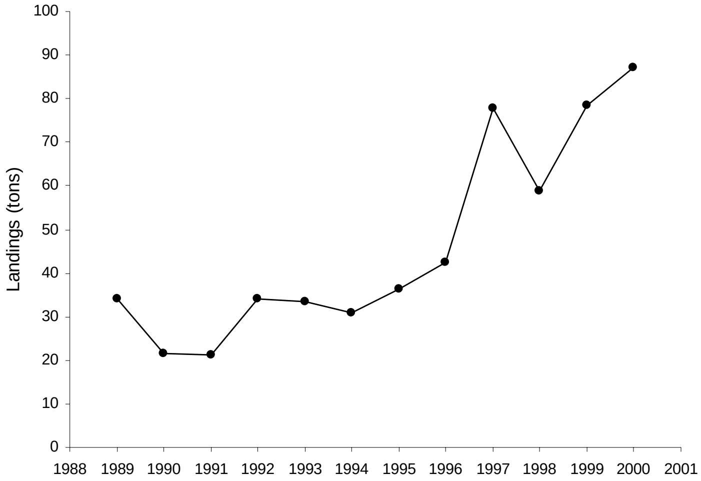


Figure 3: *C. taeniops* landings corresponding to São Vicente and São Nicolau islands from 1989 to 2000.

2.2 Study area

The geographical coverage of the sampling scheme delimits the study area. No studies have been done on *C. taeniops* stock identification around the Cape Verde islands. However, it is assumed that due to the great depths existing between some of the islands, it is likely that there are several stocks rather than one in the waters of the archipelago. The sampled individuals come from the landings of the Salamansa fisheries community. Salamansa fishermen used to fish demersal fishes in several fishing grounds around the São Vicente and Santa Luzia Islands and the Branco and Raso islets (Figure 4). All those islands and islets, as well as the São Nicolau Island share the same insular shelf up to 200 m in depth. For this reason, a unit stock of *C. taeniops* is assumed to exist in the insular shelf from São Vicente to São Nicolau. Fishermen from São Nicolau operate in fishing grounds around their own island and in the Branco and Raso islets, sometimes reaching Santa Luzia.

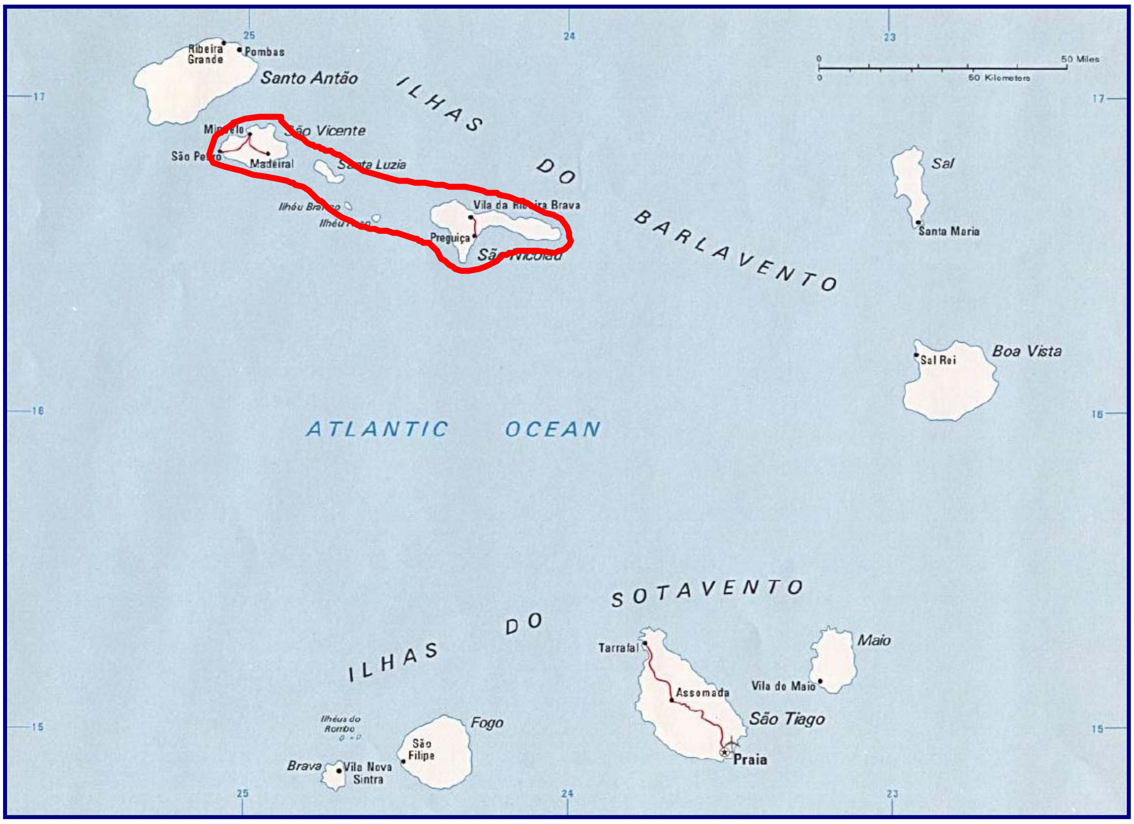


Figure 4:The study area: São Vicente - Santa Luzia - São Nicolau insular shelf.

2.3 Methods

2.3.1 Life history parameter estimation

2.3.1.1 Time of spawning

The time of spawning for *C. taeniops* in Cape Verde waters is estimated by analysis of gonad appearance and the relative size or weight of gonads over time.

In the first case, only ovaries were taken into account, because it is easier to classify them using a maturation scale and because it is assumed that the development of ovaries and testes are synchronous (King 1995). A simple macroscopic scale was used (Appendix 5). The frequency of different development stages was plotted by month in a histogram.

The second method analyses changes in gonadosomatic index (*GSI*) over the year. The assumption is that an ovary increases in size with increasing development. The *GSI* was estimated using the formula:

$$GSI = 100 * \frac{GW}{W} \qquad (1)$$

where GW is the gonad's weight in grams and W is the total weight in grams.

The mean *GSI* per month is followed throughout the year. The entire time framework is considered as a whole, considering all years together.

In addition, changes in the proportion of males in the samples throughout the year are analysed, assuming that an increased proportion of males could be an indicator of an increase in reproductive activity.

2.3.1.2 Length at sexual maturity

To estimate the mean length at sexual maturity (L_{50} - the mean length at which 50% of the individuals are mature), a logistic curve was fitted to the proportion of mature females by length during the spawning season using logistic regression:

$$P = \frac{1}{1 + e^{-(a + b * L)}} \qquad (2)$$

where P is the proportion of mature fish, L is the length, a and b are the parameters estimated by the regression, and length at sexual maturity is calculated as $L_{50} = -\frac{a}{b}$.

The modelled ogive of maturity at length is used further (when mean length at age L_t is re-estimated using the Macdonald and Pitcher method (Macdonald and Pitcher1979)) to calculate the maturity at age.

2.3.1.3 Weight - length relationship

The weight-length relationship (Eq. 3) was linearised by log transforming both W and L (Eq. 4):

$$W = \alpha * L^{\beta} \tag{3}$$

$$\ln(W) = a + b * \ln(L) \tag{4}$$

An ANOVA (Analysis of Variance) was done to test for effects of sex, year and month variables and to estimate α = exp(a) and β = b.

2.3.1.4 Growth parameters

In this project, the basic data used for calculating growth parameters are the age estimations, based on otolith readings and about 21,000 length measurements recorded in the period 1993 - 2002. The age estimation based on otolith readings is used to calculate initial values for the growth parameters. Based on these estimations, an age-length key was constructed, extrapolating the obtained proportions to the whole sample (about 1,700 individuals measured in 1997). From these data, initial estimates of growth parameters (L_∞ and K) were estimated for the von Bertalanffy growth curve using the Ford-Walford plot (Sparre *et al.* 1989):

$$L_t = L_\infty * \left[1 - e^{(-K*(t-t_0))}\right] \tag{5}$$

Assuming $t_0 = 0$ and performing algebraic manipulations equation 3 was linearised, writing the length for the next age-group (L_{t+1}) as a function of L_t:

$$L_{(t+1)} = L_\infty * (1 - e^{-K}) + L_t * e^{(-K)} \tag{6}$$

Plotting (L_{t+1}) against L_t linear regression model was fitted:

$$L_{(t+1)} = a + b * L_t \tag{7}$$

The initial parameters were estimated from the regression coefficients: K = - ln (b) and $L_\infty = \frac{a}{1-b}$.

A non-linear minimisation was performed using the estimated parameters along with $t_0 = 0$ to re-estimate the growth parameters.

Combining the von Bertalanffy growth equation (Eq. 5) with the weight-length relationship (Eq. 3) the weight as a function of age was estimated:

$$W_{(t)} = W_{\infty} * \left[1 - e^{(-K*(t-t_0))}\right]^{\beta} \tag{8}$$

where W_{∞} is the asymptotic weight, corresponding to the L_{∞} and β is one of the parameters of the weight-length relationship .

2.3.1.5 Cohort splitting

The Macdonald and Pitcher method was used to estimate age-group parameters from length-frequency data and to re-estimate the initial values of L_∞, K and t_0, using a larger data set. For cohort splitting a von Bertalanffy growth model was assumed.

The input data consists of the length frequency distribution. The assumptions for the analysis are the following:

a) Each age is normally distributed.

b) The number of age groups present in the distribution, η, derived from the aged sub-sample. In this case, η= 9 (ages 2 to 10).

c) An initial guess of π_t that denotes the relative abundance of each age group (t) as a proportion of the total population. An initial guess of the proportion will be unimportant, as choosing them close to the true values will actually save little or no calculation (Macdonald and Pitcher 1979). A starting value of $\pi_t = \frac{1}{\eta}$ for all age groups was used, in this case $\pi_t = \frac{1}{9}$.

d) Initial values of L_∞, = 54 cm; K=0.18 year $^{-1}$and t_0 = 0.78 year, estimated from the sub-sample aged by biological methods (otolith readings), as described earlier and which give initial estimates of the mean length at age L_t.

e) Initial estimates of the standard deviation σ of L_t, which were obtained from the aged sub-sample.

A worksheet was prepared in EXCEL, introducing the necessary initial values, formulas and constraints. The programme proceeds iteratively, using the solver function to minimise the sum of squared errors (SSE) between the calculated (corresponding to the theoretical model) and the observed length distributions (Macdonald and Pitcher 1979).

The starting values were initially re-estimated for 1997, because the aged sub-sample corresponds to this year. The re-estimated growth parameters and σ were fixed for all the other years, assuming that the growth rates remain more or less constant for the 1993-2002 period. After that, π_t was estimated for each age group and year separately. A final iteration was performed, to obtain the final growth parameters, σ and π_t, by minimising the sum of the SSE of each year.

On the basis of the growth parameters obtained by the Macdonald and Pitcher method, other life history parameters were estimated: growth performance (ϕ'), life span (t_{max}) and the length class giving highest yield (L_{opt}).

A median value of ϕ' is estimated by the formula (Pauly 1997):

$$\phi' = \log K + 2 \log L_\infty \tag{9}$$

Life span, or the approximate maximum age that fish of a given population would reach (t_{max}) is calculated as the age at 95% of L_∞, by the formula (Pauly 1997):

$$t_{\max} = t_0 + 3K \tag{10}$$

The L_{opt} is the length class with the highest biomass in an unfished population, where the number of survivors multiplied with their average weight reaches a maximum (Beverton 1992). Theoretically, setting the minimum length (size of first capture) at this length will give the maximum yield. L_{opt} is estimated by the formula (Beverton 1992):

$$L_{opt} = L_\infty * \frac{3}{3 + \frac{M}{K}} \tag{11}$$

where *M* is the natural mortality.

Further, the obtained L_{opt} is tested in YpR analysis, setting the selectivity for ages ≤ to age corresponding to L_{opt} to zero ($s_{a \le 4} = 0$).

2.3.1.6 Natural mortality

The natural mortality *M* was estimated using two different methods.

Pauly's empirical formula assumes that *M* is a function of the von Bertalanffy parameters K, L_∞, T (temperature) and constants from Pauly (1980):

$$\ln(M) = -0.0066 - 0.279 * \ln(L_\infty) + 0.6543 * \ln(K) + 0.463 * \ln(T) \tag{12}$$

where T is 24.1ºC, the average of the sea surface temperature (Almada 1996).

The Rikhter and Efanov formula (*in* Sparre *et al.* 1989) assumes that *M* is a function of $Tm_{50\%}$ (age at which 50% of the population reaches the sexual maturity):

$$M = \frac{1.521}{T_{m50}^{0.720}} - 0.155 \text{ per year} \qquad (13)$$

where $Tm_{50\%}$ is 4.2 years, based on the estimation described earlier and constants were derived by Rikhter and Efanov

2.3.2 Stock assessment

One of the main objectives of the present work is to use the estimated biological information and life history parameters, combined with catch data, to assess the status of the *C. taeniops* stock on the São Vicente - São Nicolau insular shelf, applying age-based assessment methods.

2.3.2.1 Catch in numbers at age

To estimate the catch in numbers at age, the input data consists of:

a) The relative abundance of each age-group for each year (π matrix), obtained as described in section 2.3.1.5.

b) The weight-length relationship (section 2.3.1.3).

c) Total landings in kg, for São Vicente and São Nicolau islands, for the 1993-2000 period (INDP 1994-2001).

d) The mean weight at age $W_{(t)}$, (Appendix 8) which was calculated using the weight converted von Bertalanffy equation (section 2.3.1.4).

The π matrix is used to estimate the number of fish by age in the sample, which are converted to weight (in kg) using the weight-length relationship. The ratio of the estimated sample weight and the total landings gives the raising factor (RF):

$$RF = \frac{W(tl)}{W(s)} \qquad (14)$$

where *W (tl)* is the total landings weight in kg and *W(s)* is the sample weight in kg.

The RF multiplies the numbers at age in the sample, giving the catches in numbers at age.

2.3.2.2 Virtual Population Analysis

Virtual Population Analysis (VPA) is a general method to model a progression of a cohort through time, and is based on the population dynamics model which defines the number of fish in a cohort based on the fishing history and age of the fish (Lassen and Medley 2001).

A classic VPA was applied. The input data are:

a) Catches in numbers at age, estimated in section 2.3.2.1.

b) The natural mortality *M*, which was estimated using the Rikhter and Efanov formula, as described in Section 2.3.1.6. Then two more values were used (*M*=0.25 and *M*=0.51) to test the sensitivity of the model to different *M*-values.

It is assumed that the catch at age in numbers is measured without errors and that the natural mortality *M* is known.

VPA is based on two basic equations:

the stock equation, which relates stock size in one year with the next:

$$N_{a+1,y+1} = e^{-(Zay)} * N_{ay} \tag{15}$$

and the catch equation, which relates stock size to catches in the previous year:

$$C_{ay} = \frac{F_{ay}}{Z_{ay}} * \left(1 - e^{-Z_{ay}}\right) * e^{(Zay)} * N_{a+1,y+1} \tag{16}$$

where N_{ay} is the size of age group *a* in year *y*

$N_{a+1,y+1}$ is the size of age group *a*, one year later

Z_{ay} is the total mortality rate for age group *a* in year *y* (Z = F+*M*)

F_{ay} is the fishing mortality rate for age group *a* in year *y*

C_{ay} is the total catch in numbers of age group *a* in year *y*

For starting back calculations initial values of $N_{a+1,\ y+1}$ are necessary. Those initial values are guessed at, assuming that the entire cohort is fished out at the end of the last year.

From the matrix of catch at age, stock sizes at age are back calculated using McCall's equation 1986 (Haddon 2001). This equation does not include fishing mortality F_{ay} (which is unknown) and is used instead of the Eq. 15, which gives almost the same results (Stefánsson 1997).

Pope's approximation is useable with values of M up to 0.3, while McCall's formula is useable at higher values of M (Haddon 2001). For these reasons, McCall's formula is used in the present work:

$$N_{ay} = N_{a+1,y+1} * e^{M} + C_{ay} * \left(\frac{M}{1-e^{-M}}\right) \tag{17}$$

From the matrix of stock size at age, Fay is estimated by:

$$F_{ay} = \ln\left(\frac{N_{ay}}{N_{a+1,y+1}}\right) - M \tag{18}$$

For the oldest group (in this case, age 8) Fay is estimated as the average of the Fay of earlier ages, in this case, of ages 5-7, which are fully recruited to the fishery.

The average of the F_{ay} ($\overline{F}$) of the more represented age groups in the catches (ages 4-6, in this case) is used to estimate the selection pattern s_{ay}.

$$s_{ay} = \frac{F_{ay}}{\overline{F}_{y}} \tag{19}$$

The initial value for F terminal (F_{term}) was estimated as the average of $\overline{F}_{4-6}$ for earlier years.

Having estimated F for the oldest age group and selection pattern for the last year, stock sizes were recalculated through the inversion of the catch equation. Several iterations, re-estimating F_{ay}, s and stock sizes were performed until stable estimates of s_a and the final estimation of F_{term} were obtained.

2.3.2.3 Yield and Spawning Stock Biomass per Recruit models

A simplified Yield per Recruit (YpR) model of Beverton and Holt was applied to estimate the YpR Management Targets (Haddon 2001). A Spawning Stock Biomass per Recruit (SSBpR) was also estimated.

The input data are:

a) The estimated natural mortality M.

b) The selection pattern s_t, as an average of s for 1993-1997, resulting from the VPA.

c) The mean weight at age W_t (Section 2.3.2.4).

d) The maturity at age (2.3.1.2).

The stock equation (Eq. 15) and the estimates of M and F are used to determine the number of fish (N) by age. For age 2 (age of recruitment) N is assumed to be 1, because the yields are relative (i.e. relative to the recruitment) and are expressed on a "per recruit basis". This is a common alternative, which simplify the calculations (Haddon 2001).

Using the catch equation (Eq. 16), the catches in numbers by age are obtained, and then, using $W_{(t)}$, the Yield per Recruit (YpR) is estimated:

$$YpR = \sum_{t=t_c}^{t_{\max}} (W_{(t)} * C) \tag{20}$$

where t_c is the age at first catch (in this case age 2), t_{max} is the age of the oldest group (in this case 8+ group) and C is catch in numbers.

An EXCEL spreadsheet is used to calculate YpR for a range of $\overline{F}$ -values, which give a YpR curve as a function of F.

The SSBpR curve is obtained similarly, but here the proportion of mature individuals at age multiplies the YpR at age to obtain the SSBpR.

The YpR curve was used to estimate F_{max} and $F_{0.1}$. F_{max} corresponds to the highest value of YpR and $F_{0.1}$ is determined numerically by finding the F at which the slope of the YpR curve is 10% of the slope at the origin.

To test the sensitivity of the model, three different scenarios were set up, considering the estimated M=0.38, M=0.25 and M=0.51. Those values were arbitrarily chosen, but assuming Normally distributed values around the M-estimate.

The expected catch from a single cohort over lifetime was estimated simply by multiplying the YpR by recruitment (R). The calculations were performed using the highest, lowest and average R for the 1993-2000 period.

Changes in selection pattern were modelled to consider L_{opt}. The estimated L_{opt} was tested for two different *M* value scenarios (*M*=0.25 and 0.38), setting selectivity for ages ≤ 4 years to zero.

2.3.2.4 Yield prediction

The expected yield for 2001 was predicted for three scenarios of *M*-values (*M*=0.25, 0.38 and 0.51) based on the stock size of the final year in the VPA (2000) and assuming the average level of recruitment, constant selection (fishing) pattern and natural mortality.

From the numbers of fish at age in 2000, the number of fish at age for 2001 was estimated, using the stock equation (Eq. 15). The average recruitment was assumed to be the stock size at age 2. Through the catch equation (Eq. 16) the catch at age for 2001 was estimated. Finally, predicted yield was estimated multiplying the catch at age by the mean weight at age.

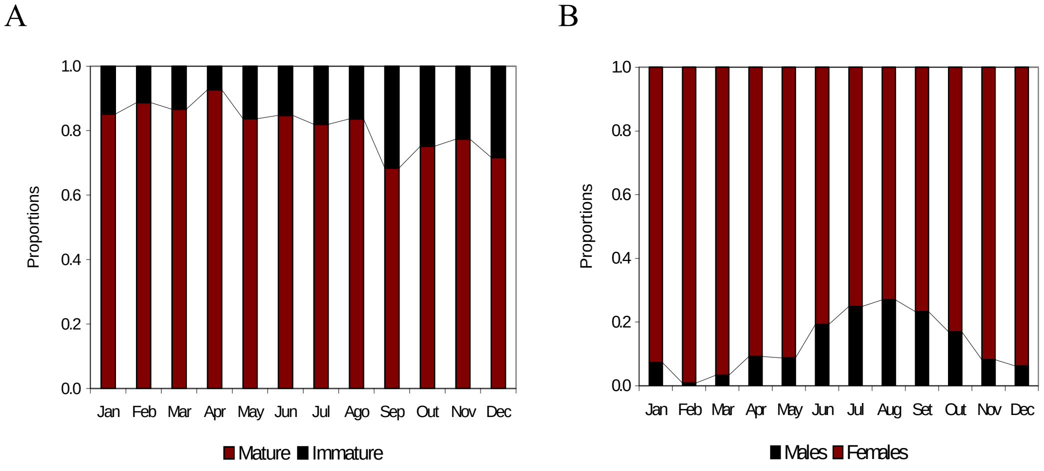
3 RESULTS

3.1 Life history parameter estimation

3.1.1 Time of spawning

Analysis of maturity stages shows that on average for the years 1993-2002 no less than 68% of sampled females were mature throughout the year (Figure 5A). The ratio of mature females from September to December decreases slightly, indicating possible decreases in reproduction activity. On the other hand, on average, the proportion of males in the samples is around 13%. (Figure 5B) There is a clear increase of this proportion during the June to October period: on average, around 22%, with a peak of 27% in August. This could be an indicator of increasing reproductive (spawning) activity in these months.

Further analysis shows a steady increase of GSI from January to May, corresponding to the increase in ovary weight with increasing development. This rise becomes sharp from May to August and is followed by a sharp decrease in September and October (Figure 6).

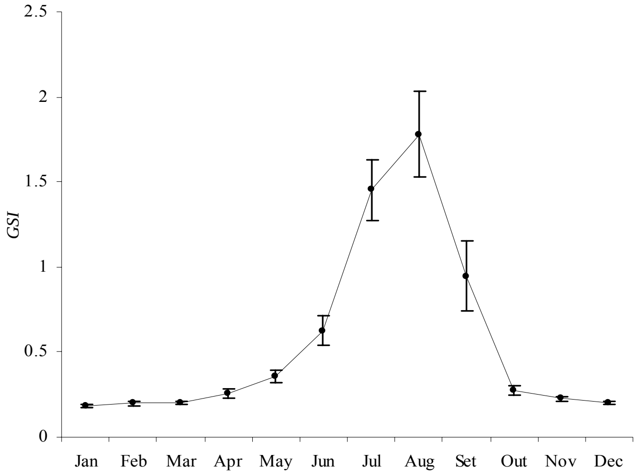


n= 5411 individuals

n=6234 individuals

Data are combined for all the years (1993-2002)

Figure 5: Proportions by month of A) mature and immature females B) males and females of *C. taeniops*.



Vertical bars indicate confidence intervals; n= 5241 individuals.

Figure 6: Gonadosomatic Index for *C. taeniops* 1993-2002.

3.1.2 Length at sexual maturity

h

The L_{50} (mean length at sexual maturity) was estimated at 26.5 cm TL (Figure 3).

The maturity ogive provides an estimate of the maturity at age when combined with data on growth (Appendix 8).

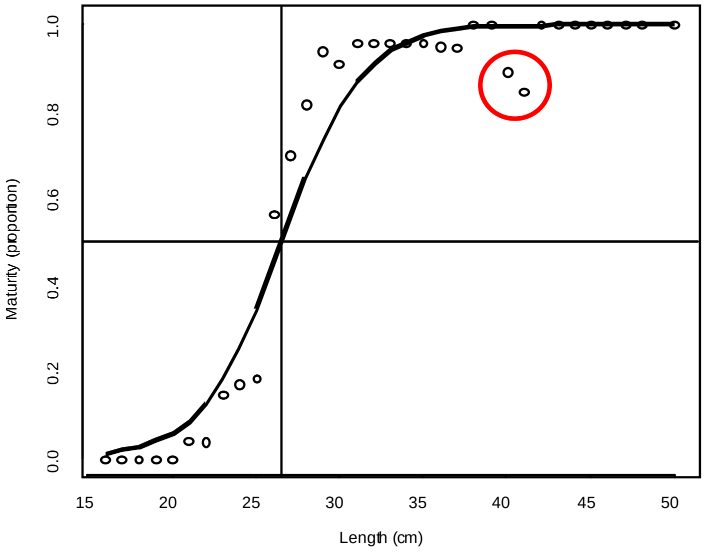


Figure 7: Maturity at length ogive for *C. taeniops* 1993-2002.

The outliers (in a red circle) probably result from sampling errors, due to the difficulties in detecting differences between immature and resting phases, n=3749 individuals.

3.1.3 Weight - length relationship

A W/L relationship was estimated with α= 0.0067 and β= 3.2 (Figure 8)

n= 6137 ind. ; r^2=0.97

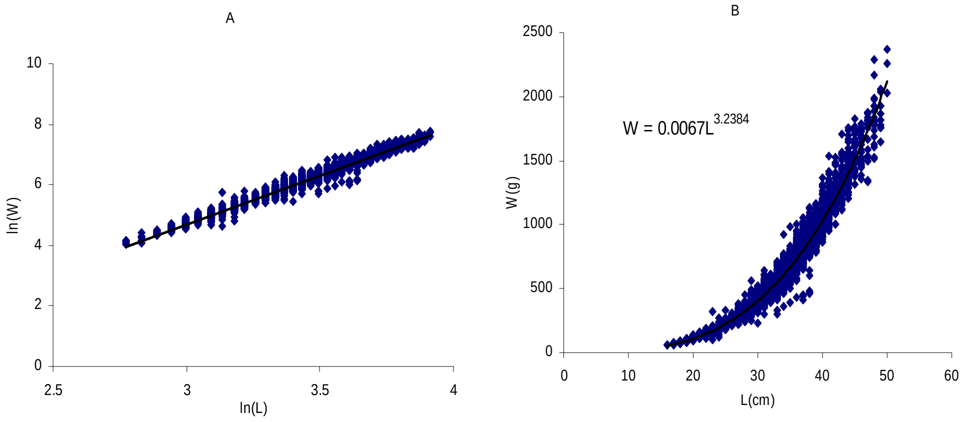


Figure 8: Weight-length (L/W) relationship of *C. taeniops* A) the log-transformed L/W relationship B) the L/W curve.

3.1.4 Growth parameters

Two sets of von Bertalanffy growth parameters that provided estimates of the mean length at age were obtained (Table 1 and Figure 9). In VPA, the parameters re-estimated using Macdonald and Pitcher were used.

Table 1: Estimation of von Bertalanffy growth parameters for *C. taeniops* using two different methods.

Parameters	Ford-Walford plot	Macdonald and Pitcher
L_∞ (cm)	54	62.9
K (per year)	0.18	0.12
t_0 (year)	0.78	- 0.28

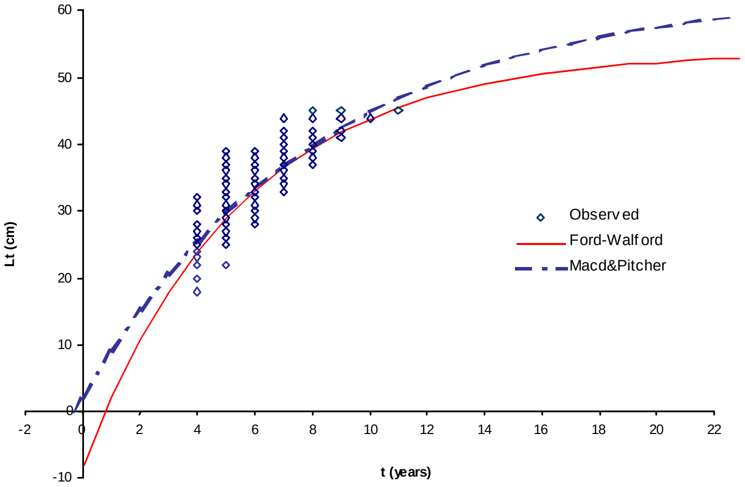


Figure 9: Growth curves obtained from aged sub-sample(Ford-Walford), fitted through minimisation and from Macdonald and Pitcher re-estimation (Macdonald and Pitcher 1979).

3.1.5 *Cohort splitting*

As an outcome of the Macdonald and Pitcher method, the observed length-frequencies were separated into cohorts, fitting the theoretical length-frequencies to the observed ones (Figure 10).

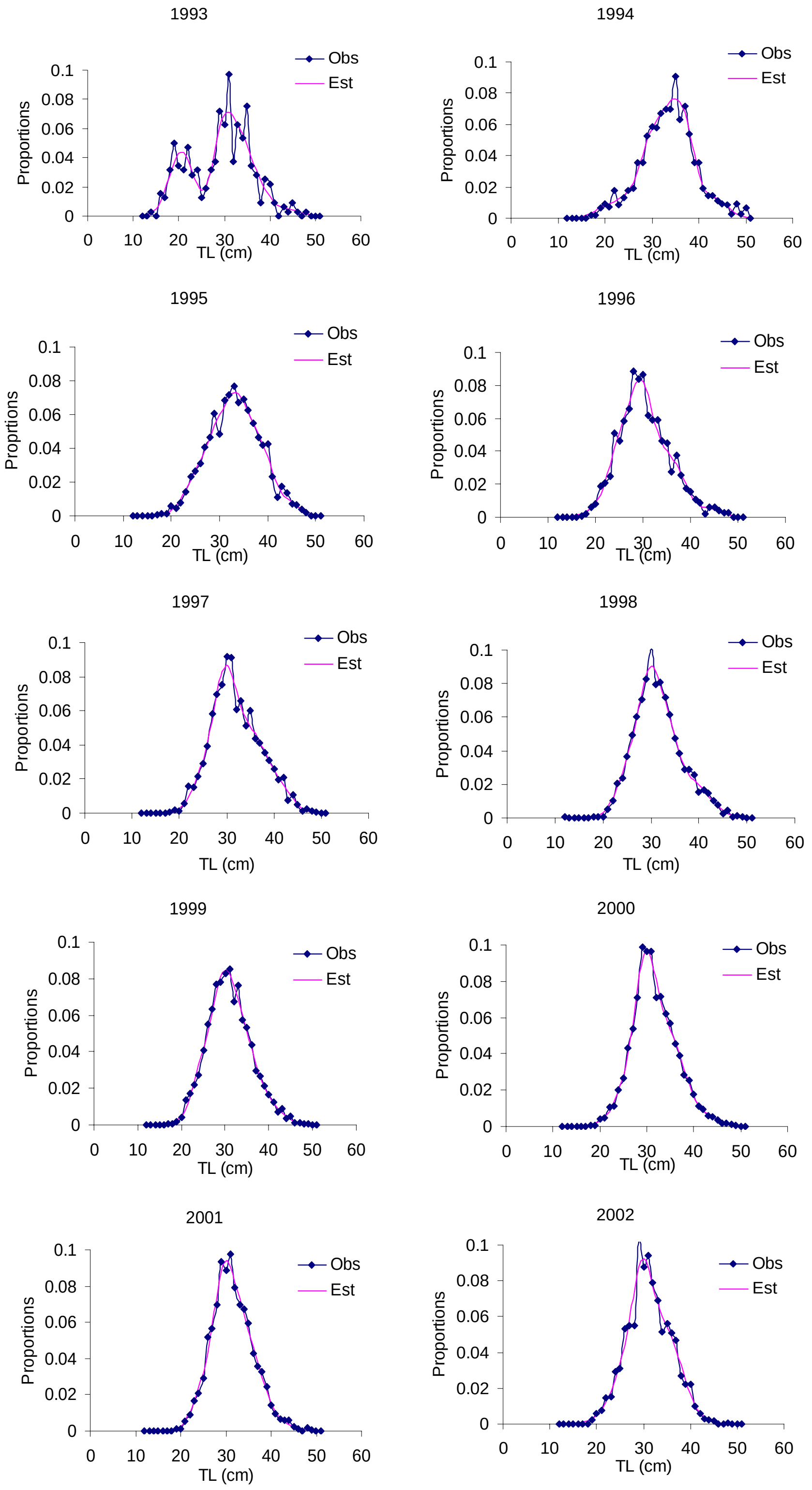


Figure 10: Observed and estimated length-frequencies for *C taeniops* 1993-2002.

The estimated life history parameters are summarised in Table 2.

Table 2: Summary of the estimated life history parameters for *C. taeniops.*

Parameter	Estimated value
L_{50}	26.5 cm
$tm_{50\%}$	4.2 years
K	0.12 per year
L_∞	62.9 cm
t_0	- 0.28 year
ϕ'	2.676
W_∞	4361 g
α	0.0067
β	3.2
t_{max}	24.72 years
L_{opt}	30.2 cm

3.1.6 Natural mortality

M was estimated to be *M*=0.34 (Pauly’s empirical formula) and 0.38 (Rikhter and Efanov’s formula).

3.2 Stock assessment

3.2.1 Catch in numbers at age

Appendix 6 shows the estimated catch in numbers at age.

3.2.2 Virtual Population Analysis

Three different scenarios were set up to test the sensitivity of final results to the assumptions of different *M*-values. For each scenario a final estimation of stock size (in numbers of fish at age) for the population, after it had been exposed to natural and fishing mortality was obtained (Appendix 7). Based on this matrix, fishing mortality (Appendix 8) and the selection pattern at age were estimated according to the method described in section 2.3.2.2. Using iterations, the *F* terminal was estimated as the average of the $\overline{F}$ of the 1997-1999 years. The Spawning Stock Biomass (SSB) was estimated on the basis of the final stock size matrix and maturity ogive. *F* and SSB trends are shown in Figure 11.

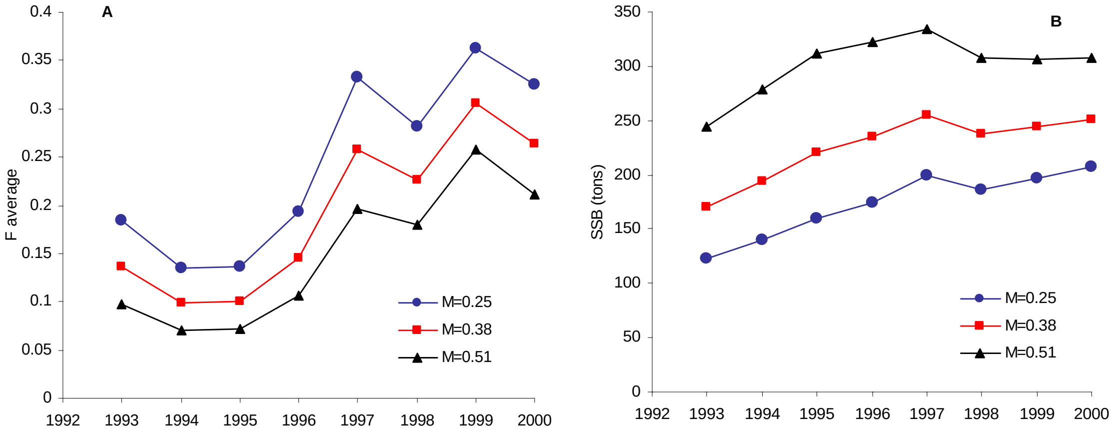
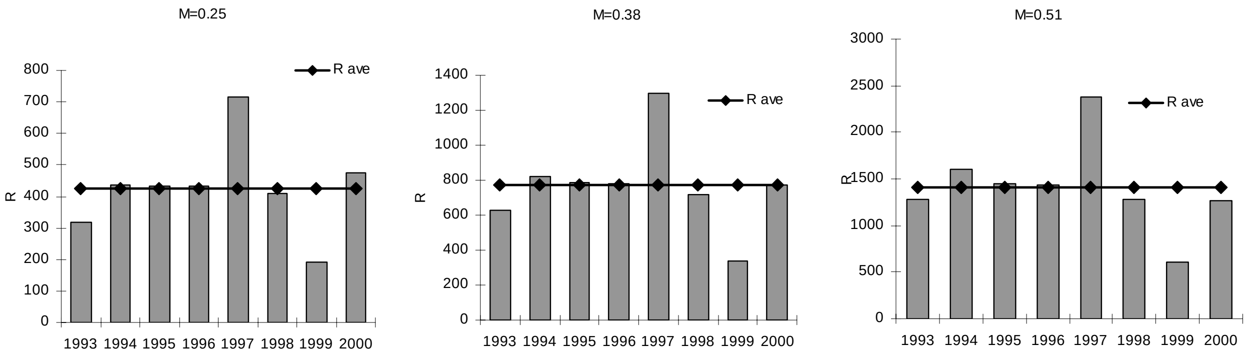


Figure 11: Trends in A) the average fishing mortality and B) the spawning stock biomass for *C. taeniops* in the 1993-2001 period, giving three different scenarios of *M*-values.

The estimated number of fish at age 2 shows the recruitment to the fishery. Annual recruitment (number of fish at age 2) in the analysed period along with the average recruitment is shown in Figure 12.

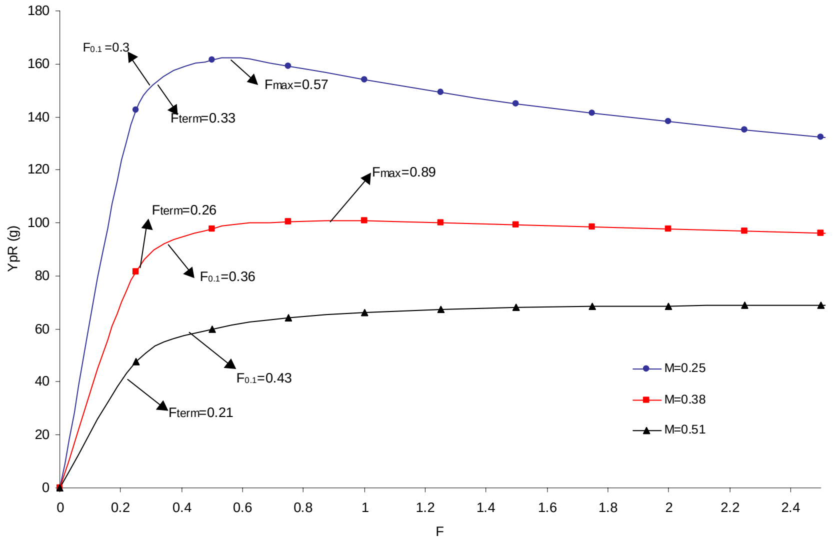


R -number of fish at age 2, in thousands
R ave- Average recruitment

Figure 12: Estimated recruitment R and the average recruitment for *C. taeniops* in the 1993-2000 period, giving three different scenarios of *M*-values.

3.2.3 Yield and Spawning Stock Biomass per Recruit Models

The results of YpR and SSBpR analyses are summarised in Figure 13 and Appendix 10.



The YpR in the *M*=0.51 scenario maximises at a value of F out of the graph range.

Figure 13: Yield per Recruit for *C. taeniops*, giving three different scenarios of *M*-values.

The L_{opt}, estimated in 30 cm was tested in YpR analysis (for two different *M*-value scenarios), setting selectivity for ages ≤4 years to zero (Figure 14).

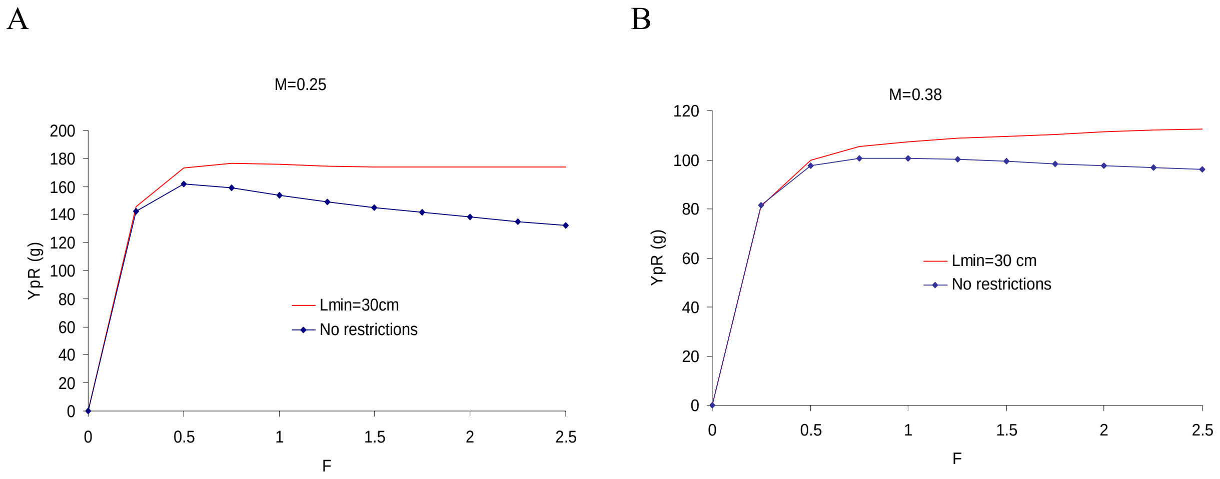


Figure 14: Estimated YpR for two *M*-value scenarios setting the minimum size of capture at 30 cm (Lmin=30 cm) and without restrictions in the size of capture.

3.2.4 Yield prediction

The expected yield was predicted for two different *M* value-scenarios. Results are summarised in Table 3.

Table 3: Yield predictions at different values of *F*, for two different *M*-value scenarios.

M scenarios	Yield at $F_{0.1}$ (tons)	Yield at F_{max}(tons)	Yield at F_{term}(tons)
M=0.25	75	91	77
M=0.38	86	99	74

4 DISCUSSION

4.1 Life history parameters estimation

4.1.1 Time of spawning

All the different analyses indicate that *C. taeniops* has a continuous or at least prolonged spawning period, as in the case of other tropical fish species. Both the results from analysing the *GSI* and the proportion of males indicate a peak in spawning activities somewhere between June and October, probably with more incidences in September and October. The results from analysing the maturity stages, on the other hand, contradict those obtained from the other three methods, because they seems to indicate a decrease in spawning activities in the last quarter of the year (the proportion of immature fishes increases).

A sharp increase in *GSI* from May to August followed by a sharp decrease in September and October, could be interpreted as follows:

January- May: preparation for reproduction

June - August: maturation, pre-spawning period

September-October: spawning

November-December: resting, preparing for the next cycle

The discrepancy in results could be due to the subjective nature of macroscopic maturation scale (qualitative method), whereas the *GSI* is objective technique and the difference between male and female is easier to detect than that between immature and resting phases. The classification is highly dependent on the expertise of the samplers.

Results from *GSI* analysis and estimation of the proportion of males are used further to estimate the length at sexual maturity.

For comparison, *C.taeniops* in the waters off Senegal spawns during the summer, extending to September (Siau 1994), which coincides with the results obtained in this report.

It is concluded that the highest reproductive activity period for *C. taeniops* on the São Vicente - São Nicolau insular shelf extends from June to October. For this reason, the samples taken during those months were used to estimate the length at sexual maturity L_{50}. The peak of spawning occurs in September and October.

4.1.2 Length at sexual maturity

In Senegal waters L_{50} for *C. taeniops* occurred at 18 cm TL (Siau 1994), but at 26.5 cm in Cape Verde (São Vicente - São Nicolau). This difference could be related to the fact that those populations have different biological parameters and are exploited at different levels of fishing effort. Siau reported that the most fished specimens range from 20 to 30 cm (Siau 1994), while the maximum size is 40 cm. In Cape Verde waters, the maximum reported length for the species is 70 cm (Reiner 1996). The maximum size in the samples (from 1993 to 2002) is 52 cm and most of fished specimens range from 25 to 40 cm.

4.1.3 Growth parameters

Graphical representation of the *C. taeniops* length data shows a length-frequency distribution typical of a highly selective fishery (in this particular case, due to the hook selectivity) in which a single mode is obtained, and almost no movement in the mode can be followed through time. In these circumstances, the length composition of the sample gives little information about the length composition of the population and it would be difficult to separate the cohorts from the length distribution, unless information on ageing or growth is available (Gulland and Rosenberg 1992). For this specific work, otolith-reading data gave information on the species growth.

Growth parameters estimated by the Ford-Walford plot and using Macdonald and Pitcher method are quite different, but looking at the two curves it can be seen that the difference between them is mainly in ranges outside the observed lengths (Figure 9). Although there was considerably more data available for Macdonald and Pitcher analysis, almost non-difference was found in the relation between L_∞ and K (ϕ') resulted from both methods and the estimates of the mean length at age are similar for the observed lengths.

The estimated growth parameters are in accordance with what is known about the species biology: *C. taeniops* is a long-lived, slow growing species, the growth is characterised by a curve with a smooth slope, with relatively low K. Based on obtained growth parameters, ϕ', t max and L opt were estimated.

ϕ' is the overall growth performance and is useful for comparing a set of growth parameters to other growth studies on the same species (or even on the same stock) if such works exist. In this case, there are no previous works on the growth of *C. taeniops* for comparison. The ϕ'-value obtained in the present work would be used as a reference point for future work in this area (Table 3.2). Another possible use for the estimated ϕ' is to get a first rough estimate of K for species that have not been previously studied, but which belong to the SERRANIDAE family, because species within the same family have similar ϕ'-values (Pauly 1997).

4.1.4 Cohort splitting

I Computer techniques, such as minimisation through solver iterations, can almost always produce a result (e.g. estimates of parameters that give the best fit of the model to the observed data). It is also true that those techniques will not produce sensible results unless there are signals in the data. In this case, information on growth of ageing or growth was available, which made the cohort slicing possible.

Estimating age groups from length-frequency data through attaining the best fit may involve a trade off between statistical precision and biological plausibility. (Macdonald and Pitcher 1979). When necessary, knowledge of the biology of the species should be used to ensure biologically meaningful results. In this case, constraints were imposed on the L_∞ value (less than 70 cm) and the K (less than 0.3).

One way on improving the data collection is to try to obtain information on the length composition of the population from other sources, such as scientific surveys operating with less selective gears or in areas of juvenile concentration.

4.1.5 Weight - length relationship

By performing the analysis of the variance of the weight-length relationship, it was concluded that even if the variance was for some factors statistically significant (especially when analysing the "year" factor), those factors do not explain the variability in the data (Appendix 11). Thus, a unique W/L relationship was estimated, with α= 0.0067 and β= 3.2. The differences between this relationship and the one in 1985 (Magnússon and Magnússon 1987) could be explained by the differences in the sample size and in the covered length range (Table 4).

Table 4: Weight - length relationship parameters for *C. taeniops.*

α	β	L range	No. of specimens	Reference
0.0073	3.2	28-53 cm	162	Magnússon & Magnússon,1987
0.0067	3.2	12-52 cm	6137	Present work

4.1.6 Natural mortality

The natural mortality *M* estimated for *C. taeniops* are likely to be too high for a SERRANIDAE species, a top predator. Problems in estimation of the natural mortality *M* could be related to the fact that the estimation is based on life history parameters, having a restricted number of age groups for calculating. Fish older than 12 years are not caught, probably due to gear (hook) selectivity and/or migration patterns.

Perhaps, a better method of determining the natural mortality *M* is to estimate first the total mortality (Z) and then, using values of Z and effort data, to estimate *M* through the Paloheimo method (Sparre et al. 1989). For the present work, no reliable effort data was available. The other methods, including the ones used by the author in the present work, give only a very rough estimation or a "qualified guess" of the natural mortality, but when no other information of *M* exists, to apply those methods is the better choice. (Sparre *et al.* 1989)

For this reason it is necessary to test the effect of the assumed *M* in terms of the stock estimate and in terms of advice given on the utilisation of the stock. In such cases, the tests are based on reasonable limits, which include the provision that is not inconsistent with available data (Stefánsson 1992).

4.2 Stock assessment

4.2.1 Virtual Population Analysis

Virtual or Sequential Population Analysis (VPA or SPA) is considered to be the "grandfather" of all stock assessment models (Stefánsson 1992) and was introduced in fish stock assessment by Gulland. VPA is an analytical strategy developed to back-calculate a matrix of numbers at age that would have given rise to the observed catches, given the imposed effort and estimates of the selectivity and catchability coefficients (Haddon 2001).

Applying a VPA model requires an estimate of M and of the F terminal (F_{term}). To estimate the F_{term} the most common approach is to produce independent estimates of F, obtained from surveys or using catchability by age, for which effort data are needed. In this case, no effort or survey data are available, so the VPA was applied without tuning the data, which makes the results less reliable, because the method is highly sensitive to the estimate of F_{term} values.

When estimating F_{term}, some corrections were made, attempting to get a sound estimate. At the beginning, it was estimated on the basis of the average F (F_{ave}) for ages 4-6, considering all years. Then, it was decided not to use the F_{ave} of the early years, because there seems to be an increase in fishing mortality for the last years. The F_{term} was re-estimated based only in the F_{ave} for the period 1997-2000. It is probable that the F_{term} is underestimated because, following the model, it is calculated as the average of the last years, while the F-trends (Figure 11) show an increase.

Another problem is that the time series is short, while *C. taeniops* is a long-lived species. Consequently, for the final years the cohorts are incomplete which makes the stock size estimates less reliable. Secondly, the recruitment was estimated only through back-calculations (in the VPA model) because no independent information on recruitment is available.

One of the assumptions made (that the cohort is fished out at the end of the last year) could be problematic in this specific situation, because the oldest fishes are not caught, due to hook selectivity or migration.

4.2.2 Yield and Spawning Stock Biomass per Recruit models

The results of YpR analysis are very sensitive to the different assumptions of M-values made. Three different value were used: M= 0.38 (estimated using the Rikhter and Evanov formula), M=0.25 and M=0.51, trying to set two values (lower and higher), normally distributed around the estimated value.

Three situations or scenarios are assumed to be possible. The most pessimistic one considers the possibility of a recruitment failure and assumes the R of 1999 (the lowest one obtained in VPA). The other two assume the average recruitment and the highest one.

The M=0.38 scenario indicates an F_{term} lower than the $F_{0.1}$. Potentially, as follows from the model and considering the estimated average recruitment, it could still be possible to increase the effort approximately 1.3 times. This increase could lead to raising the yield by about 9%. Given the uncertainties regarding F_{term} estimates, it is safer to consider that the actual level of fishing mortality could be underestimated possibly beyond the $F_{0.1}$. The apparent increasing trend of the F, which results from VPA and the general trends which official statistics show, emphasise the possibility of F_{term} being underestimated. In this case, recommendations could be made to maintain the fishing effort at most, at the current levels.

In the M=0.25 scenario the estimate of the F_{term} is higher than the estimated $F_{0.1}$, and results indicate that a 75% increase could give a maximum yield of 69 tons, if fishing at F_{max}. This strategy is not recommended, however, because empirically and due to the uncertainties inherent in equilibrium YpR analysis, F_{max} tends to be too high for a target fishing mortality, as other parameters in these models can only be estimated with limited statistical precision. A conservative approach would be to use $F_{0.1}$ for alleviating these uncertainties. Many fisheries around the world are managed using $F_{0.1}$ as a reference point of optimum fishing mortality because it appears to be a more robust and conservative replacement for F_{max} (King 1995). Adopting the $F_{0.1}$ strategy, for relatively small losses in yields, often results in a great gain in stock resilience to poor recruitment years or other sources of uncertainty (Haddon 2001). Yield at $F_{0.1}$ corresponding to average R was estimated in about 64 tons, while the corresponding Y at F_{max} is about 69 tons. The actual fishing mortality (and hence, the actual effort level) seems to be above the estimated $F_{0.1}$ by more or less 7%.

The M=0.51 scenario is used just for setting an upper limit, but it is far too high for *C. taeniops*. For this reason, it is excluded from the discussion.

Comparison of the $F_{0.1}$ and F_{max} resulted from YpR analysis with the $\overline{F}$ resulted from VPA for the different M scenarios gives different results (Figure 15). In none of the scenarios had $\overline{F}$ attained the F_{max} levels. In the M=0.38 scenario $\overline{F}$ had not reached $F_{0.1}$ levels, while in the M=0.25 scenario $\overline{F}$ had been around the $F_{0.1}$ levels since 1997. It should be noticed that statistics show increasing landings for the past years and from the model it follows that $\overline{F}$ is increasing too.

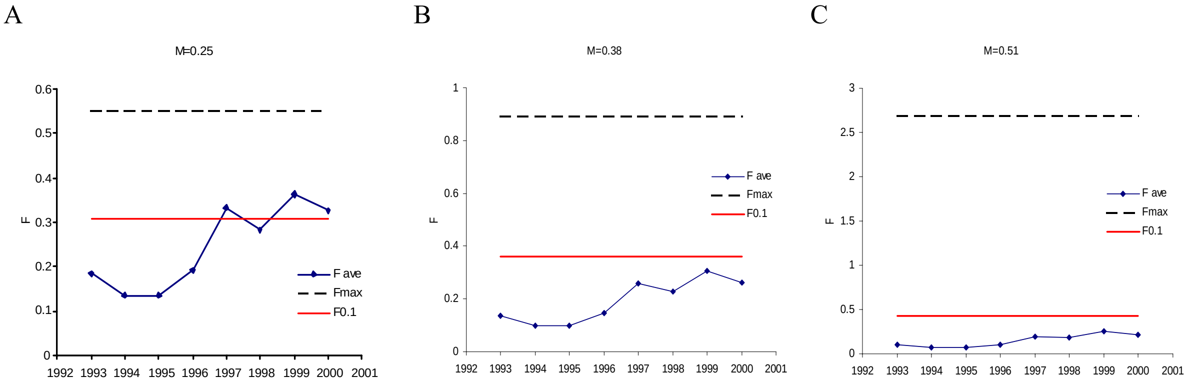


Figure 15: Comparison of the $F_{0.1}$ and F_{max} resulted from YpR analysis with the $\overline{F}$ resulted from VPA for the different *M* scenarios.

Testing the effect on YpR of setting L min at 30 cm shows that some increase in catches is expected, when the *M* is low, but no increases are expected if the population has a high natural mortality. From the biological point of view, given the age at first maturity of around four years, it would also be reasonable to recommend fishing the individuals of five years or more, which gives individual fishes opportunity to reproduce at least once in their life-cycle. Five-year old individuals have a mean length of approximately 30 cm, and have nearly reached the estimated L_{opt}. In this case, recommending to set the minimum size in the catches at 30 cm sounds logical both from conservative and economic points of view, but technically this is almost impossible to implement.

Finally, it is important to notice than the YpR model works best when applied to long-lived species, with *M* lower than 0.5 (King 1995) and this holds true for *C. taeniops*.

4.2.3 Yield prediction

The results obtained from yield forecasting for 2001 show that for different values of natural mortality the expected yields are quite similar if current levels of *F* and the fishing pattern are maintained. For *M*=0.38, a yield of around 77 tons is expected, while for *M*=0.25 the predicted yield is around 74 tons. Fishing at $F_{0.1}$, the expected yield for *M*=0.38 would be around 86 tons, while for *M*=0.25 would be 75 tons. The average of the catches for the last years (1997-2000) has been around 76 tons.

5 CONCLUSIONS

An important outcome from this work is the estimation of life-history parameters for *C. taeniops*, as a basis for stock assessment and management. This kind of work is being done for the first time for this species. Some of the parameters could be used in the future as reference points for similar works for the same or similar species in the region.

Estimated growth parameters demonstrated, as expected, that *C. taeniops* is a slow growing species, which makes it very sensitive to high fishing pressures. Regarding the sampling scheme and the data itself, some changes are recommended in order to improve data collection.

Available data are valuable, especially for life-history parameter estimation and for understanding some basic aspects of *C. taeniops* biology, but still not complete enough for a reliable assessment of the stock status. The existing scheme aims at sampling the commercial landings, but independent information of the stock length distribution and abundance indices are needed. In this sense, it is concluded that for improving results in future works, it is necessary to carry out scientific surveys covering also the length-classes that do not appear in commercial catches (especially the smaller ones), using less selective gears and operating in areas of juvenile concentration. Independent sources of information on recruitment are also needed. In this sense, eggs-larvae surveys and studies on fecundity estimation could be recommended in order to determine spawning and nursery areas.

Some changes are proposed to the land-based (commercial catches) sampling scheme. The present work shows that the spawning season of *C. taeniops* in São Vicente- São Nicolau insular has a clear peak from June to October. Once the spawning season has been determined, it is not necessary to carry out complete biological sampling throughout the year, because estimation of length at first maturity, which is relevant for management purposes, can be based on data collected during the reproduction season. In this sense, we recommend to carry out complete biological sampling in the June to October period every two years, in order to monitor changes in length at first maturity. It is recommended to keep the estimated relationship for further stock assessment works. Indeed, it is recommended to monitor the changes in this weight-length relationship every two or three years.

Reducing the sampling effort in such a way will allow intensifying the length sampling throughout the year and, probably, create the basis for moving to better assessment models. In this sense, the rationale is not only that length data are easier and cheaper to collect, but also that age data are often difficult to interpret in tropical species. A careful statistical analysis must be done to determine the optimum sampling design. Again, due to the high selectivity of the sampling gear (hook), other sources of information on the length-composition of the population are needed, e.g., from research surveys. To obtain survey abundance, indices or any other measures of recruitment have to be considered as a priority.

This work refers only to the São Vicente- São Nicolau *C. taeniops* stock. However, the fact that this is a separate unit is an assumption that must be verified. In this direction, studies on stock identification are needed. It is also recommended to extend the sampling to other zones, especially where the fishing effort is high and the abundance of the species seems to be decreasing.

Regarding the assessment, it is necessary to take into account that the assumptions made in VPA analysis possibly led to an underestimation of the $F_{term.}$ At the same time, the initial estimate of M seems to be too high, probably due to the restricted range of age groups on which estimation is based. For those reasons, estimations based on M=0.25 seem to be more reasonable. Following this scenario, it seems that since 1997 $\overline{F}$ has been around the $F_{0.1}$ level. Giving this value of M, the yield for 2001 was predicted as to be around 77 tons, if fishing at F_{term} and 75 tons, if fishing at $F_{0.1}$.

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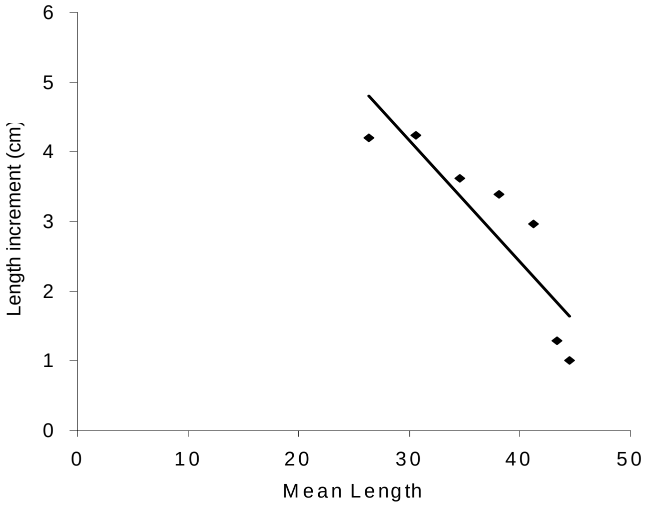
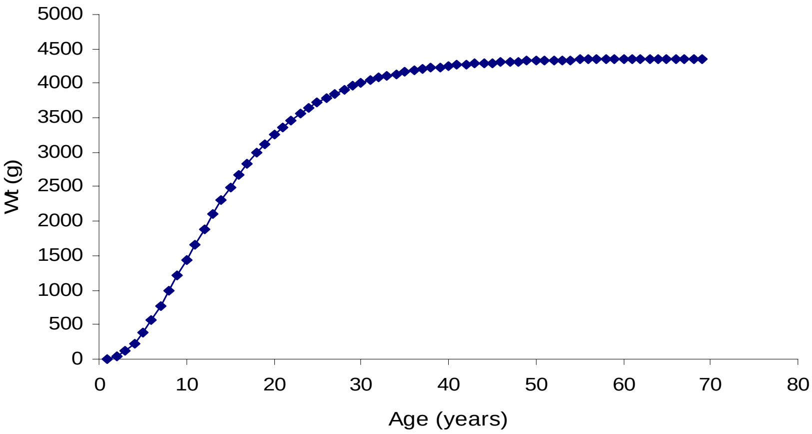
APPENDIX 1: GULLAND & HOLT PLOT



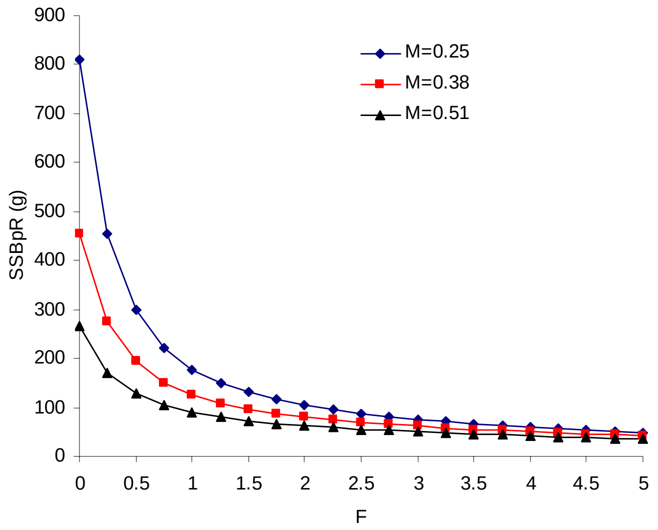
Gulland & Holt plot for estimating L∞ and K from the aged sub-sample (n=321 individuals, $r^2 = 0.7946$). L∞ = 53.95 cm and K = 0.17.

APPENDIX 2: WEIGHT CONVERTED VON BERTALANFFY GROWTH CURVE



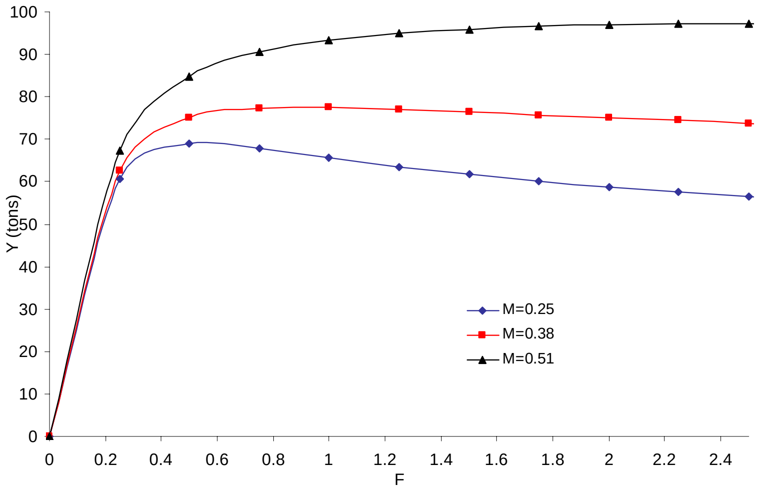
Weight converted von Bertalanffy growth curve for C. taeniops, which gives an estimate of the weight at age. W∞ = 4361 g.

APPENDIX 3: SPAWNING STOCK BIOMASS PER RECRUIT



Spawning Stock Biomass per Recruit for *C. taeniops*, giving three different scenarios of *M*-values.

APPENDIX 4: YIELD ESTIMATES FOR A SINGLE COHORT



Yield estimates for a single cohort over it's lifetime at different levels of fishing mortality, giving three different scenarios of *M*-values and the average Recruitment.

APPENDIX 5: STAGES OF REPRODUCTIVE DEVELOPMENT OF *C. TAENIOPS*

Maturity Stage	Ovary appearance	Eggs appearance
Stage 1: Immature	Thin, small and large. It is possible to determine sex with naked eye.	None visible to naked eye.
Stage 2: Maturing, Developing	Bigger, opaque.	None visible to naked eye.
Stage 3: Ripe, Pre-spawning	Big, fill body cavity	Large, translucent, round
Stage 4: Spawning, post-spawning	Releases eggs when pressed	Some free in the ovary

APPENDIX 6: CATCHES AT AGE IN NUMBERS FOR *C. TAENIOPS*, 1993 - 2000

	Ages						
Years	2	3	4	5	6	7	8+
1993	58	22072	75	24165	17019	7448	4199
1994	38	2318	3493	11183	12886	13805	5474
1995	46	265	8558	13104	17827	9637	9875
1996	70	2616	24945	33551	12954	11027	5142
1997	330	447	20700	57657	26319	21776	15180
1998	88	114	20402	45848	28152	7892	11550
1999	123	1369	35279	57837	38939	15421	10325
2000	130	1106	19862	77767	34319	25173	9293

APPENDIX 7: STOCK SIZE IN NUMBERS FOR *C. TAENIOPS*, 1993 - 2000.

Stock sizes are estimated for different natural mortality values: A) M=0.25 B) M=0.38 C) M=0.51

A	Ages						
Years	2	3	4	5	6	7	8
1993	317568	271674	166701	104061	87270	30010	11513
1994	435538	247271	192152	129761	59773	52986	16816
1995	432357	339163	190535	146573	91215	35209	29114
1996	432637	336680	263907	140856	102617	55347	18938
1997	714775	336877	259904	183574	80167	68516	33399
1998	408040	556377	261967	184193	92218	39268	34194
1999	192666	317704	433206	186062	103095	47040	23636
2000	473548	149940	246224	306329	93997	46016	23061

B	Ages						
Years	2	3	4	5	6	7	8
1993	628122	508541	286234	148527	118159	37967	13641
1994	823799	428990	329227	195450	81600	66727	19814
1995	786168	562663	291117	222008	124315	45151	34237
1996	782322	536953	384108	191817	140877	70269	22924
1997	1299524	534306	364616	241873	103458	85585	38939
1998	719593	887367	364590	232046	117846	49046	40570
1999	340941	491445	606021	232273	120835	57368	27018
2000	775461	232778	334556	384961	111141	50548	26517

C	Ages						
Years	2	3	4	5	6	7	8
1993	1281018	991637	503414	221151	162817	48462	16238
1994	1608253	769201	578554	302240	114276	84724	23392
1995	1442477	965720	460125	344741	172921	58744	40294
1996	1430770	866166	579707	269743	196970	90173	27888
1997	2383785	859118	518124	328989	136259	108349	45696
1998	1278043	1431199	515554	295263	153357	61648	48371
1999	608605	767391	859341	293948	142158	70510	30970
2000	1263835	365370	459766	488987	132178	55515	30519

APPENDIX 8: FISHING MORTALITY AT AGE FOR *C. TAENIOPS*, 1993 - 2000

Fishing mortality at age is estimated for different natural mortality values: A) M=0.25 B) M=0.38 C) M=0.51

A	Ages							
Years	2	3	4	5	6	7	8	Fave 4-6
1993	0.000	0.096	0.001	0.304	0.249	0.329	0.294	0.185
1994	0.000	0.011	0.021	0.102	0.279	0.349	0.244	0.134
1995	0.000	0.001	0.052	0.107	0.250	0.370	0.242	0.136
1996	0.000	0.009	0.113	0.314	0.154	0.255	0.241	0.194
1997	0.001	0.001	0.094	0.438	0.464	0.445	0.449	0.332
1998	0.000	0.000	0.092	0.330	0.423	0.258	0.337	0.282
1999	0.001	0.005	0.097	0.433	0.557	0.463	0.484	0.362
2000	0.000	0.043	0.092	0.399	0.485	0.635	0.507	0.325
						F term: Ave 97-99		**0.325**

B	Ages							
Years	2	3	4	5	6	7	8	Fave 4-6
1993	0.000	0.054	0.000	0.218	0.190	0.269	0.226	0.136
1994	0.000	0.007	0.013	0.071	0.211	0.286	0.189	0.098
1995	0.000	0.001	0.036	0.074	0.189	0.297	0.187	0.100
1996	0.000	0.006	0.081	0.236	0.117	0.209	0.188	0.145
1997	0.000	0.001	0.071	0.338	0.365	0.365	0.356	0.258
1998	0.000	0.000	0.070	0.271	0.339	0.215	0.275	0.227
1999	0.000	0.003	0.073	0.356	0.490	0.391	0.412	0.306
2000	0.000	0.024	0.062	0.281	0.359	0.502	0.380	0.234
						F term: Ave 97-99		**0.234**

C	Ages							
Years	2	3	4	5	6	7	8	Fave 4-6
1993	0.000	0.029	0.000	0.150	0.143	0.218	0.171	0.098
1994	0.000	0.004	0.008	0.048	0.155	0.233	0.146	0.071
1995	0.000	0.000	0.024	0.050	0.141	0.235	0.142	0.072
1996	0.000	0.004	0.056	0.173	0.088	0.170	0.143	0.106
1997	0.000	0.001	0.052	0.253	0.283	0.296	0.278	0.196
1998	0.000	0.000	0.052	0.221	0.267	0.178	0.222	0.180
1999	0.000	0.002	0.054	0.289	0.430	0.327	0.349	0.258
2000	0.000	0.017	0.053	0.247	0.334	0.504	0.362	0.211
						F term: Ave 97-99		**0.211**

APPENDIX 9: ESTIMATES OF THE MEAN LENGTH, WEIGHT, MATURITY, FISHING MORTALITY AND SELECTION PATTERN AT AGE

t (years)	L (t) in cm	W(t) in g	Mat	F_a	s_a
2	15.16	45.59	0.010	0.000	0.001
3	20.59	121.52	0.100	0.024	0.102
4	25.40	238.14	0.296	0.062	0.265
5	29.67	391.55	0.673	0.281	1.200
6	33.45	575.00	0.909	0.359	1.535
7	36.80	780.76	0.980	0.502	2.147
8	39.77	1001.22	0.998	0.381	1.627

L(t) - Mean length at age , W(t) - Mean weight at age, Mat - maturity at age, F_a - Fishing mortality at age , s_a - Selection Pattern at age
F_a and s_a were estimated for the oldest (8+) group.

APPENDIX 10: SUMMARY OF YPR AND SSBPR MODELS RESULTS

YpR and SSBpR results for different natural mortality values: A) *M*=0.25 B) *M*=0.38 C) *M*=0.51. For each *M*-values three scenarios of recruitment are set up: R min (minimum), R ave (R average) and R max (R maximum). Y and SSB are the yield and spawning stock biomass (in tons) expected from a single cohort over it's lifetime.

A				R min 192666		R ave 425891		R max 714775	
		YpR (g)	SSBpR (g)	Y	SSB	Y	SSB	Y	SSB
$F_{0.1}$	0.31	152	405	29	78	**65**	173	109	290
F_{max}	0.55	162	279	31	54	**69**	119	116	200
F_{term}	0.33	154	394	30	76	**65**	168	110	282

B				R min 340941		R ave 769491		R max 1299524	
		YpR (g)	SSBpR (g)	Y	SSB	Y	SSB	Y	SSB
$F_{0.1}$	0.36	92	231	31	79	**71**	178	119	300
F_{max}	0.89	101	139	34	47	**78**	104	131	176
F_{term}	0.26	83	268	28	91	**64**	206	108	348

C				R min 608605		R ave 1412098		R max 2383785	
		YpR (g)	SSBpR (g)	Y	SSB	Y	SSB	Y	SSB
$F_{0.1}$	0.43	58	138	35	84	**82**	195	138	329
F_{max}	2.68	69	53	42	32	**97**	75	164	127
F_{term}	0.21	44	182	27	111	**62**	257	105	433

APPENDIX 11: ANOVA TABLE TO TEST THE WEIGHT-LENGTH RELATIONSHIP FOR EFFECTS OF SEX, YEAR AND MONTH VARIABLES

Response: log(W)

Terms	Resid.Df	RSS	Test	Df	Sum of Sq	F Value	Pr(F)
1	6153	2115.037					
log(L)	6152	59.749		1	2055.288	225029.5	0.000000e+00
log(L) + Y	6143	56.912	+Y	9	2.837	34.5	0.000000e+00
log(L) + Y + S	6141	56.408	+S	2	0.505	27.6	1.000000e-12
log(L) + Y+ S+ *M*	6130	55.988	+*M*	11	0.420	4.2	3.486835e-06

L - length
Y - Year
S - Sex
M - Month