Labomar
Arquivos de Ciências do Mar

VIRTUAL POPULATION ANALYSIS OF THE CARIBBEAN SHARPNOSE SHARK, *Rhizoprionodon porosus* (POEY, 1861) (CARCHARHINIDAE), CAUGHT OFF PERNAMBUCO STATE, NORTHEASTERN BRAZIL

Análise de população virtual do cação rabo-seco, *Rhizoprionodon porosus* (Poey, 1861) (Carcharhinidae), capturado na costa do Estado de Pernambuco, Nordeste do Brasil

Sérgio Macedo Gomes de Mattos[1], Francesc Maynou[2]

ABSTRACT

We applied a steady-state Virtual Population Analysis–VPA to the stock of the Caribbean sharpnose shark, Rhizoprionodon porosus *(Poey, 1861) (Carcharhinidae) population caught off Pernambuco State continental shelf, North-eastern Brazil. Through the computational program VIT – "Software for fishery analysis", we show that even short-data series (1 year of sampling) can produce a useful (diagnosis) of fishery resources. The main objective of VIT program is to study the dynamics of a single species' population subject to exploitation, the variations in the exploitation rate, the interaction among fishing gears, and the reaction of the population to changes in the exploitation pattern, independently to the changes on catch and recruitment. The decision to conduct a VPA rely on the importance to observe the impact of fishery in a non-target species, and the difficulty to implement regulation and management measures on such a fishing stock. The results showed that the female stock is submitted to high levels of fishing mortality, but this is not true for the male stock; the current level of effort would drive the Caribbean sharpnose shark to a status of risk, denoting the susceptibility of this species to fishing pressure; the stocks undergo size-selective mortality; there are high levels of uncertainty on population density- and stock-recruitment relationship, which increase as abundance declines. The results suggest that the best regulation and management measures in the short-run should be a reduction of 25% in the current fishing effort.*

***Key words**: VPA, Caribbean sharpnose shark,* Rhizoprionodon porosus, *susceptibility, Pernambuco State.*

RESUMO

Foi aplicada uma Análise de População Virtual–VPA ao estoque do cação rabo-seco, Rhizoprionodon porosus *(Poey, 1861) (Carcharhinidae), capturado na plataforma continental do Estado de Pernambuco, Nordeste do Brasil. Através do programa informático VIT – "Software for fishery analysis", demonstrou-se que mesmo para uma série de dados não-históricos (1 ano de amostragem) pode-se produzir um diagnóstico útil dos recursos pesqueiros. O principal objetivo do programa VIT é estudar a dinâmica de uma população submetida à exploração pesqueira, a variação na taxa de exploração, a interação entre artes de pesca e a resposta da população aos câmbios nas estratégias de explotação, independente dos câmbios na captura e no recrutamento. A decisão em conduzir um VPA se deve à importância em observar o impacto da pesca em uma espécie que não é alvo das capturas e a dificuldade em implementar medidas de ordenamento e gestão para esse estoque. Os resultados permitiram inferir que o estoque de fêmeas está submetido a um alto nível de mortalidade por pesca, diferente do estoque de machos; o esforço de pesca atual pode conduzir os estoques de fêmeas e machos do cação rabo-seco a situações de risco, o que demonstra a susceptibilidade da espécie à pressão pesqueira; o estoque estudado sofre mortalidade seletiva por tamanho; há altos níveis de incertezas na densidade populacional e a relação estoque-recrutamento, os quais aumentam com a redução na abundância. Os resultados sugerem que a melhor medida de ordenamento e gestão em curto prazo deverá ser a redução de 25% no esforço de pesca atual.*

***Palavras-chaves**: VPA, tubarão rabo-seco,* Rhizoprionodon porosus, *susceptibilidade, Pernambuco.*

[1] Secretaria Especial de Aqüicultura e Pesca da Presidência da República (SEAP/PR). E-mail: sergiomattos@seap.gov.br
[2] Instituto de Ciências do Mar, Barcelona - Espanha (ICM/CSIC). E-mail: maynouf@icm.csic.es

INTRODUCTION

Aiming to better understand the answers of a given fishery resource to the fishing effort applied, one must take into account that many of the species commercially exploited have distinct characteristics and susceptibility to the employed methods of capture. Nowadays there is an increasing awareness for the management of fishing stocks and models have been developed for population dynamic studies of a particular fishing stock. Questions that commonly arise highlight the importance of such studies for the general comprehension of the fishery activity, and which model should be more appropriate for the analysis of the data available and the expected results, especially when stock assessment analysis is to be conducted. As pointed out by Willmann & García (1986), the main objective of a model is to proportionate to decision-makers and administrators a straightforward instrument that can assess possible consequences deriving from the adoption of important political decision.

We applied a virtual population analysis (VPA) of the Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861) (Carcharhinidae), population caught off Pernambuco State continental shelf, Northeast Region of Brazil (Figure 1), by the gillnet artisanal fleet, through the application of a model suitable for small-scale fishing, such as those developed for the North-western Mediterranean by Lleonart & Salat (1997). The reason for such an option is that the small-scale coastal fishery of Pernambuco State and that of North-western Mediterranean have similar characteristics, according to descriptions provided by Martín (1991) and Lleonart *et al* (1999b) for the latter. Both have a variable activity and highly multispecific catches and multi-gear utilization. On the other hand, different from the Mediterranean, fishing intensities and strategies off Pernambuco are relatively stable, with low fluctuations in space and time, which does not mean that the evaluation of the elementary fishing effort and yields of every component, and their corresponding variations, is an easy task. On the contrary, other problems facing the artisanal fishery sector such as lack of effort control, dispersion of landings, dependency of fishermen on wholesalers, etc., are the main problems to quantitatively assess such a fishery in Pernambuco.

Sharks represent a fishing resource of great importance in the whole world, caught mainly as by-catch. Out of the availability of catch and effort data for the Caribbean sharpnose shark, the decision to conduct a VPA rely on the importance to observe the impact of fishery in a non-target species, and the difficulty to implement regulation and management measures for a stock or population

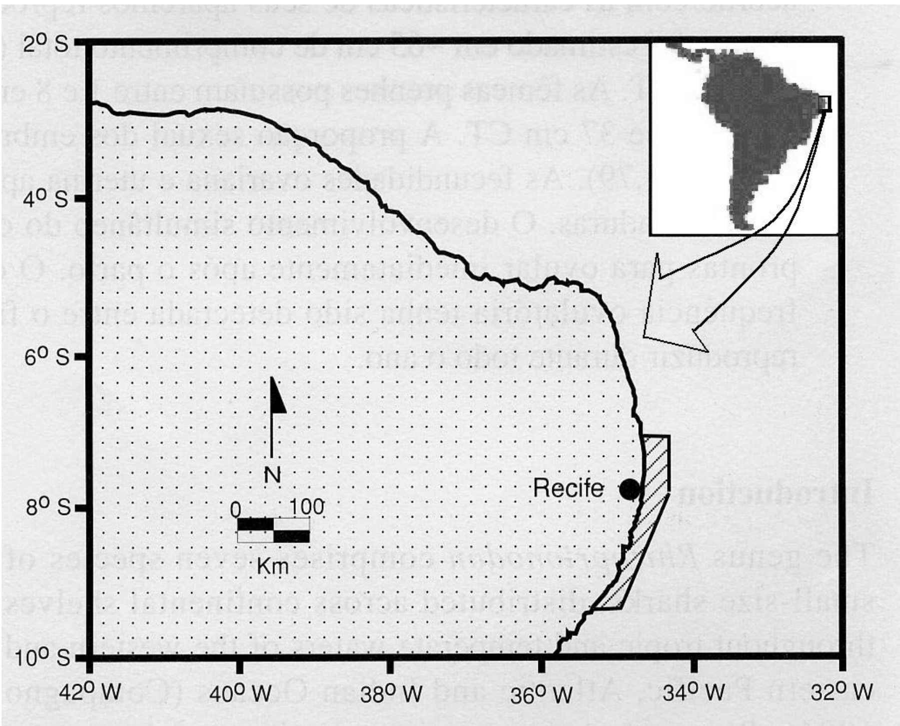

Figure 1 – Area of operation of the gillnet artisanal fishing fleet.

caught as by-catch. Besides its relevance as a source of protein for poor fishing communities located in the State of Pernambuco (Brazil), *R. porosus* also plays a significant role in the balance of the coastal ecosystem, being an important part of the food chain (Mattos, 1998), and population dynamics studies on this species are scarce.

MATERIAL AND METHODS

During April 1996 to July 1997 the operations of bottom gillnet fishing boats had been followed. Fishery and biological information have been registered during landings. Total and fork lengths and eviscerated weight, aiming population dynamic studies, was annotated. Identification of the caught species was conducted through the guides of fish species proposed by Compagno (1984) and Gadig (1994).

For the establishment of the von Bertalanffy's growth parameters, and consequently the determination of the growth curve in size (total length - TL) and weight (eviscerated weight - EW) the method of size frequency distribution was applied, according to the methodology described in Gulland (1969 and 1983), Santos (1978) and Fonteles Filho (1989). As an aid to this methodology, and aiming at examining the modal groups of the length-frequency of the sample distribution to verify if they were adequately described by growth parameters, it was used the analysis of modal progression, through the Method of Bhattacharya, through FISAT - The FAO-ICLARM Stock Assessment Tools. Aiming at confirming the parameters $L\infty$ and K, the stages *Response Surface Analysis* and *Scanning of K-values* (Gayanilo *et al*, 2002), were mainly utilised.

Through the computational program VIT – "Software for fishery analysis" developed by Lleonart and Salat (1997), in its Windows version (Maynou, 1999), a virtual population analysis (VPA) was conducted leading to reconstructing the population of the studied species. The main objective of the VIT program is to study the dynamics of a single species' population subject to exploitation, the variations in the exploitation rate, the interaction among fishing gears, and the reaction of the population to changes in the exploitation pattern, independently to the changes on catch and recruitment. The program allows studies on the current situation of the stock under intense fishing pressure, having as main assumption that of steady state, or equilibrium.

The program works with pseudo-cohorts, therefore suitable for analyses of non-historic series. Other analysis tools and reporting options are the yield-per-recruit (Y/R) analyses based on the fishing mortality (F) vectors, analyses of sensitivity to parameters inputs, and transition analysis – outside the equilibrium – due to changes in the patterns of exploitation or recruitment. Program flow is detailed in Lleonart and Salat (1997). Even considering the small sample size, a good size range length was obtained, so the method of pseudo-cohort analysis applied was the classic catch equation, denoted as standard VPA (Gulland, 1969), and the usual population dynamics equations were used.

To run the program VIT, ancillary parameters of the studied populations were established, such as: the parameters of von Bertalanffy's growth equation, the parameters of the length-weight relationship, the vectors of natural and fishing mortalities, sexual maturity ratio, and catch proportions by fishing gear. Before actually carrying out the computations, the program checks for the validity of data and parameters. As input parameters were structured by size class and the performed analysis was done on an age-structured population, it was necessary to precede a conversion of size-structure composition to age-structure composition. After the definition of the ancillary parameters a VPA was conducted, which allowed the provision of indicators and reference points.

The input value of the terminal fishing mortality (F_{ter}) as constant parameters for the whole population was calculated considering that the coefficient F is proportional the stock density and the intensity of fishing defined as the fishing effort per unit of area. Lacking a better method for estimating natural mortality (M), the relationship $Z = F + M$ was used after the estimation of total (Z) and fishing (F) mortalities. Thus, Z was calculated through the Beverton and Holt Model using FISAT (Gayanilo *et al*, 2002). A constant value of M was considered. As it seemed to be of concern for Lleonart *et al.* (1999), our result might be somewhat biased because the VPA analysis is very sensitive to variations in M and we have assumed it to be constant although it is likely to be higher in younger fish.

The analysis requested to obtain the yield-per-recruit (Y/R) was performed and the results displayed in two grids, the top one for the situation of virgin stock (factor of effort 0) and the other one for the various levels of effort variation. Note that effort factor 1 corresponds to the present level of fishing effort. The usefulness of the Y/R analysis resides precisely in observing the behaviour of the Y/R curve as fishing effort varies, being a function of it. With the stock rebuilt by means of VPA, the selected method for computation of mean weights computed for each class was chosen. In the sequence a transition analysis was conducted attempting to verify the effects of changes in the fishing patterns or the effort level on a non-equilibrium population, through the age-structured data set, i.e. the evolution of the fishery in the presence of changes in recruitment, very useful for a medium term evaluation of the risk associated with the exploitation pattern, because permits to study the sensitivity of the stock to recruitment. The analysis of fishing regime shifts was done under conditions of deterministic and stochastic recruitment, using the Beverton and Holt's stock-recruitment model with a 20 years simulation period. In order to at least obtain a minimally significant value, the number of interactions fixed was 30.

The initial hypotheses state that the stock is in equilibrium and that, at the level of spawning stock biomass per recruit calculated by the VPA, recruitment is equal to 1. Considering a deterministic simulation, a change in exploitation pattern was incorporated in the first year of the simulation, homogeneously for all age classes. For a stochastic simulation, the variance of the recruitment was defined through a variance assistant incorporated in the program for the definition and visualisation of the variance model, lognormally distributed with mean 1. The lognormal distribution error model was plotted on the recruitment model with 95% confidence interval. The variance value for the recruitment was defined at 0.1, and during simulation were stipulated a 25% increase and decrease conditions for F with the applied fishing gear. Also, the stock condition was simulated under the application of an optimum effort factors defined in the yield-per-recruit analysis for each stock of the model, the one that leads to the Maximum Sustainable Yield (MSY).

The sensitivity of the parameters, known also as risk analysis, was also evaluated. Since several of these parameters values are doubtful, in order to obtain reliable results it is necessary to know how the errors pass from parameters to results (Lleonart, 1993). It must be understood that it is a purely theoretical analysis, and that no one can avoid to strictly monitoring the exploitation changes of a real fishery.

RESULTS

The population dynamic study by means of virtual population analysis (VPA), through the computational program VIT – Software for Fisheries Analysis, was conducted for the Caribbean sharpnose shark, *Rhizoprionodon porosus*. A total of 273 specimens of the Caribbean sharpnose shark were analysed, being 167 females and 106 males. The total length (TL) of the individuals examined in the present study varied from 31.5 to 100.5 cm, for females, and from 31.0 to 80.0 cm, for males (Fig. 2).

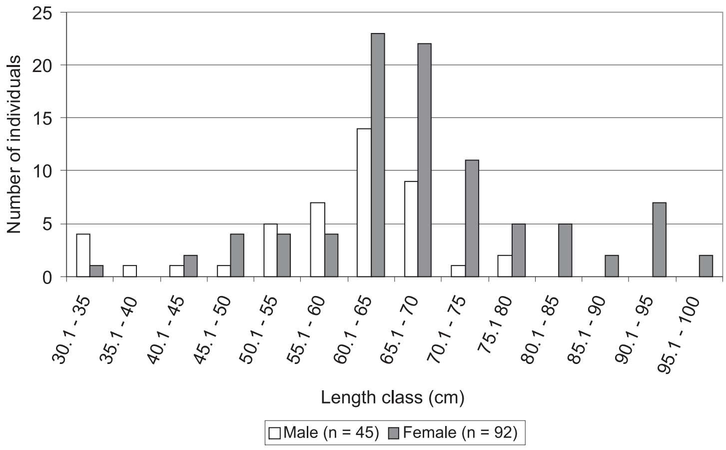

Figure 2 - Length frequency distribution of males and females Caribbean sharpnose shark, *Rhizoprionodon porosus*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

For this species it was utilised von Bertalanffy's growth parameters established by Mattos and Pereira (2002), and these authors found significant difference between sexes considering the asymptotic length ($L\infty$) and weight ($W\infty$), the growth rate (K) and the theoretical age (t_0) at which the length of the fish (L_0) is zero, so the analysis was conducted distinctly for each sex. The length-at-age vector was computed from the von Bertalanffy's growth parameters for the Caribbean Sharpnose Shark. For females the growth parameters are: $L\infty$ = 106.82 cm; $W\infty$ = 4.513 kg; K = 0.3; and t_0 = -1.12 year; and the length-weight relationship parameters: a = 0.0017, and b = 3.1666. For males the growth parameters are: $L\infty$ = 87.13 cm; $W\infty$ = 2.278 kg; K = 0.42; and t_0 = -1.1 year; and the length-weight relationship parameters are a = 0.0054, and b = 2.8993. Age, length and weight vectors for females and males of Caribbean sharpnose shark are depicted in Table I.

These data allowed the estimation of the fishing (F) and natural (M) mortalities. The total mortality Z was found to be 0.358 and 0.379, for females and males, respectively. F was calculated to be 0.251 for females, and 0.228 for males. M was calculated considering the relationship $Z = F +$

Table I – Age, length and weight values for female and male Caribbean sharpnose shark, *Rhizoprionodon porosus*, caught off Pernambuco State, North-eastern Brazil, continental shelf. (source: Mattos & Pereira, 2002).

Age (year)	Total Length – TL (cm)		Eviscerated Weight - EW (g)	
	Female	Male	Female	Male
0	32.5	32,5	104	131
1	51.7	51.4	453	492
2	65.9	63.7	980	919
3	76.5	71.8	1,568	1,299
4	84.3	77.1	2,135	1,597
5	90.2	80.6	2,636	1,814
6	94.4	82.8	3,056	1,966
7	97.6	84.3	3,396	2,071
8	100.0	85.3	3,664	2,141
9	101.8	85.9	3,872	2,187
10	103.1	86.3	4,031	2,218
11	104.0	86.6	4,152	2,239
12	104.8	86.8	4,243	2,252
13	105.3	86.9	4,312	2,261
14	105.3	87.00	4,363	2,267
15	106.00	87.0	4,401	2,271

M, and the values found were 0.107 and 0.151, for females and males, respectively. The 3-year age class presented the higher mortalities rates for both sexes; for females VIT calculated a Z = 1.016 (mean rate of 0.482) and an F = 0.909 (mean rate of 0.375), while for males Z = 0.930 (mean rate of 0.508) and F = 0.779 (mean rate of 0.357). For females the global fishing mortality was found to be 0.333, and 0.323 for males; while the terminal F was found to be 0.114 and 0.196, for females and males, respectively. Fishing effort (f) and CPUE were established by Mattos (1998).

From Mattos *et al.* (2001), who studied the reproductive biology of this species, was possible to calculate the maturity ratio. For females it was found that in the length class 60-65 cm, 25.7% of the sample distribution was considered mature or maturing, and in the length class 65-70 cm, the percentage of mature individuals was 62.2%. Above 70 cm of total length, 100% were mature. Through a standard VPA, and after converting the size-structure data set to an age-structure data set, it was found that in the population 8.6% of females at age 1 and that 82.1% of females at age 2 were mature. For males it was found that, for the same length class, the percentages of matured individuals were 3.6% and 54.2%, respectively, and also above 70 cm all males were found to be mature. Through a standard VPA, and after converting the size-structure data set to an age-structure data set, it was found that in the population 1% of males at age 1 and that 53.2% of males at age 2 were mature. For both males and females, 3+ age class individuals were mature. Summary VPA results for the Caribbean sharpnose shark can be found in Table II.

Table II – Summarised information of the virtual population analysis for female and male Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), caught off Pernambuco State, Northeastern Brazil.

VPA Parameters	Females	Males
Catch Data		
Catch mean age (year)	2.4	1.8
Catch mean length (cm)	67.3	59.5
Mean fishing mortality, F	0.375	0.357
Global fishing mortality, F	0.333	0.323
Total catch /year (kg)	19484	8555
Catch /biomass balance, D (%)	82.0	72.6
Catch/biomass, B (%)	48.9	40.1
Population Status		
Current Stock Mean Age (year)	1.7	1.4
Current Stock Critical Age (year)	2.0	1.0
Virgin Stock Critical Age (year)	7.0	0
Current Stock Mean Length (cm)	56.5	53.8
Current Stock Critical Length (cm)	64.9	51.1
Virgin Stock Critical Length (cm)	97.5	32.2
Number of recruits, R	21967	16808
Mean Biomass, B_{mean} (kg)	39863	21326
Spawning Stock Biomass (SSB) (kg)	24920	85001
Biomass Balance (D) (kg)	23750	11774
Natural death/D (%)	17.96	27.35
Maximum Biomass /Mean Biomass	27.24	29.53
Turnover, D/B_{mean} (%)	59.58	55.21
Recruitment		
Biomass/Recruit (B/R) - g	1814.9	1268.8
Stock Spawning Biomass/Recruit (SSB/R) - g	1134.6	505.7
Yield/Recruit (Y/R) - g	887.1	508.9

Table III – Results of the yield-per-recruit analysis for females and males Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), caught off Pernambuco State, Northeastern Brazil.

	Females			Males		
Slope (intersection) at origin (g)	6191.2			1235.6		
Virgin biomass (g)	346353648			552011223		
Factor	Y/R	B/R	SSB/R	Y/R	B/R	SSB/R
0	0	15769.4	14874.4	0	3284.2	2118.1
0.37	941.6	5659.3	4858.6	-	-	-
0.55	981.9	3872.2	3108.3	-	-	-
1.01	887.1	1814.9	1134.6	508.9	1268.8	505.7
1.02	-	-	-	511.2	1249.5	491.9
1.53	-	-	-	534.1	891.5	250.4
2.00	690.2	817.3	264.7	524.2	693.0	135.0

The performed yield-per-recruit analyses for the Caribbean Sharpnose Shark are displayed in Table III.

Caribbean sharpnose shark stocks are composed of very young individuals (female = 1.7-year olds; males = 1.4-year olds) and relatively small and medium size (females = 56.5 cm; males = 53.8 cm) individuals, on the assumption of the asymptotic length (females = 106.82 cm; males = 87.13 cm). The effort is being applied mainly on older ages (females = 2.4-year olds; males = 1.8-year olds) and medium sizes (females = 67.3 cm; males = 59.5 cm) than the critical ones (females = 2-year olds and 64.9 cm; males = 1-year olds and 51.1 cm), which means that, especially for females, the spawning stock population is heavily fished.

Although the Caribbean sharpnose shark, as well as the others small coastal sharks, is not the target species of the gillnet fishery, it seems that the fishing effort applied is driving such stock to overexploitation. From the results displayed for current and the virgin stock critical age (female = 7-year olds; males = 0-year olds), it seems that the female stock is represented by a wide variety of age-class, while the male stock mainly by younger individuals. Considering the low number of recruit (females = 21,964; males = 16,808), the balance between biomass and catch (females = 48.9%; males = 40.1%), and the fishing mortality rates (females = 0.375 – mean and 0.333 – global; males 0.357 – mean and 0.323 – global), the rate of exploitation (*F/Z*), or the rate of current catch per unit of production (*D*), is extremely high for both stocks (females = 82%; males = 72.6%), while the natural mortality represents only 18% for females and 27.4% for males of the biomass balance. The smaller size attained by males shall be one of the reason that can explain a higher natural mortality rate. Also, the production per unit of biomass, expressed as turnover (D/B_{mean}) and in percentage, shows a rate of 59.6% for females and 55.2% for males, which is equivalent to the total mortality rate in terms of biomass. Such results denote that the Caribbean sharpnose shark female stock is under a higher fishing pressure than the male stock.

Further analysis of yield-per-recruit depicted in Table III, for both sexes, and Figs. 3 (females) and 4 (males) shows the low level of recruitment of such stocks and that fishing effort for females is beyond maximum sustainable yield (*MSY*), whilst this do not hold true for males. For females the results suggest a sharp decline on biomass and that a recovery would be possible under a decrease of *f* to a factor of 0.55, which means a reduction of 45% of the current *f* applied, that would generate a maximum yield-per-recruit. For males maximum *Y/R* shall be reached at an *f* factor of 1.53, which means that without any other variable the male stock support an increase of fishing effort of 53%.

The following transition analysis confirms the susceptibility of this species to fishing pressure. Figs. 5 (females) and 6 (males) show the transition analysis under deterministic condition; while Figs. 7 through 9, for females, and Figs. 10 through 12, for males, under stochastic condition. It can be seen that, under the deterministic condition, that any increase in fishing effort would sharply decrease the current level of both females and males stock biomasses, leading to an overexploitation situation. Increase of 25% (factor = 1.25) must decrease the current biomass by approximately 43.1% and 32.6%, respectively. The results show that a biological equilibrium shouldn't occur. Although the *Y/R* analysis for males indicates that a maximum *Y/R* could be reached at a factor of 1.53, under non-stable equilibrium the stock presents high vulnerability. On the other hand, a decrease in *f* by 25% (factor 0.75) would favour recovery of the total and spawning stock biomasses (71.4% and 40% respectively for females and males). Applying a factor

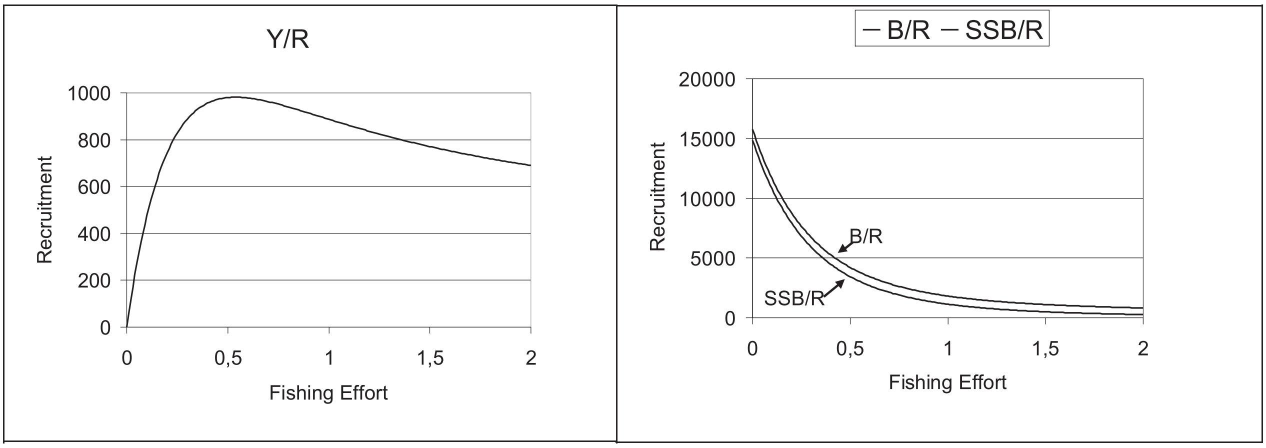

Figure 3 – Yield-per-recruit (Y/R), Biomass-per-recruit (B/R) and Spawning stock biomass-per-recruit (SSB/R) curves, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

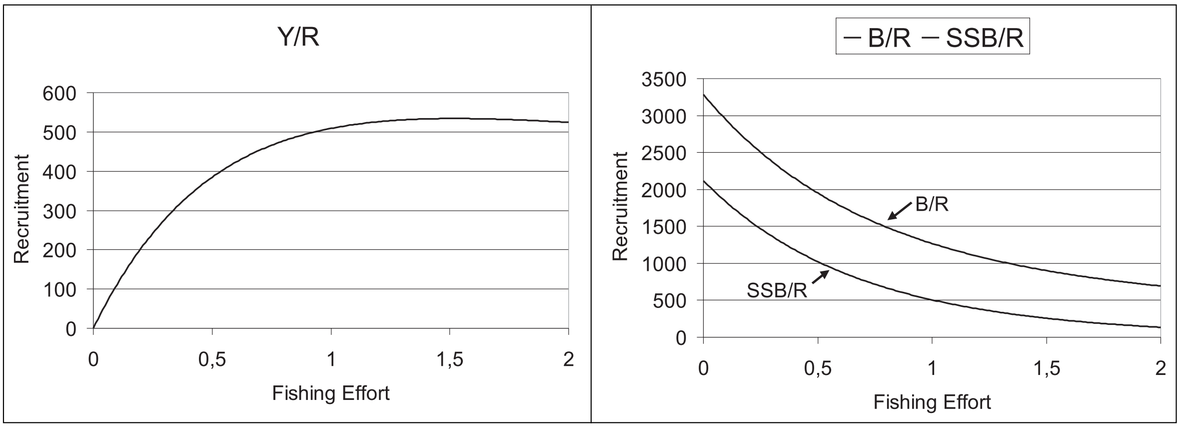

Figure 4 – Yield-per-recruit (Y/R), Biomass-per-recruit (B/R) and Spawning stock biomass per-recruit (SSB/R) curves, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

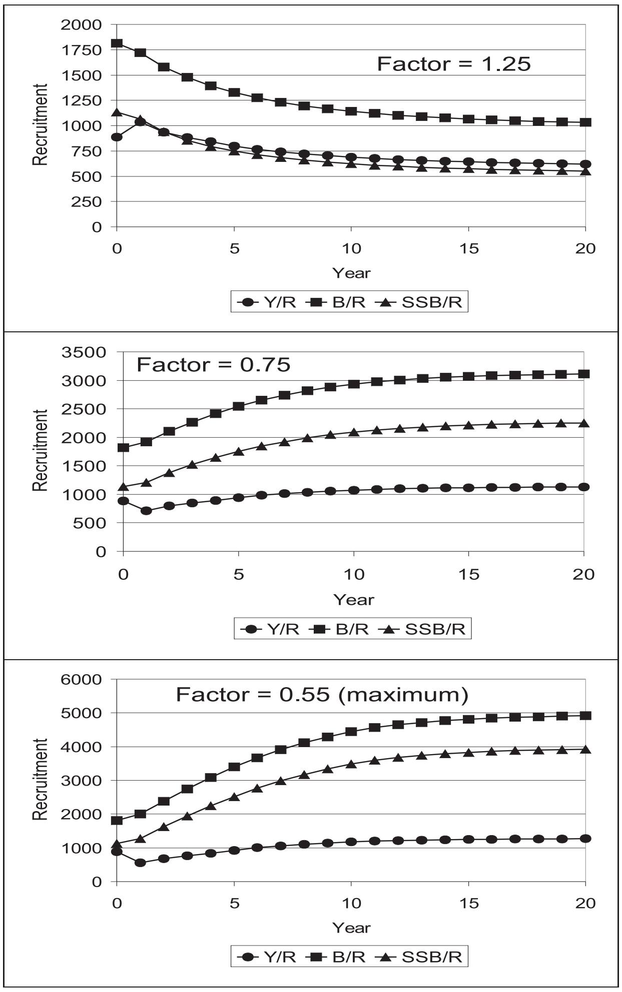

Figure 5 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (F), given by the factor of effort (f), for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

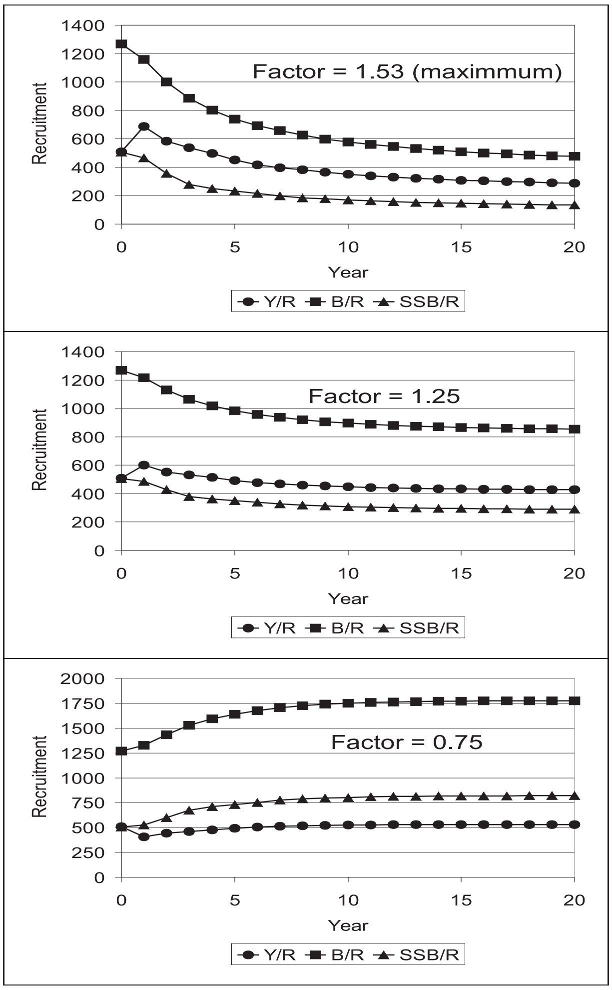

Figure 6 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (F), given by the factor of effort (f), for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

of 0.55 (maximum for females), would represent a recovery of 170.7%. The yield-per-recruit for females, should increase by 27.4% (factor 0.75) and 43.2% (factor 0.55), and for male would practically stabilise at present population status in the fifth year.

Under stochastic conditions, at a level of 25% increase in *f*, the female stock continues to decline (Fig. 7), while the male stock seems to support such increase (Fig. 11), because the biomass level seems to reach a biological equilibrium after the 8th year. For females, however, a factor of 1.25 represents a great reduction in the present recruitment level. The curves show that, in the long-run (20 years), the difference depicted by the confidence limit (95%) does not present great variability, denoting that although the stock should further stabilise, a new biological equilibrium could be reached even for a factor of 1.25. Considering the effort decreasing factor (0.75) simulation of reduction in the current fishing effort of 25%, in the long-run the curves seem to approximate for females (Fig. 8) and to separate apart for males (Fig. 12), denoting that the high susceptibility to

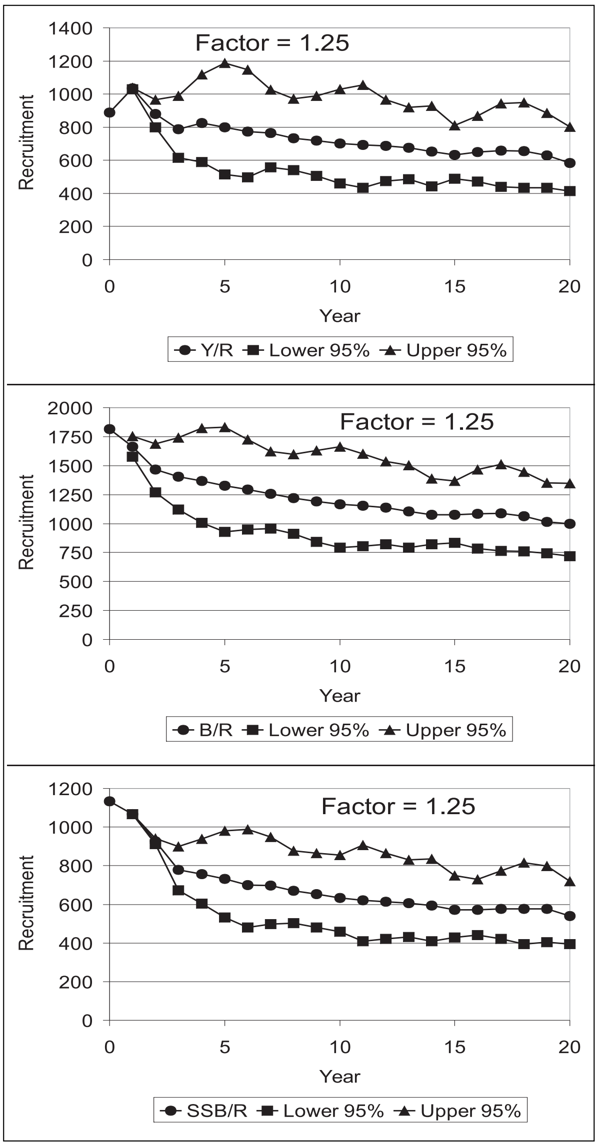

Figure 7 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 1.25, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

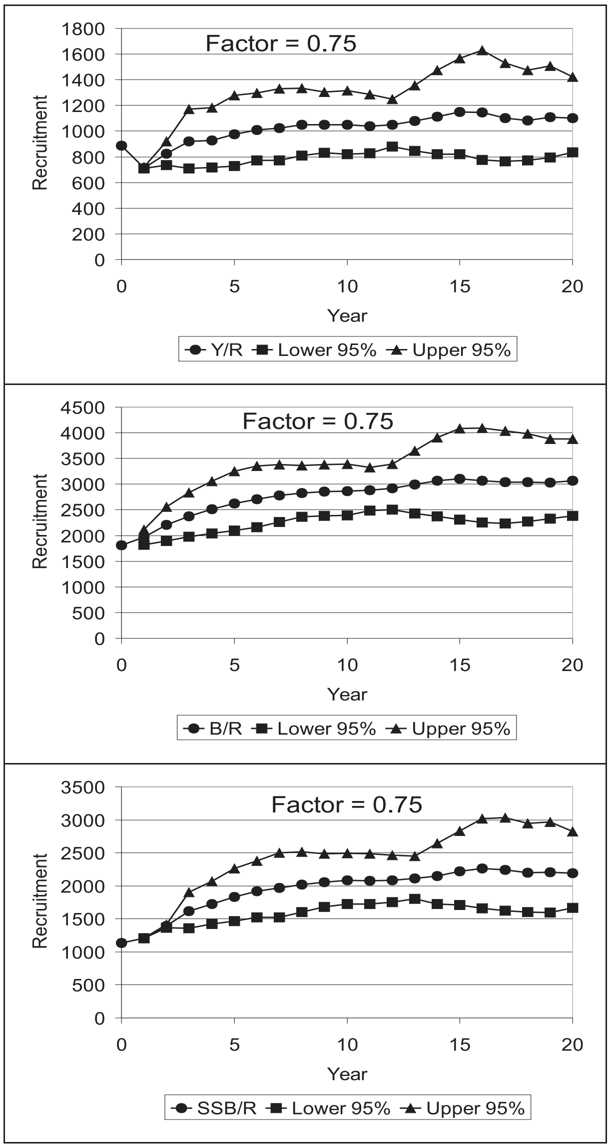

Figure 8 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 0.75, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

fishing pressure of such stocks lead to increasing uncertainty in the long-run. The female stock would recover at a level of 71.4%, while de male stock ate a level of 40%. Although the *Y/R* analysis for males indicates that a maximum *Y/R* could be reached at a factor of 1.53 (Fig. 10), under non-stable equilibrium the stock presents high vulnerability. On the other hand, a decrease in *f* to a Factor of 0.55 (maximum for females) (Fig. 9), would favour recovery of the total and spawning female stock biomasses of 170.7%. The yield-per-recruit for females, should increase by 27.4% (Factor 0.75) and 43.2% (Factor 0.55), and for male would practically stabilise at present population status in the fifth year.

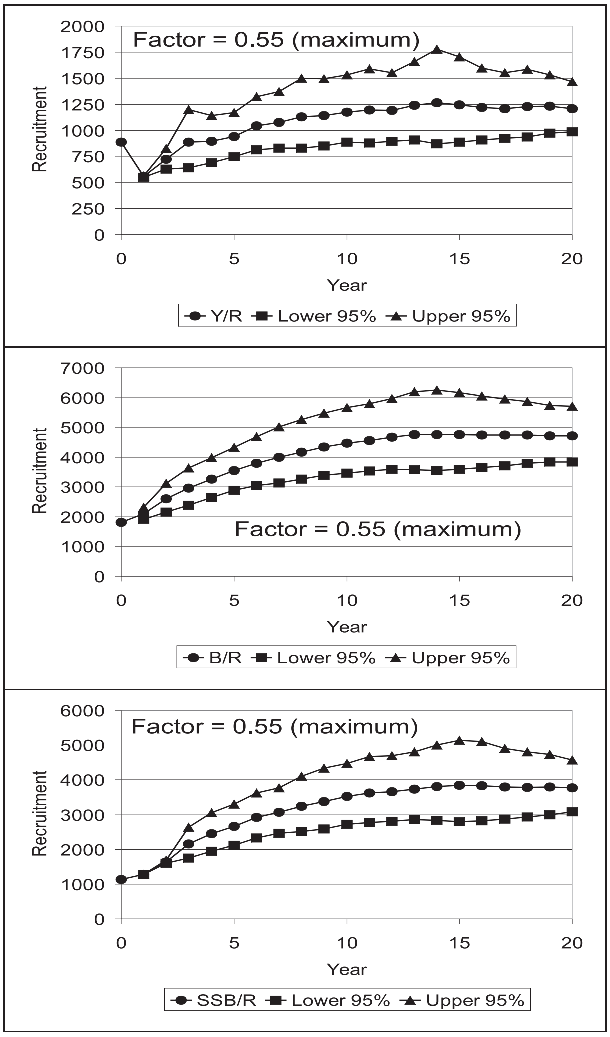

Figure 9 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 0.55 (maximum), for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

Such results indicate that Caribbean sharpnose shark have a low reproductive rate, already stressed by Mattos *et al.* (2001) and a common feature among elasmobranches; cannot support any increase in fishing effort; and that both stocks seems to present a recruitment dependent on the size of the adult population.

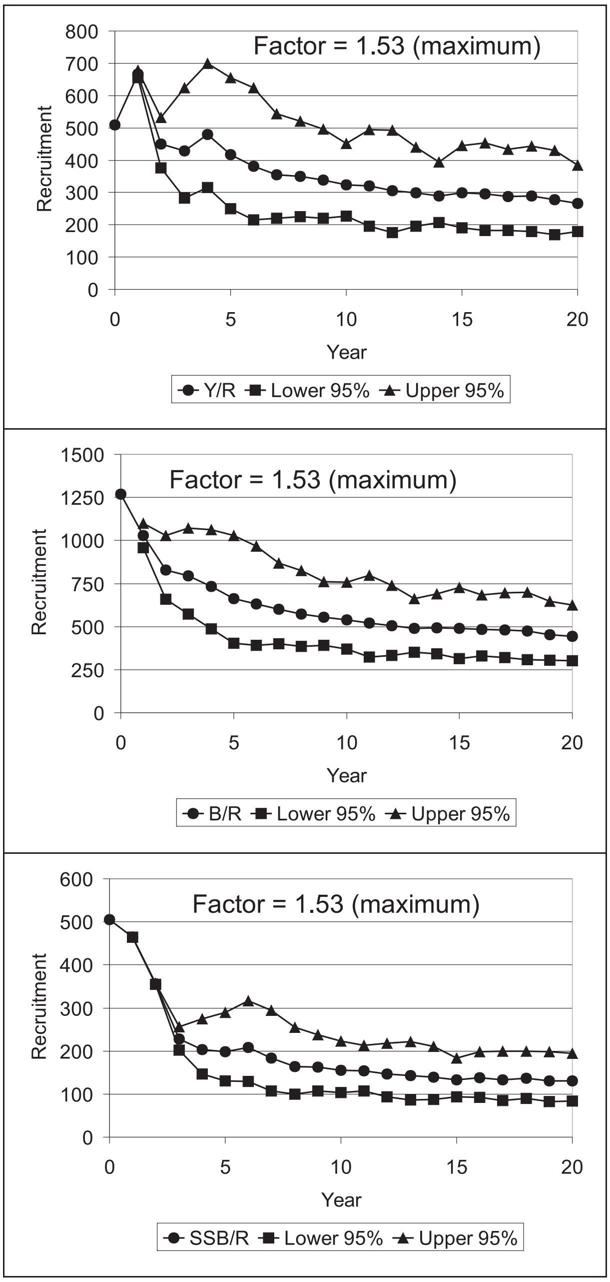

Figure 10 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 1.53 (maximum), for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

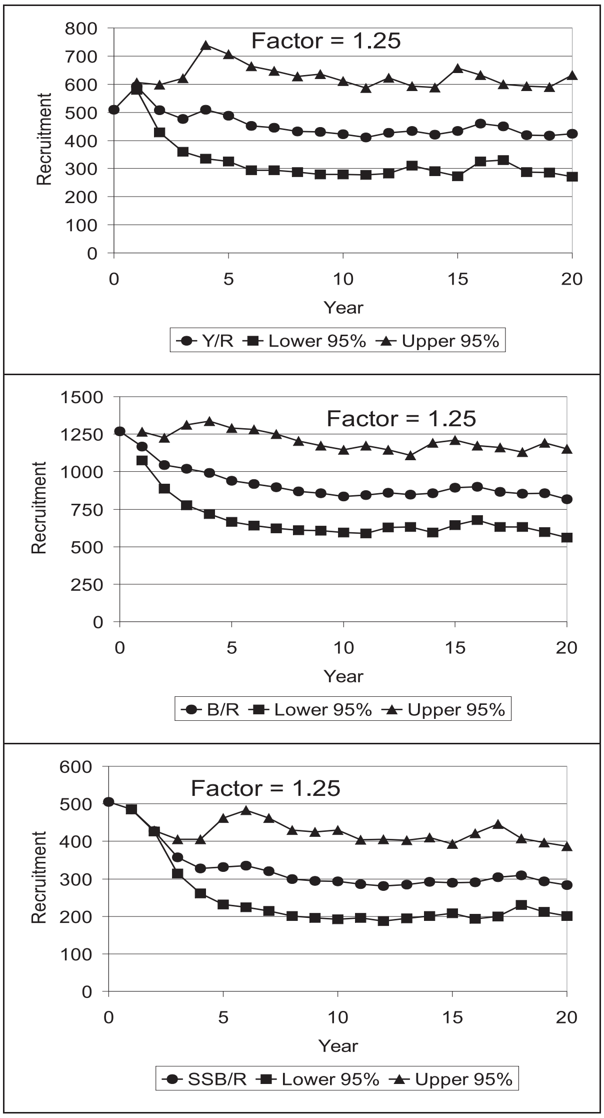

Figure 11 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 1.25, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

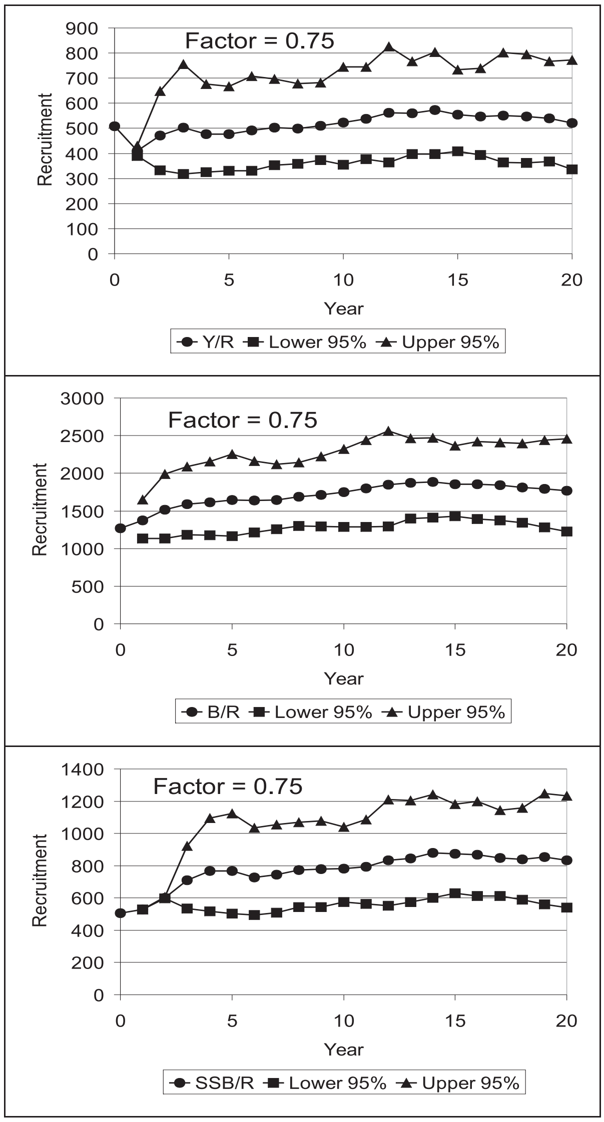

Figure 12 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (F) by a factor of 0.75, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text). Y/R – Yield-per-Recruit; B/R – Biomass-per-recruit; and SSB/R – Spawning stock biomass-per-recruit.

It seems that the best management procedure concerning fishing effort should be a reduction of 25% of the current level (Factor = 0.75), although further analysis should be conducted to define, with as low as possible level of uncertainty, the best fishing effort for each stock on the biological point of view.

The sensitivity analysis of the 3 parameters of the von Bertalanffy's growth equation (L_∞, *k* and t_0), the two parameters of the length-weight relationship (*a* and *b*), the terminal fishing mortality (F_{term}) and the natural mortality (*M*) showed that the parameter *b* was the one that more variation incurred in the *Y/R* analysis. Being a quite easy parameter to estimate and being close to 3, as it is expected, there is no explanation for such a variation. Notwithstanding the magnitude in which it is considered that VPA analysis is very sensitive to variations in *M*, in the two groups the change implied a variation lower than 4%, even for a sensitivity factor of 0.1. Hence, F_{term} was the parameter which less affected the yield-per-recruit analysis, with variations lower than 1%, excepted for male, which variation were close to 2% when a factor of 0.1 was applied.

DISCUSSION

In the small-scale coastal fishery of Pernambuco there are a great number of artisanal wooden boats and a variety of species are caught. This makes the control of the activity extremely difficult, especially if it is considered also that landings occur in a variety of places along the coast. Lack of control and regulation favoured the definition of fishing strategies to be developed inside the artisanal fishery communities, weaken the administration in the way that data gathering is not taken seriously by fishermen and prevent the proper implementation of regulations and management measures.

The decision to use VIT software, and to obtain the maximum information from it, was that the program runs with short time data series, as it is this case study, and allows raising the hypotheses that the fishery is in steady state, or equilibrium. Thus, the assumption is that the size structure of the stock is identical to the size structure of the cohorts (and in this case, they are known as pseudo-cohorts). As stressed by Lleonart and Salat (1997) & Maynou (1999), this is clearly a very restrictive hypothesis because, in general, the population is not in equilibrium, as neither recruitment nor mortality is constant over time. Knowing the errors associated with accepting these hypotheses does not eliminate them, but helps make a well-founded interpretation of the results and produce an objective assessment of the population under study.

The evaluation of natural *vs.* fishing mortality is often considered in the fishery literature, but irrespective of the natural mortality, the fishery-based mortality is almost always a significant component of failed fisheries (Francis, 1974). Obviously, the natural mortality and the natural recruitment failures must be evaluated, but they are rarely independent. The previous comments raised the concern on the assumption that many models do consider M constant, although it is supposedly greater in the early stages of the fish life cycle. Unfortunately, this is indeed one of the VIT Program limitations and the available data did not allow estimation by size or age.

The problem in choosing a method for age determination concerns many scientists, but in the view of the present analysis it depends on the data available and infrastructure. It can be said that seldom are precise the estimates of growth parameters through the method of size-frequency analysis, because is not possible to validate the temporal periodicity of band deposition, especially if is taken into account between-readers differences. Otherwise, in the impossibility of using other methods to determinate age in fishes, size-frequency can be an important tool, but must be recommended that further studies be conducted with the application of a more precise method for validation.

Considering that age determination can be described as the process of confirming an age estimated by comparison with other indeterminate methods, validation acquires an overwhelmingly importance. Instead, concerned with this problem, the decision to accept and conduct a size-frequency analysis for length-at-age estimation as the only possible method, yet that is what the main objective is attempting to define and corroborate for the definition of some management measures for Pernambuco State coastal fishery by virtue of a biological analysis.

For instance, Cailliet (1990) stressed that for elasmobranchs, in the impossibility of using a more accurate method, the analysis of size-frequency may be possible, especially with small size species, as it is the case of *R. porosus*, to trace size modes *vs.* time and compare the rates derived through this procedure with growth curves generated by others methods. Thus, the validation of the parameters presented in this study is needed, considering the importance and prudence to utilise two or more methods simultaneously.

As discussed by Mattos and Pereira (2002), the parameters of K, t_0 and $L\infty$ (0.42; -1.10 and 87.13 for males; and 0.30, -1.12 and 106.82 for females, respectively) are accurately close to values previously estimated for other species of the *Rhizoprionodon* genus, not being possible, on the other hand, comparisons with other populations of the species in the eastern coast of the American continent, due to lack of information. In any way, such results corroborate with those reported by Compagno (1984), according to whom the maximum values for males reach at least 85 cm, while that for females 108 cm.

Being of general concern that, during a VPA analysis of the expected and the reported data of catch, the last year of the analysis could be biased because of VPA' are unreliable (Pope, 1972), the widespread use of such a method in fisheries stock assessment throughout the world makes it imperative that the differences in long-term abundance between VPA and research-survey abundance indices be identified (Myers *et al.*, 1997).

However, concerning the small sample size and that it should may augment the probabilities of misinterpretation of data and results, because data may be insufficient to indicate the functional form of the stock-recruitment relationship, it must be emphasised the assumption that errors in measuring spawning stocks can have a profound effect on the appearance of stock-recruitment relationships, and large errors can make recruitment appear independent of spawning stock.

This pattern can be explained by Lee's phenomenon, well described by Ricker (1969). Since, in general, fish become vulnerable to nets or hooks over a particular size range, rather than a particular age, and since fish of a given age vary greatly in size, it is obvious that fishing during the recruitment period will normally be a cause of selective mortality within the age-groups concerned. The faster-growing fish become vulnerable first, and are selectively removed from the year-class until all its members become fully vulnerable.

Spawner-recruit relationship plays an important role in the application of population dynamics theory in support of fisheries management. As stressed by Fromentin and Restrepo (2001), it is only with some assumptions about this relationship that scientists can state something about the likely long-term consequences of a management regime, i.e. to make projections to forecast the state of the exploited stock during the next years. The goal, thus, is the consideration that stock-recruit relationship fits the procedure for stock assessment in age-structure models, independently of the assessment of catch and effort data, as a result of a VPA analysis to calculate time series of stock biomass and recruitment.

Although not a target species it seems that the female stock of this species is under heavy fishing pressure, not been true for males, but even the male stock would not support increase in the current fishing effort level, presenting rapidly population decline. These results strengthen previous observation on the susceptibility of shark (and elasmobranch) populations to fishing pressure, and that recruitment in this species must be density-dependent on the parental stock. As evinced by Mattos (1998) and Mattos *et al.* (2001), the under-exploitation condition of males should be related to the species migration pattern. The artisanal gillnet fleet fish mainly in coastal regions and catches a greater amount of young male and adult female and it can be inferred that the population segregate by size, sex and maturation stage, and that the fleet does not operate in all the area of the population distribution off Pernambuco State continental shelf (Mattos and Pereira, 2002).

It is a fact that unregulated fishing exploration, beyond the sustainable maximum limit, resulted, in its great majority, in the reduction of the main marine fishing stocks, with some clearly overexploited (Mattos *et al*., 2001). Current management measures of the exploited fishing resources, based on the conservation of the stocks and the accomplishment of a sustainable fishing, are beyond society expectations. On such a way, it is necessary the definitions of a "fishery policy", aiming at fishing regulations and management. As an example, and as stressed by Castillo-Géniz *et al.* (1998) for Mexican waters, nursery areas specially for small coastal sharks off Pernambuco coastal zones should be considered of paramount importance for any management plan for stock conservation, because fishing mortality is extremely high in these areas and the stock-recruitment dynamics are undoubtedly affected.

Complaining about the fact that length-frequency distribution is not the best method to estimate age in fishes, further studies should be conducted if regulation and management measures shall be implemented. The mortality vectors indicated that female stock are submitted to high levels of fishing effort, but this not holds true for male stock of the Caribbean sharpnose shark, and that increase in the current level of effort would drive the Caribbean sharpnose shark to risk population status, even for males, denoting the susceptibility of this species to fishing pressure, because new biological equilibrium shall be hardly reached.

Given that VPA grossly underestimates the rate of increase in mortality at age 3 and that the VPA's depend upon reliable catch statistics, high levels of uncertainty on population density and stock-recruit relationship and catch misreporting occur and that these levels increase with declines in population abundance and the concomitant increases in fishing mortality. On the biological point of view the presented results suggest that the best regulation and management measures in the short-run should be a reduction of 25% of the current fishing effort, although further studies should be carried out to define specific conditions, and improve control on fishing gear selectivity.

REFERENCES

Cailliet, G.M. Elasmobranch age determination and verification: an updated review, p. 157- 167, *in* Hartold Jr., L.P, Gruber, S. & Taniuchi, T. (eds.), *Elasmobranch as living resources: advances in the biology, ecology, systematics and the status on the fisheries*, 1990.

Castillo-Géniz, J.L.; Márquez-Farias, J.F.; Rodriguez De La Cruz, M.C.; Cortés, E. & Cid Del Prado, A. The Mexican artisanal shark fishery in the Gulf of Mexico: towards a regulated fishery. *Mar. Freshw. Res***.**, v.49, p.611-620, 1998.

Compagno, L.J.V. Sharks of the world - An annotated and illustrated catalogue of sharks species known to date. FAO Species Catalogue. *FAO Fish. Synop.,* v.4, p. 1-655, 1984.

Fonteles Filho, A.A. *Recursos pesqueiros: biologia e dinâmica populacional.* Imprensa Oficial do Ceará, xvi+296 p., Fortaleza, 1989.

Francis, R.C. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock production model. *J. Fish. Res. Board Can.,* v.31, n.9, p.1539-1542, 1974.

Fromentin, J.M. &. Restrepo, V.R. Recruitment variability and environment: issues related to stock assessments of Atlantic tunas. *Col. Vol. Sci. Pap. ICCAT*, Madrid, v.52, p.1780-1792, 2001.

Gadig, O.B.F. *Fauna de tubarões da costa norte e nordeste do Brasil.* Tese de Mestrado., Universidade Federal da Paraíba, Pós-Graduação em Ciências Biológicas, 230 p., João Pessoa, 1994.

Gayanilo Jr., F.C. ; Sparre, P. & Pauly, D.. FAO and ICLARM Stock Assessment Tools (FISAT II). *FAO Computerised Information Series.* Online User Guide, 2002.

Gulland, J.A. Manual of methods for fish stock assessment. Part 1. Fish population analysis. *FAO Manuals in Fisheries Science, n.4, p.1*-154, 1969.

Gulland, J.A. *Fish stock sssessment: a manual of basic method*s. FAO/Wiley series on food and agriculture, 1, 223 p., 1983.

Lleonart, J. Methods to analyse the dynamics of exploited marine populations: use and development of models. *Scientia Marina,* v.57, n.2-3, p.261-267, 1993.

Lleonart, J.; Morales-Nin, B. Massutí, E.; Deudero, S. & Reñones, O. Population dynamics and fishery of the dolphinfish (*Coryphaena hippurus*) in the western Mediterranean. *Scentia Marina,* v.63, n.3-4, p.447-455, 1999*a*.

Lleonart, J. & Salat, J. VIT: software for fishery analysis – User's manual. *FAO Computerized Information Series-Fisheries,* n.11, p.1-110, 1997.

Lleonart, J.; Salat, J. & Franquesa, R. The problems of fisheries management in the Mediterranean Catalonia as a case study. *1st International Congress on Maritime Technological Innovations and Research*, Barcelona, 1999*b*.

Martín, P. La pesca en Cataluña y Valencia (NO Mediterráneo): análisis de las series históricas de captura y esfuerzo. *Inf. Téc. Scien. Mar.,* n.162, p.1-43, 1991.

Mattos, S.M.G. *Aspectos da biologia e dinâmica populacional de Rhizoprionodon porosus (Poey, 1861) (Pisces-Elasmobranchii-Carcharhinidae) na plataforma continental do Estado de Pernambuco.* Dissertação de Mestrado, Universidade Federal de Pernambuco, 99 p., Recife, 1998.

Mattos, S.M.G. *A bioeconomic analysis of the coastal fishery of Pernambuco State, Northeastern Brazil.* Ph.D. Tesis, Universitat Politècnica de Catalunya, Barcelona, 2004.

Mattos, S.M.G.; Broadhusrt, M.K.; Hazin, F.H.V. & Jonnes, D.M. Reproductive biology of the Caribbean sharpnose shark, *Rhizoprionodon porosus*, from Northern Brazil. *Aust. J. Mar. Freshw. Res.,* v.52, p.745-52, 2001.

Mattos, S.M.G. & Pereira, J.A.. Parâmetros de crescimento do tubarão rabo-seco, *Rhizoprionodon porosus* (Poey, 1861), no litoral do Estado de Pernambuco, Brasil. *Arq. Ciên. Mar,*Fortaleza, v.35,, p.57-66, 2002.

Maynou, F. VIT for Windows (version: 1.2): Software for fisheries analysis. Original program and MS-DOS version by J. Lleonart & J. Salat. *FAO Computerized Information Series–Fisheries,* n.11, 1999.

Myers, R.A.; Hutchings, J.A.. & Barrowman, n.j.. Why do fish stock collapse? The example of cod in Atlantic Canada. *Ecol. Appl.*., v.7, n.1, p.91-106, 1997.

Pope, J.G. An investigation on the accuracy of Virtual Population Analysis using Cohort Analysis. *Int. Comm. Northwest Atl. Fish. Res. Bull***.**, v.9, p.65-74, 1972.

Ricker, W.E. Effects of size-selective mortality and sampling bias on estimates of growth, mortality, production, and yield. *J. Fish. Res. Bd. Can.,* v.36, n.3, p.479-541, 1969.

Santos, E.P. *Dinâmica de populações aplicada à pesca e piscicultura.* HUCITEC, Ed. Universidade de São Paulo, 129 p., 1978.

Willmann, R. & Garcia, S.M.. Modelo bioeconómico para el análisis de pesquerías secuenciales artesanales e industriales de camarón tropical. *FAO Doc. Téc. Pesca***,** Roma, n.270, p.1-47, 1986.