A BIOECONOMIC ANALYSIS OF THE COASTAL FISHERY OF PERNAMBUCO STATE, NORTH-EASTERN BRAZIL

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*To my father and mother (**in memorian**)*

To my beloved wife Ana, my daughter Deborah, and son Felipe.

We can never do nothing.
Garret Hardin (1968)

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ABSTRACT

Modern bioeconomic concepts invoke the importance to define the property rights possible to be implemented within a management context. In conducting a fishery research, local expectancies must be achieved, as for fisheries researchers, managers, stakeholders, industries, the concerned public at large, and it need to be devolved down to the level of communities or fishermen. Following this concept, a bioeconomic analysis of the coastal fishery of Pernambuco State, North-eastern Brazil, was conducted, directed to the hand-line and gillnet coastal fisheries management, as part of a regional planning project, in virtue of the found social, economic and cultural peculiarities, the existing low Human Development Index (HDI) of this Region, and the importance of social insertion of the less favoured fishing communities.

The main objective of this study was to apply a bioeconomic fishing model developed for the North-western Mediterranean Sea fisheries, named *ME*diterranean *FI*sheries *S*imulation *TO*ols - MEFISTO, justified by some existing similarities among Mediterranean and Pernambuco State coastal fisheries, such as diversity of species and fishing gears, seasonal variations of the captures, commercialisation process, fishing fleet dynamics, etc. The model allowed significant contributions for the understanding of the coastal fishing dynamics, making possible to reproduce the general conditions on how the activity occurs and to simulate alternatives management strategies. Also, it was possible to observe and analyse its economic conditions, helping decision-makers to achieve a sustainable development of the activity, so that future generations can also benefit from the resource.

To achieve the defined objectives, questions concerning these aspects were raised: Current planning and management measures for the coastal fishery are adequate to the local and actual reality?; Is there a necessity to remove the pressure/effort on the traditional fishing stocks and to diversify the coastal fishery activity for other resources and/or fishing areas?; and Is there any feasibility to invest in the coastal fishery? Thus, the hypotheses raised considering the strategies to implement management measures were: *The importance to apply and adequate bioeconomic model for the management of the small-scale existing fishing activity*; *Most important commercial fish stocks are depleted, with low biomass levels, and there is a necessity to diversify the existing fishery*; and *The small-scale fishing activity must be a priority of governmental policies for the sustainable development of the fishery sector*.

The proposed study was thus developed to support assessment procedures, and may be considered as a determining factor in the capacity for the development of assessment systems to be applied to establish the potential limits in the development of scientific research. Certainly much more work is needed before a bioeconomic model of the Pernambuco coastal fishery can be perfected, but with some adjustment and careful analysis it was possible to obtain important results and informations for fisheries management. From the raised hypotheses can be concluded that the use of bioeconomic models for the assessment of these fisheries showed to be a very important tool for the *administration*, which may have informations based on scientific advise for the definition and implementation of management strategies for fisheries development; for the *scientific community*, which may improve knowledge on the population dynamics of the fishing stocks off Pernambuco and the dynamics of fishing fleets; and for the *fishermen*, which can join their empirical knowledge with the model outputs informations to improve their fishing strategies.

From a biological and economic point of view it seems that Pernambuco State hand-line and gillnet coastal fisheries has reached an equilibrium. The stock susceptibility and the institutional and productive fragility may indicate that a critical state is evident, leading to economic inefficiency, since it is not the result of a planned action. From the results obtained there is no evidence of commercial fish stocks depletion, inasmuch the target hand-liners and gill-netters species are considered, but that there is a necessity to diversify these fisheries, because any increase in fishing effort would collapse these commercial stocks. Such a biological and economic equilibrium should be maintained, nonetheless with the implementation of management conservation measures that encourage the reduction of the current level of effort, jointly with measures that can bring about fishermen claim. It became clear that the small-scale fishery activity must be a priority of governmental policies for the sustainable development of the fishery sector, showing to be economic viable, desirable on the social point of view and ecologically adequate.

ANÁLISIS BIOECONÓMICA DE LA PESCA COSTERA EN EL ESTADO DE PERNAMBUCO, NORDESTE DE BRASIL

RESUMEN

Los conceptos bioeconómicos modernos invocan la importancia de definir los derechos de propiedad posibles de ser llevados a cabo dentro del contexto de gestión. La investigación pesquera debe considerar las expectativas locales, en cuanto a los investigadores, administradores, mayoristas, las industrias, el público en general, y necesita volver al nivel de comunidades o pescadores. Partiendo de ese supuesto, realizase un análisis bioeconómico de la pesquería costera de Pernambuco, Nordeste de Brasil, dirigido a las pesquerías costeras de línea y redes de fondo. Se puede considerar como parte de un proyecto de planificación regional, en virtud de las peculiaridades sociales, económicas y culturales encontradas, el bajo Índice de Desarrollo de Humano (HDI) existente en esta Región, y la importancia de inserción social de las comunidades pesqueras menos favorecidas.

El objetivo principal de este estudio fue aplicar un modelo bioeconómico pesquero desarrollado para las pesquerías del Mar Mediterráneo Norte-occidental, denominado *ME*diterranean *FI*sheries *S*imulation *TO*ols - MEFISTO (Herramientas de Simulación de Pesquerías Mediterráneas), justificado por algunas similitudes existentes entre las pesquerías costeras de esa Región y del Estado de Pernambuco, entre las cuales la diversidad de especies y de los artes de pesca, las variaciones estacionales de las capturas, la comercialización, la dinámica de las flotas, etc. El modelo permitió extraer importantes contribuciones para la comprensión de la dinámica de la pesca costera, haciendo posible reproducirse las condiciones generales de como ocurre la actividad, así como simular las estrategias alternativas de gestión. Fue posible también observar y analizar las condiciones económicas, que pueden contribuir para que los tomadores de decisión logren un desarrollo sostenible de la actividad, de forma que las generaciones futuras también puedan beneficiarse del recurso.

Para lograr los objetivos definidos, se plantearon cuestiones que involucran estos aspectos: ¿La planificación actual y las medidas de gestión para la pesca costera son adecuadas a la realidad local?; ¿Hay necesidad de quitar la presión/esfuerzo de las pesquerías tradicionales y diversificar la actividad para otros recursos y/o áreas de pesca?; y ¿Hay alguna viabilidad para invertir en la pesca costera? Así, las hipótesis levantadas, considerando las estrategias para llevar a cabo las medidas de gestión, son: *La importancia de aplicar y*

adecuar modelos bioeconómicos para la gestión de la actividad pesquera de pequeña escala existente; Los niveles de biomasa actual de los estocs de peces de importancia económica son preocupantes y hay una necesidad para diversificar las pesquerías existentes; y *La actividad de pesca de pequeña escala debe ser una prioridad de las políticas gubernamentales para el desarrollo sostenible del sector pesquero*.

El estudio propuesto fue desarrollado para apoyar los procedimientos de valoración y puede ser considerado como un factor determinante en la capacidad para el desarrollo de sistemas de valoración a ser aplicados para establecer los límites potenciales en el desarrollo de la investigación científica. Ciertamente, aun se necesita mucho trabajo para perfeccionar un modelo bioeconómico de gestión para la pesquería costera de Pernambuco, pero con ajustes y un análisis cuidadoso fue posible obtener resultados importantes e informaciones para la gestión de las pesquerías. De las hipótesis levantadas se puede concluir que el uso de modelos bioeconómicos para la valoración de estas pesquerías mostró ser una herramienta muy importante para la *administración*, que puede tener las informaciones basadas en los conceptos científicos para la definición y aplicación de estrategias de gestión para el desarrollo de las pesquerías; para la *comunidad científica*, que puede mejorar el conocimiento de la dinámica poblacional de los estocs pesqueros de Pernambuco y la dinámica de las flotas; y para los *pescadores*, que pueden conjugar sus conocimientos empíricos con las informaciones de rendimientos del modelo para mejorar sus estrategias de pesca.

De un punto de vista biológico y económico parece que las pesquerías costeras de línea y red de fondo de Pernambuco han alcanzado un equilibrio. Pero, la susceptibilidad de los estocs y la fragilidad institucional y productiva pueden indicar, que un estado crítico es evidente, llevando a la ineficacia económica, puesto que no es el resultado de una acción planeada. De los resultados obtenidos no hay evidencia del agotamiento de los estocs de peces comerciales, considerando las especies blancos de las pesquerías de línea y red, pero hay la necesidad de diversificar esas pesquería, porque cualquier aumento en el esfuerzo de pesca colapsaría esos estocs. Ese equilibrio biológico y económico debe mantenerse, con la aplicación de medidas de gestión para la reducción del nivel actual de esfuerzo, juntamente con medidas que pueden atender las demandas de los pescadores. Sin embargo, la actividad pesquera de pequeña escala debe ser una prioridad de las políticas gubernamentales para el desarrollo sostenible del sector, mostrando ser económicamente viable, deseable del punto de vista social y ecológicamente adecuada.

ANÁLISE BIOECONÔMICA DA PESCA COSTEIRA NO ESTADO DE PERNAMBUCO, NORDESTE DO BRASIL

RESUMO

Os conceitos bioeconômicos modernos invocam a importância para definir os direitos de propriedade possíveis de serem implementados dentro do contexto de gestão. A pesquisa pesqueira deve considerar as expectativas locais, para os pesquisadores, administradores, atacadistas, as indústrias, o público em geral, e precisa ser devolvido ao nível de comunidades ou pescadores. Seguindo este conceito, realizou-se uma análise bioeconômica da pesca costeira do Estado de Pernambuco, Nordeste do Brasil, dirigida à pesca de linha-de-mão e à de rede-de-espera. Pode-se entendê-la como parte de um projeto de planejamento regional, em virtude das peculiaridades sociais, econômicas e culturais, o baixo Índice de Desenvolvimento Humano (HDI) existente nesta Região, e a importância da inserção social das comunidades menos favorecidas.

O objetivo principal deste estudo foi aplicar um modelo bioeconômico pesqueiro desenvolvido para as pescarias da região Noroeste do Mar Mediterrâneo, denominado *ME*diterranean *FI*sheries *S*imulation *TO*ols - MEFISTO (Ferramentas de Simulação de Pescarias Mediterrâneas), o qual justifica-se por algumas semelhanças existentes entre as pescarias costeiras do Mediterrâneo e do Estado de Pernambuco, tais como diversidade de espécies e petrechos de pesca, variações sazonais das capturas, o processo de comercialização, a dinâmica de frotas, etc. O modelo permitiu extrair contribuições significantes para a compreensão da dinâmica de pesca litorânea, tornando possível reproduzir as condições gerais de como a atividade ocorre e simular estratégias alternativas de gestão. Também foi possível observar e analisar as condições econômicas que podem contribuir para que os tomadores de decisão alcancem um desenvolvimento sustentável da atividade, de forma que gerações futuras também possam beneficiar-se do recurso.

Para alcançar os objetivos definidos, algumas perguntas considerando esses aspectos foram levantadas: O planejamento atual e as medidas de gestão para a pesca litoral são adequadas à realidade local?; Há alguma necessidade em remover a pressão/esforço sobre os estoques tradicionais e diversificar a atividade de pesca costeira para outros recursos e/ou áreas de pesca?; e Há alguma viabilidade em investir na pesca litoral? Assim, as hipóteses levantadas, considerando as estratégias para implementar medidas de gestão, foram: *A*

importância em aplicar e adequar modelos bioeconômicos para a gestão da atividade de pesca de pequena escala existente; Os níveis de biomassa atual dos estoques de peixe de importância comercial são preocupantes e há uma necessidade em diversificar as pescarias existentes; e *A atividade de pesca de pequena escala deve ser uma prioridade das políticas governamentais para o desenvolvimento sustentável do setor pesqueiro.*

O estudo proposto foi desenvolvido para apoiar os procedimentos de avaliação, e pode ser considerado como um fator determinante na capacidade para o desenvolvimento de sistemas de avaliação a serem aplicados para estabelecer os limites potenciais no desenvolvimento da pesquisa científica. Certamente muito trabalho ainda é necessário antes que um modelo bioeconômico para a pesca costeira do Estado de Pernambuco seja aperfeiçoado, mas com alguns ajustes e análise criteriosa foi possível obter resultados importantes e informações para a gestão da pesca. Das hipóteses levantadas pode-se concluir que o uso de modelos bioeconômicos para a avaliação dessas pescarias mostrou ser uma ferramenta importante para a *administração*, que pode ter informações fundamentadas em evidências científicas para a definição e implementação de estratégias de gestão para o desenvolvimento de pescarias; para a *comunidade científica*, que pode enriquecer conhecimentos sobre a dinâmica de populações pesqueiras da costa pernambucana e a dinâmica de frotas; e para os *pescadores*, que podem igualmente enriquecer seus conhecimentos empíricos com os resultados do modelo e melhorar suas estratégias de pesca.

De um ponto de vista biológico e econômico parece que as pescarias de linha-de-mão e de rede-de-espera alcançaram um equilíbrio. A suscetibilidade dos estoques pesqueiros e a fragilidade institucional e produtiva podem indicar, entretanto, que um estado crítico é evidente, conduzindo a ineficiência econômica, posto que não é o resultado de uma ação planejada. Dos resultados obtidos não há nenhuma evidência de que os estoques de peixes comercialmente importantes estejam esgotados, considerando as espécies alvo das pescarias de linha-de-mão e de rede-de-espera, mas há a necessidade de diversificar a pesca existente, porque qualquer aumento do esforço de pesca se colapsariam esses estoques. Esse equilíbrio biológico e econômico deve ser mantido, no entanto com a implementação de medida de conservação que encoraja a redução do nível atual de esforço, juntamente com medidas que possam atender as reinvidicações dos pescadores. Evidenciou-ser que a atividade de pesca em pequena escala deve ser uma prioridade de políticas governamentais para desenvolvimento sustentável do setor pesqueiro, mostrando ser economicamente viável, desejável no ponto de vista social e ecologicamente adequado.

INTRODUCTION

From ancient time fishery, including acquaculture, has been a major source of food for humanity and a provider of employment and economic benefits to those engaged in this activity, and must, on this way, be conducted in a responsible manner. However, with increased knowledge and the dynamic development of fisheries, it was realised that living aquatic resources, although renewable, are not infinite and must induce responsibilities to allow effective conservation and management measures for resources perpetuation, if their contribution to the nutritional, economic and social well being of the growing world's population was to be sustained. Generally, it can be said that a rapid increase of the fishing effort, followed by over planned measures without the necessary technical and scientific knowledge about the resource can collapse the activity.

Since long exploited as a free access resource, without defined property, facilitating the indiscriminate extraction from those that had conditions to first reach the resource, the concepts nowadays posed is that natural resource, and consequently the fishing resource, must be directly related with State – for coastal and non-shared stocks – and international organisations – for shared stocks – regulations, and, on this way, must be emphasised. The significant reduction of certain available natural stocks imposes a vigorous and generalised combat to wastefulness, aiming changes in the prodigal patterns of production and consumption that inspired – and hence inspire – the industrial civilisation. What really occurs is that each production system determines a specific way of ecosystem exploitation, and consequently the good and bad rules of nature utilisation.

Research on renewable natural resources are important to identify regional potentialities, aiming the establishment of local development policies, and the investment in successful experiences to generate employment and income, considering a widespread concern as to the sustainability of the present trends in developments and called for a more holistic and ecosystem-based governance for fisheries resources management. According to Clark (1990), the fact that free access to valuable resource inevitably leads to overexploitation and economic impoverishment is an inescapable truth that is conveniently and widely ignored. However, continuing to mismanage naturals resources is a luxury that a crowded world can no longer afford. As stressed by Varela (1987), the free access and appropriation of marine environment and the renewable nature of the resources have contributed to build up a peculiar frame around the fishing economic activity. In this frame it is possible to recognise, however, a variety of productive processes whose characteristic production units show different organisations and economic behaviour.

Nonetheless, it may be emphasised the concern raised by Hardin (1968) with which is not always that a technical solution is possible due to the conception of a class of human problems, because population problems cannot be solved in a technical way. It is fair to say that most people who anguish over the population problem are trying to find a way to avoid the evils of overexploitation without relinquishing any of the privileges they now enjoy. Theories that states that the greatest good for the greatest number must be realised fail, according to Hardin, for two reasons: (1) it is not mathematically possible to maximise for two (or more) variables at the same time; and (2) to live, any organism must have a source of energy.

That is why fisheries resources must be understood as finite populations, whose optimum yield is less than the maximum, and a rational management of fish stocks and populations is difficult to be conducted by individual countries, because, as stressed by Anderson (1977), the rational exploitation of fisheries presents many important aspects – biological, legal, political, and economics – each of which has given rise to voluminous literature. This difficulties may be understood by Hardin (1968) statement on man’s behaviour to maximise earn: each pursuing his own best interest in a society that believes in the freedom of the commons is locked into a system that compels him to increase his property without limit – in a world that is limited – whose destination is man overthrow, because freedom in a commons brings ruin to all. Oceans of the world continue to suffer from the survival of the philosophy of the commons, because maritime nations still respond automatically to the shibboleth of the freedom of the seas.

The correct management of natural resources requires the analysis of physical, social, institutional and technological data in conjunction with those strictly economic, and must be outlined on a dynamic setting. Although, in this sense, natural resource has a wide definition, for economics purposes it is important to define it as living or non-living (Surís and Varela, 1995). From the economic point of view, according to Lopes (1985), two main fishing marine zones can be specified: the coastal and the oceanic. The interest on such division is evident, because it will allow the study of each one of these zones as an independent economic unit, where the environmental characteristics will have different influences on each population. The natural habitats of many commercial fish species are the relatively shallow continental shelf, isolated from water streams of different temperature and from deep channels. Such hydrographical characteristics constitute an obstacle for the displacement of many fish populations, which acquire a non-migratory behaviour, and make them more susceptible to fishing activity. According to Pauly *et al.* (2002), continental shelves generate the biological production supporting over 90% of global fish catches, the rest consisting of tuna and other oceanic organisms that gather their food from the vast, desert-like expanse of the open oceans. According to Perrings (2000), marine systems are argued to contribute around two-third of the total value of ecological services, and the coastal environments – estuaries, coastal wetlands, beds of sea grass and algae, coral reefs and continental shelves – are of disproportionately high value to humankind.

Thus, taking in consideration the basic assumption underlying the optimal allocation of natural resources and the inherent characteristics of fisheries that determine, under unrestricted access, the failure to allocate resources, the economic inefficiency and overfishing, studies on fishing bioeconomics is of great interest to be conducted in coastal State developing countries. To mitigate any undesirable effects, the modern bioeconomic concepts invoke the importance to define the property rights possible to be implemented within a management context (Seijo, *et al.*, 1998).

In conducting a given research one must endeavour to ask if it is in accordance with the Code of Conduct for fisheries research, and if it may achieve local expectancies, because, as stressed by Caddy (2000), we need to see what is its practical significance to fisheries researchers, fishery managers, stakeholders in the fishery, the fishing industry in general, and progressively in recent years, the concerned public at large, and … it need to be devolved down to the level of coastal community or fisherman.

Following this concept, a bioeconomic analysis of the coastal fishery of Pernambuco State, located in the Northeast Region of Brazil (Figure 1), was conducted in view of the current trend to lead integrated studies on biology, economy and fishery, aiming at the activity sustainability. The analysis of the fishery was based in the accompaniment of data of fishing operations and landings of the catches carried out by the small-scale coastal fleet, based on catch effort data, to suggest the establishment of management measures. It followed current strategies of scientific research for the assessment and the feasibility of actions directed to coastal fishery management, defined as the fishing activity conducted off continental shelves limits. Can be understood as part of a general planning project, in virtue of the found social, economic and cultural peculiarities, the existing low Human Development Index (HDI)[1] of this Region, and the importance of social insertion for the increasing standard of life of the less favoured communities, nowadays emphasised by the Brazilian governmental strategic policies.

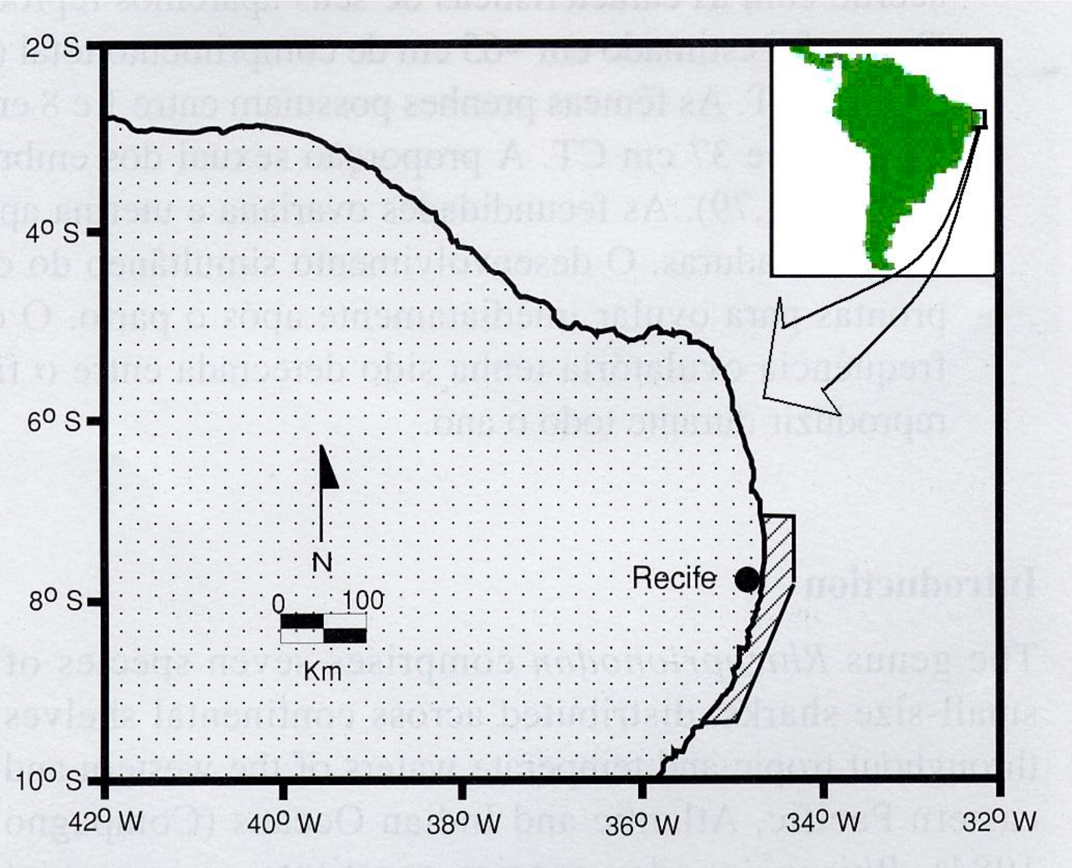

Figure 1 – Area of the coastal fisheing activity off Pernambuco State, North-eastern Brazil, continental shelf.

It can be also emphasised that the current study is under the scope of the Code of Conduct for Responsible Fisheries of FAO[2] (FAO, 1995), in whose 12 Articles a range of technical subjects matters on fisheries are included, and in three of it - Fisheries Management (Article 7), Integration of Fisheries into Coastal Areas Development (Article 10), and Fisheries Research (Article 12) – this study may be related. In its § 7.1.2 the Code states that *"within areas*

[1] The United Nation Development Program (UNDP) (Human Development Report, 1997), has taken a very different approach to one based on using economic measures and principles, in order to establish its indicator of well-being. The Human Development Index (HDI) combine separate indicators of real purchasing power, education and human health; these, themselves, are derived from more specific indicators such as access to sanitation and access to safe water. The HDI is a multi-criteria indicator and, if it suffers from anything, it is the standard difficulty in weighting various criteria. However, it is important to be ever mindful of the fact that conventional economic indicators implicitly treat a gain or a loss to a poor person as being comensurate with a same dollar gain or loss to a rich person. This is weighting to a particular kind – and it is counter to the economic principle of diminishing marginal ability (Hundloe, 2000).
[2] Food and Agriculture Organization of the United Nations.

under national jurisdiction, States should seek to identify relevant domestic parties having a legitimate interest in the use and management of fishery resources and establish arrangements for consulting them to gain their collaboration in achieving responsible fisheries". Also it is stressed by the Code, in its § 6.18, that *recognising the important contribution of artisanal and small-scale fisheries to employment, income and food security, States should appropriately protect the rights of fishers and fish-workers, particularly those engaged in subsistence, small-scale and artisanal fisheries, to a secure and just likelihood, as well as preferential access, where appropriate, to traditional fishing grounds and resources in the waters under their national jurisdiction.*

Furthermore, in ratifying the United Nations Convention on the Law of the Seas (UNCLOS), in 1988[3], Brazil assumed rights and obligations to the national and international communities, specially those concerning the *adoption of measures aiming at the preservation or re-establishment of species populations submitted to fishing pressures, allowing the maximum sustainable yields by means of ecological and economic pertinent aspects.* The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources.

The existing social, technological and ecological complexities found at fishing communities in developing countries, such as Brazil, their interdependencies, and the economic implications (fishing operations, goods, products, by-products, etc.) must be, thus, emphasised, helping the enforcement of management measures.

In this context, it must be clear the utmost importance to develop models that can integrate social and economic aspects, considering that a high contingency of people depends directly on the small-scale and artisanal fisheries. This requires an improvement of the current catch methods compatible with the maximum sustainable yield of the commercial fish stocks that can preserve the associated biota and non-target species, mainly if we take in consideration that many of the species commercially exploited have distinct characteristics and varied susceptibility to the employed methods of catch (Mattos, 1998). Scenario analysis is especially important for the fishery sector, which, although a major provider of food and jobs in many poorer countries, is small relative to the economy of richer countries and is thus downstream from most policy decisions (Pauly *et al.*, 2003). The incorporation of risks and uncertainties of models tested and an analysis for future decisions is to be considered, because

[3] The ratification was sanctioned through the Brazilian Federal Law nº 8617, of 4th of January 1993.

today is being prioritised a preventive management of the fisheries, through estimations of models on the stock and fisheries dynamics at short, medium and long run.

Considering a greater than average deficiency in Pernambuco State fishery management strategies for local development, there is a need to progressively clarify regional and local management strategies for the establishment of stock assessment plans. It is thus imperative to demonstrate the importance of the application of models for fishing management based on a joint analysis of biological, economic and fishing aspects, considering the characteristics and the reality of the small-scale existing fishery, because, as stressed by Seijo *et al.* (1998), fisheries management is a complex process that requires the integration of resource biology and ecology, with socio-economic and institutional factors affecting the behavior of fishers and policy makers.

Since the seventies is being considered that the traditional coastal fish stock off Pernambuco are over-exploited, in virtue of an intense fishing effort, allied to natural mortality and ecosystems degradation. The implementation of management measures and the improvement of life quality to those directly dependent on fishery must take into account its applicability in accordance with the reality of the local fishing communities and the coastal fishing features. The definition of a management model depends, however, on the complexity of the production system and its stage of development, as the e.g. fishery/market relationship.

Thus, the main objective of this study was to apply a bioeconomic fishing model developed in the scope of the Mediterranean Sea fisheries, named *ME*diterranean *FI*sheries *S*imulation *TO*ols, with acronym MEFISTO, in virtue of the accessibility conditions and reality of the small-scale fisheries at which this model had been developed, especially in the North-western Mediterranean. The integrated application of a bioeconomic model to the reality of the coastal fishery of Pernambuco State, allowed significant contributions for the understanding of its dynamics, making possible to reproduce the general conditions on how the activity occurs and to simulate alternatives management strategies, considering local and current realities. Also, it was possible to propose the diversification of the existing coastal fishing activity; to understand the fishery productive chain; and to observe and analyse the economic conditions at which the activity occur. According to Seijo *et al.* (1998), the purpose of this multidisciplinary field is to aid decision-makers to achieve a sustainable development of the activity, so that future generations can also benefit from the resource.

The decision to choose such a model is justified by some existing similarities among Mediterranean and Pernambuco State coastal fisheries. According to Martín (1991), the fishing activity in Catalonia, and, in general, the Mediterranean fishery, characterises itself by a great diversity as far as exploited species and fishing gears are considered, as well as by the seasonal variations of the captures that, excepting those corresponding to sardine and anchovy, are relatively small. Fish is commercialised fresh, and with few exceptions the fleet fish five days per week, returning to port every day. The destiny of the fish is the local market.

For Lleonart *et al* (1999b), the Mediterranean small-scale fishing is a variable activity with highly multispecific catches with fishing intensities and strategies showing very rapid fluctuations in space and time. The seasonal activity of the fleets is related to the ecology of the different species, meteorological conditions, the tourist season, etc. From the economic point of view, there are also similarities, such as: lack of fishing industries; individuality of the economic agents; high dependency on the local market; labour relationships based on the share system, no salaries; etc.

A recent communication from the European Union Commission for Agriculture, Rural Development and Fisheries[4] stressed the aim of building on existing measures and devising new ones adapted to the specific conditions of fisheries in the Mediterranean, through the adoption of a comprehensive and precautionary approach. Those includes technical measures to protect young fish, through measures and studies on gears selectivity; sharing management responsibility, to be set up both at EU and national levels; and strengthened control through the introduction of fishing effort management. These measures was set up a numbers of characteristics specific to this region, such as narrowness of the continental shelf, which means that a substantial part of the fishing activities are carried out close to the coast, the presence of several straddling and shared fish stocks, the dispersion of scientific data, the importance of recreational fisheries and a lack of co-operation in fisheries management in the Mediterranean. Exception being the importance of recreational fisheries, although existing but still incipient, the others are quite similar to the characteristics found at Pernambuco State and Northeast Region of Brazil.

Many fisheries around the world are managed using adaptive strategies, i.e. mainly by assessing fish stocks by quantitative modelling and recommending management actions, such as total allowable catch (TAC), based on the results of these assessments together with empirical processes of trial and errors (Bonzon, 2000). Mediterranean fisheries are not yet regulated by quantitative and adaptive management procedures, but rather by more or less static rules that

[4] Commission proposes action for sustainable fisheries in the Mediterranean. IP/03/1361. Brussels, 9 October 2003.

include effort, power and gross tonnage limits, closed areas, and other technical measures. Many such regulations are not based on scientific advice (Farrugio *et al.*, 1993). Some bottom-up management measures are usually adopted, particularly at the small-scale level, as a feedback response to the experience and behaviour of fishermen (Lleonart *et al.*, 1996). Since the management of the Mediterranean fisheries is largely driven by self-regulation based on socio-economic and cultural criteria (Franquesa, 1994), the monitoring of those fisheries would greatly benefit from analysis based on a set of economic and social indicators (Bonzon, 2000), because the management of the Mediterranean fisheries is characterised by a large variety of complex and interdependent parameters for which the economic and social dimensions are often predominant (Hundloe, 2000).

According to Franquesa and Guillén (2002), in the Mediterranean fisheries conditions, characterised by high price, reduced catch, weak financial capacity and nearness of fishing grounds, the total fishing time utilised by fishermen is all the time technically possible (not including summer holidays and weekends), and control measures should be enforced.

Bas (2002) highlighted a high level of uniformity in what can be expressed as a Mediterranean fishery model, regarding the coastal structure, as well as the marine grounds and the production level, hence showing important variability and matching. Fishing exploitation characterises as a medium level type, with which exclusiveness for a specific fishing activity is almost general rule. Fishing grounds of the artisanal fisheries are restricted to the base port vicinities, and the time-spent fishing is generally short. One of the most important characteristics, especially the trawling Mediterranean coastal fishery, is its multi-specificity, and although target species are always determined, can be asserted that the wholes of the caught species are not discarded, although commercial values may vary. A large number of Mediterranean fishing grounds have uncontrolled access, although there are administrative control mechanisms or those of the fishermen's own methods. One of the consequences of the competition for the resources at a world level, but which has also made itself felt in the Mediterranean area, has been the over-capitalisation of the fishing fleets which has led to much greater capacities than the resource's potential (Lleonart *et al.*, 1999c). In a general view, all these conceptualisations of the Mediterranean fisheries seem to describe Pernambuco State coastal fisheries.

However, the conduction of a bioeconomic study is not straightforward, and means that great effort must be done to collect biological and economic parameters that are necessary to run the chosen model, to start the analysis and the understanding of the whole process that govern the local fishing activity. Within the above arguments, to achieve those objectives was considered that some questions concerning these aspects would have to be raised to strengthen the suggested and defined methodology, such as:

- Current planning and management measures for the coastal fishery are adequate to the local and actual reality? The existing knowledge to implement fishing management measures means the necessity to apply and adequately implement fishing, biological and ecological data gathering and analysis;
- Is there a necessity to remove the pressure/effort on the traditional fishing stocks and to diversify the coastal fishery activity for other resources and/or fishing areas? For long have being said that the traditional coastal fishing stocks off Pernambuco are depleted, but the activity still existing. Lack of trustworthy statistical data and few biological and economic studies on the situation of coastal fishing stocks, leads to a pessimist prognostic. The expectation, after the conducted analysis, is to generate sufficient information to show that the alternative for the development of the fishing activity in Pernambuco goes, necessarily, to systematically assess this activity through biological and economic models appropriate to the management and planning of the small-scale coastal fishing; and
- Is there any feasibility to invest in the coastal fishery? If fishing still generating employment, there are fishermen earnings, even if it is lower than several years or decades ago. On a recent study Barros (2000) pointed out that the logic of the fishing market in the State of Pernambuco shows that it is irrelevant neither to bear on irrationality of agents nor to disregard the inner market incentives to understand the recent shortcomings faced by the fishing industry in this State. It is argued that such an approach is helpful and even more reliable to support policy definitions to promote the sector. The existence of increasing returns in the deep ocean fishing and of negative externalities in coastal fishing generates the shortcomings found in the industry, even when agents are rational. Imperfect information and increasing returns on trading activities are the source of inefficiencies on quality generation. Maybe sufficient profit is not being acquired to maintain a constant fishing capacity and profitability by the small-scale coastal fishing, but in spite of the economic difficult observed, according to the existing data, there is a necessity to observe the economic conditions at which fishing activity occur, and also the base of co-

management whilst consist in the co-responsibility of those engaged in the process of use and conservation of natural resources.

After those questions and considering the general specific objective, the hypotheses raised to consider strategies to implement management measures for the State coastal fishery was:

- *The importance to apply and adequate bioeconomic model for the management of the small-scale existing fishing activity*;
- *Most important commercial fish stocks are depleted, with low biomass levels, and there is a necessity to diversify the existing fishery*; and
- *The small-scale fishing activity must be a priority of governmental policies for the sustainable development of the fishery sector.*

After the conduction of some studies on local fisheries there still exist many questions for the adjusted management of high economic coastal fishing stocks off Pernambuco, even if we consider that important biological studies was conducted, as much for the particularities of each resource as considering the productive chain. Up to now the management of such activity is considered extremely difficult in virtue of the conduction of segmented studies, without being observed the complexity of the number of species, fishing gear, environmental conditions, and socio-economic characteristic of the fishing communities, which disabled the application of theoretical models of fishing management, in virtue of the lack of sufficient knowledge on the local reality. It was tried to incorporate the concept that one must follow analyses and simulations to reach sufficient knowledge on a complex question that could be deepen gradually in the solutions.

However, during any process of analysis, the sources of uncertainty are certainly valuable to know, although difficult to predict, but together with the nature of uncertainty it is possible to get the understanding of the risks anyone must face during data collection and analysis. With this in mind and recognising the importance of bioeconomic modelling, these aspects led as to incorporate some of the new concepts discussed and developed under the scope of the BEEMFISH[5] Project, because its objective envisaged the perspectives and

[5] Bio-economic Modelling of Mediterranean Fisheries is an inter-institutinal Project, sponsored by the European Community and co-ordinated by the Institut de Ciències del Mar del Consejo Superior de Investigación Científica (ICM/CSIC) (Q5RS-2001-01533), with participation of the Instituto de Investigación en Inteligencia Artificial – IIIA/CSIC from Spain; CEFAS Lowestoft Laboratory from United Kingdom; Fisheries Laboratory of the Ministry of Agriculture of Greece; Instituto Ricerche Economiche per la Pesca e l'Acquacoltura – IREPA from Italy; Gabinete de Economía del Mar - Universitat de Barcelona from Spain; Institut Français de Recherche pour l'Exploitation de la Mer - IFREMER from France; Departament d'Estadística i Recerca Operational -

hypotheses raised, easily accommodating the realities of the most common local fisheries and the possibility to incorporate fisheries management tools currently used.

The proposed study was thus developed in five chapters that support the procedures for the assessment of this specific fishery, inasmuch the hypotheses raised support the necessity for the understanding of the biological and economic context at which the research for the development of the artisanal coastal fishery of Pernambuco must be conducted, and may be considered as a determining factors in the capacity for the development of assessment systems to be applied to establish the potential limits in the development of intensive scientific research.

Thus, Chapter 1 (Theoretical Background) aims to summarise the theories that support bioeconomic studies, starting from the close relationship fisheries has with the environment, because of a world-wide concern that most of the commercial fish stocks are over or fully exploited; going through the aspects concerning fish stock assessment and fisheries management, which may be considered as the general objective of the present study that has, as a tool, a bioeconomic model; and getting into the specific theories that support biological fishing models, the economic of the fisheries, and the state-of the art of bioeconomic fishing models.

In Chapter II (Characterisation of the coastal fishery), a description of the local fishery system was provided, in a international, national and regional context, aiming at conceptualising the local fisheries as for the applied methodology and the importance of fisheries management for local development, highlighting specially the similarities and peculiarities the Pernambuco State fishery sector has with that at North-western Mediterranean. Description of the analysed fleets and resources in the context of the bioeconomic analysis was prioritised and a summarised description of the environmental conditions found off Pernambuco State continental shelf, as well as its prevailing climate, was provided.

In Chapter III (Fishing and Biological Analysis), the aim was to highlight the fishing and the biological aspects of the three fish stocks caught by two different fleets, which made possible to define the biological ancillary parameters required by MEFISTO model to conducted the proposed bioeconomic study. The starting point was the importance of catch and effort data for the proposed analysis and the availability of information to run a Virtual Population Analysis (VPA) study, expecting to obtain a series of recruitment values and informations on the demography of the study populations, and considering that studies on the

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dynamics of a single species' population subject to exploitation are necessary for fisheries management.

In Chapter IV (The Economics of the Fishery), the emphasis was the definition of the necessary economic parameters to be incorporated in the MEFISTO bioeconomic model, which seemed to be the first attempt on this subject, what allowed the understanding of the economic structure of Pernambuco State fishery operation system, and the analysis of the fishermen decision process. It was analysed the most significant aspects related to revenues, costs and profits that fishermen may incur involving fishing operations.

Chapter V (The Bioeconomic Analysis) provides the expected bioeconomic analysis for the definition of management measures to support the decision making process managers have to reduce uncertainties and look for a sustainable development of the fisheries. The objective of applying a bioeconomic model in such a fishery was to reproduce the biological and the economic conditions in which the fisheries occur, carrying out projections and simulations starting from the current situation, and forward into the future with the purpose of analysing the behaviour of the fishery under different conditions, particularly different management measures.

The decision process consist of a permanent confrontation between internal factors, represented for a set of conditioning linked to the structure of the production unit and the community, and external factors, represented by the local, regional, national and international socio-economic and political context. Exchange of experiences and information may generate expectations and uncertainties that many times are difficult to manage. The planning process requires the understanding of actions in progress and the main difficulties to reach objectives. These actions must be followed up by those involved in the activity, preventing and correcting possible distortions, through the analyses of the operational, economic and financial performance of fishermen organisation. This procedure will allow taking decisions for the convergence of objectives for fishery management and the sustainable development.

Actions for the development of the fishery sector must be understood as for the necessity to combine efforts from the productive sector (fishermen, industries, etc.), the government, and the scientific community towards a holistic planning and strategic management for the implementation of a continuous and harmonic process of sustainable development. Most of the fishing nations give huge importance to the regulation of this activity, with the objective of species and environmental protections, international cooperation and investigation, and economic sustainability.

CHAPTER I - THEORETICAL BACKGROUND

I.1 - INTRODUCTION

In this first chapter it is not the intention to describe in details the theories that support the fishery management and fisheries biological and economic modelling. Details and discussion on most of these theories, of course, can be found in well known papers and books, and a single thesis's chapter could not be enough to describe it and would be a repetition of what many scientists did last century.

Nevertheless, the basic concept herein emphasised is the understanding that, according to Bas (1987), fisheries may be defined as the interaction between the biological development of the resources and the economic simulation of the fishing process. The interaction between these two factors is of great interest for fisheries researches. Hence, it is useful in this chapter to briefly trace the development of the standard biological and economic models, aiming at highlighting the broad themes that have emerged in these disciplines and the fundamental assumption and methodologies.

The intention, thus, is to have it as a basis to support the suggested bioeconomic analysis that follows without getting bogged down in finer theoretical points. Bearing this in mind, the intent is to provide an overview and description on the discussed and developed theories that made possible the development of bioeconomic fisheries models for the management and assessment of specific fisheries, starting from the cumbersome relation fishery has with the environment; going through the development of biological fisheries models; the comprehension of fishery as an economic activity and in what extend such science may help to manage the activity; and finally the state-of-the-art of bioeconomic modelling as a special tool for the comprehension of the dynamic of the fisheries.

The importance to theoretically establish these concepts may be better clarified through the interpretation gave by Bas (1987). For this author the comprehension of the fishery process may be regarded as an ecological process close related, considering its dynamic, with those observed in any other and particularly with all those in which man intervenes as constituent factor of perturbation of the equilibrium situation between the ecosystem living resources and its characterised bio-type. In reality, in a regulated fishery, the man factor (fisher) must be considered as an additional ecosystem-disturbing element, at the same level of an environmental alteration or, more frequently, as the competition between the diverse components of the biocenosis. Hence, as it may hold true that the human action is steered by distinct biological, economic, and even socio-economic laws, such an assumption neither contradict that both strategies are perfectly compatibles nor the possibility to reach a model for the comprehension of the fishery process that include both self-facet: the biological and the economic.

The objective of a fishery model may be summarised as: what products can be exploited, in what quantities, who is to do it and how? Thus, why a bioeconomic model rather than a single biological and well know one? The answer, in such case, must take several ways, depending on the theoretical background and believes one have. First, it can be said that if the overall objective on following a particular fishery is its sustainability, it must be understood that fishing resources sustainability is an economic problem rather than a biological one. Biologically a sustainable exploitation is feasible, but the problem lies on the acceptability of the insistence of growth of the fishing production on the economic point of view. As stated by Clark (1990), the current state of affairs, in which most professional economists ignore resource limitations and in which most ecologists maintain a proud disdain of economics, must give way to a science of renewable resource management based on sound principles of bioeconomics. The practical application of these bioeconomics principles will be essential if the vision of sustainable development is to be realised.

Whereas only recently bioeconomic models have been developed, if compared with the biological ones, a statement made by Beverton & Holt (1957) shows the importance of the economic of fisheries in the study of fish stocks. For those authors, *although the simple idea of a single biologically most effective rate of fishing coinciding with a inflexion point in the curve of diminishing return from increasing expenditure of effort, must now be discarded or at least modified, nevertheless there are definite biological statement to be made, the significance of which cannot be appreciated without first an excursion into the economist's domain. Some overlapping is thus highly desirable; and we would go further, in suggesting that the biological requirement cannot be regarded as simply one among many independent factors of which administration must take account.*

I.2 – FISHERY AND THE ENVIRONMENT

Clear signs of over-exploitation of commercial fish stocks, modifications of ecosystems, significant economic losses, and international conflicts on management and fish trade threatened the long-term sustainability of fisheries and the contribution of fisheries to food supply. Therefore, …fisheries management embracing conservation and environmental, as well as social and economic, considerations are urgently needed (FAO, 2000).

Overexploitation is not a localised problem and if production seems stabilised, external factors should be analysed and considered before the implementation of management measure. As pointed out by Loftas (1996), several factors are masking the decline of stocks on which global marine fisheries capture depends on since long ago, such as: the spread of fishing effort from northern waters to the southern oceans; a change in the composition of the world catch from dominance by a comparatively few, mainly high value, food fish to a greater variety of species, including lower value pelagic ones, mostly converted into animal feed; and the exploitation of species previously neglected by commercial fisheries.

It is clear that current fishing has global-scale impacts because the mean trophic level of animals harvested from the sea is decreasing (Pauly *et al.*, 1998), and examining the history of fishing and fisheries makes also clear that humans have been disturbing marine ecosystem (Jackson *et al.*, 2001), and have had for thousands of years a major impact on target species and their supporting ecosystems (Pauly *et al.*, 2002). Those impact suggests that the global ocean has lost more than 90% of large predatory fishes (Myers and Worm, 2003), being important to emphasise the needs for enforcement of regulation and management measures because, as stated by Pauly *et al.* (2003), overfishing and habitat degradation are likely to continue. Such evidence may be stressed by the argument of Verity and Smetacek (1996) for a shift in perspective among oceanographers towards assessing not just resource controls, but also predation and population dynamics as key features that structure marine ecosystems.

Local extinction constitutes a critical impact of fisheries on aquatic ecosystems that has been too often downplayed by fisheries science (Pitcher, 1998a), because most scientists and managers may not be aware of the true magnitude of change in marine ecosystems, … whose reduction of biomass to low levels may compromise the sustainability of fishing, and support only relatively low economic yields (Myers and Worm, 2003).

Jackson *et al.* (2001) stated that overfishing may have pervasive disturbances to coastal ecosystems, even higher than pollution, degradation of water quality, and anthropogenic climate change. Expansion and intensification of different forms of human disturbance and their ecological effects on coastal ecosystems have increased and accelerated with human population growth, unchecked exploitation of biological resources, technological advance, and the increased geographic scale of exploitation through globalisation of markets. Myers *et al.* (1997) stressed that although environmental changes may have played some part in the collapse of all the major herring fisheries throughout the north Atlantic and Pacific, economic factors, e.g. the demand for fish meal, contributed to such a collapse and were common to all. Pauly *et al.*, (2002) expressed that this is perhaps most clearly illustrated by a study[6] in the North Atlantic showing that the biomass of predatory fishes declined by two-third through the second half of the twentieth century, even though this area was already severely depleted before the start of this time period and, in a comparison with recent observations, Jackson, *et al.* (2001) demonstrated that historical abundance of large consumer species were fantastically large. These authors described that reports of severely depleted fish stocks and shifting of fishing grounds farther and farther from home port to or distant areas were commonplace by the beginning of the 19th century.

According to Myers (1995), the recently decline on natural resources stocks portents environmental problems that share several characteristics. First they are a regional or a global phenomenon. Second, they are unprecedented in our scientific experience and in our general ecological understanding. Third, there is no immediate or obvious explanation, although a primary or contributory cause is probably widespread pollution. Fourth, this pollution seems to cause the most harms when it works in conjunction with other stresses such as aquatic eutrophication, other form of habitat disruption, etc.

This is particularly true among high valued, slow growing and late maturing species, which have limited geographical range, and/or have sporadic recruitment (Sadovy, 2001), large marine vertebrates that are now functionally or entirely extinct in most coastal ecosystems (Hutchings, 2000), and invertebrates that were once so abundant as to pose hazard to navigation (Ingersoll[7] *apud* Jackson *et al.*, 2001). Evidence from retrospective records strongly suggests that major structural and functional changes due to overfishing occurred world-wide in coastal marine ecosystems over many centuries (Jackson *et al.*, 2001). On the other hand, it is important to point out that, for Dayton *et al.* (1995), natural changes in the

[6] Christensen, V. *et al.* (2002) in *Fisheries impacts on the North Atlantic Ecosystems.* Guénette, S.; Christensen, V. & Pauly, D. (eds.) Fisheries Centre Res. Rep. **9**(4):1-25.

[7] Ingersoll, E. (1881) in *The History and Present Condition of the Fishery Industries,* G. B. Goode (ed.), U.S. Department of Interior, Tenth census of the United States. pp. 1-252.

marine environment are responsible for the dramatic reductions of an exploited population rather than the fishery *per se*.

Freire and García-Allut (2000) mentioned that the causes of the collapse of exploited marine populations have been the subject of wide debate, confronting hypothesis that centre the problem in an excessive fishing effort which brings about overexploitation, against those that argue that fluctuations in population dynamics are attributable to natural environmental changes. It would appear to be evident that the collapse of many stocks constitutes the final stage of overexploiting generated by an excessive fishing effort. This process may be attributed both to a lack of appropriate scientific information or, on occasion and in spite of suitable assessments, to faulty management systems or failure to enforce the compliance of the fishers. Freire and García-Allut quote Roughgarden and Smith (1996) proposition that theoretically the collapse of several fisheries (such as cod and other demersal species) is due to the failure of the management system, which is often directed at obtaining the maximum sustainable yield and not towards the ecological stability of the system.

On the assumption of this new approach, recent studies faced the fact that fisheries may drive stocks to extinction, because trophic relationships are being disturbed (Pitcher, 1998a), and ought to maintain the exploitation of the oceans for fish and marine invertebrates, both wholesome and valuable products, the sector are fishing down marine food web, and must be understood that the global crisis is mainly one of economics or of governance, whereas the global resource base itself fluctuates naturally (Pauly *et al.*, 1998).

The existing imbalance between the fleet capacity and the biological state of the fishing resources produces, as a consequence, untenable volumes of capture for many of the species of fish, which can cause adverse repercussions in target species and the marine ecosystem. Marine exploitations also depend on the ecosystems, since its success and survival are intimately related to the quality of the water and foods, as well as for the diversity of the species. Perrings (2000) suggest that even in relatively simple cases involving the regulation of fish stocks whose ecology is considered to be well understood, uncertainty about the population dynamics has led to the overestimation of allowable catches.

Otherwise, Pauly *et al.* (2003) advise against this perception of local and species-specific, managed to directly benefit the fishers themselves, is conducive neither to global predictions nor the collaborative development of long-term scenario. Also Myers (1995) alerted that as human communities continue to expand in numbers and demands, they would exert increasing pressure on ecosystems and natural resource stocks, whereupon environmental surprises will surely become more frequent. Tegner and Dayton (1999) stressed that fishermen generally remain concerned about economic hardship and property rights, but acknowledge increasing public concerns over the environmental impacts of fishing.

It is well known also that to be a fisherman is a very difficult task and has never been easy. With the continual decline in fish stocks currently under way, it is becoming an even harder way to grind out such a task. And it is not only fish that are disappearing, but also marine fauna generally. Fishermen seem to be fishing with economic losses, but still in the activity, even with economic collapse prognosis, because there is no other professional choice, which strengthen the importance to follow catch landings in accordance with the existing technical and scientific concepts, allowing to infer on the real situation of the fisheries resources, and, consequently, to define plans of action for the management and conservation of these resources.

Pitcher (1998a), to support his hypothesis on the extinction of fishing stocks driven by fishery, rescued the ‘self-regenerating’ yield curve (SRYCs) of Beverton and Holt (1957), a very important concept that was way ahead of its time. This curve combines yield estimation for levels of fishing mortality with a recruitment curve to estimate absolute yield, not equilibrium yield-per-recruit. This first explicitly acknowledged the possibility of extinction by fishing, and should have revolutionised stock assessment, stuck since then in a safe yield-per-recruit universe, bounded by a comforting notion that fishers will stop fishing as economic returns diminish. Nowadays it is known that fishing intensity slacken for economic reasons do not occur because fishers overcome such problems by improving gear, boat autonomy to go further offshore, and switch to fishing species further down the food web (Pauly *et al.*, 1998; Pitcher, 1998b).

Indeed, Myers *et al.* (1997) stressed their views on such important step to improve models of population dynamics when the analysis emphasises the per capita reproductive success declines at low population levels, known as depensation, the Allee effect, and inverse density-dependence. The causes of the sudden declines and the potential for recovery for a stock when fishing is reduced have remained undetermined, because populations can have multiple equilibria and may suddenly shift from one equilibrium to another. If such depensatory dynamics exist, although sometimes it cannot be entirely ruled out, reduced mortality may be insufficient to allow recovery of a population after abundance has been severely reduced by harvesting. The important conclusion, after the analysis of multispecies interactions, and even based on single-species data, was that overfishing, at the stage found is still generally reversible.

I.3 - FISH STOCK ASSESSMENT AND FISHERY MANAGEMENT

In virtually any stock assessment, results will vary with input assumptions or hypotheses about the structural formulation of the stock assessment model under consideration. This may occur when different assumptions are made about future recruitment to the exploited fish population, for example, about the form of the stock-recruit relationship, and there is uncertainty over which one is correct. This is often troublesome because different predictions about the consequences of alternative management actions can result from applying such different hypothesis in a stock assessment (McAllister *et al.*, 2001).

In fisheries stock assessment, it is often important to consider uncertainty over competing models for population dynamics. This has been or rarely poorly applied in most of artisanal fisheries, and small-scale coastal fishing as well, implying that these fisheries have not been well managed, if they have been managed at all. They didn't follow technological development or the driving forces of economics, population growth, demand for food, and poverty. Uncertainty pervades fisheries analysis, and for Hilborn and Walters (1992), one of the reasons that major fisheries management disasters occur with discouraging regularity is the traditional inability and unwillingness of fisheries management agencies to deal directly and explicitly with uncertainty.

Beyond providing rough estimation of the stock distribution, stock size, and productivity, an important role of stock assessment early in fishery development is to help key monitoring requirements that will permit more precise assessments later in the development. Fishery science has largely been devoted to stock assessment with restricted geographical and disciplinary focus. Specially, it neither addressed the socio-economic needs of fishing communities nor the potential benefits of more collaborative forms of governance, and only recently interdisciplinary natural and social studies of fisheries management for developing regions have been considered, including community-based management and co-management. Morales and Freire (2003) stressed that the main organisational and social benefits of community-based co-operative management, as outlined by Brown (2001), have also been identified in the case of goose barnacle fisheries in Galicia. These are:

- co-operation among individual fishers and local fishing groups in planning the improvement or conservation of local fish stocks;

- commitment among local fishers to share both the costs and benefits of their efforts toward enhancement and conservation;
- conflict resolution among fishers; increased motivation to negotiate sharing of access, which is perceived as equitable;
- a more equitable negotiating relationship between local fishers and other marine resource users (i.e. harvesters of mussel seed);
- a higher degree of organisation and mutual commitment among fishers, so that they have a stronger bargaining position; and
- a higher degree of trust between fishers and government and greater willingness on the part of government to allow a range of self-management responsibilities to be assumed by fishers, and to explore options for regulation which reduce inefficiencies for fishers.

For McAllister *et al.* (2001), traditionally, assessment scientists choose the most believable set of assumptions as a base case scenario, and then run models with other assumptions as sensitivity analyses. Decision-makers, when presented with a base case, and sensitivity analyses, tend to consider only the base case in choosing management policies. In the case when two or more hypotheses are considered believable, assessment scientists may present decision-makers with results for several sets of assumptions without choosing a preferred model. Managers are then presented with a variety of results in which the best action depends upon which state of nature is assumed to be true. Without any formal scientific guidance about how to weight the different hypotheses or assumptions, scientific considerations may be down-weighted in the decision making process.

Normal assessment methods still in used for exploited fish populations are those that utilise catch and effort statistics, length and age composition, etc. In many different stock assessment, due to many imperfection in sampling design and the application of fishery dependent abundance indices, there is large uncertainty over whether the time series can provide an unbiased estimate of the trend in abundance of the part of the population it is supposed to track.

Resource management, until now considered largely a luxury affordable only by rich nations, will increasingly become a necessity if the aspirations of humanity are to be realised (Clark, 1990). According to Dayton *et al.* (1995), management involves two overriding objectives: (1) striving from the optimal sustainable use of resources and maintenance of natural values of the long term, including the preservation of genetics diversity; and, (2) preserving the integrity of the ecosystem, both its structure and function. The preservation of these attributes includes managing the many humans' effects on marine environments. In addition to the normal ramifications of harvest, it also includes preservation of cultural, spiritual, or philosophical and aesthetic values. Management for the integrity of the ecosystem is extremely difficult because, as stated and was the milestone of item I.2, most marine ecosystems have been fundamentally altered by the removal of top predators and by habitat destruction, and in many coastal areas the cumulative effects of civilisation including pollution, habitat and nursery destruction, sedimentation, etc. may completely alter the natural ecosystems, so fisheries management must include the protection of species and habitats as well as the target species.

Fishery management can be defined as governance of human behaviour, not fish behaviour, which is studied by fishery biological science, because the application of measures for the management of a fish stock can only be possible through well-managed fishing communities, based in concepts and knowledge's developed by the resources users, researchers and administration. There isn't a set of items that defines the rules to be followed, because it is unrealistic to expect a perfect management system. Each case is unique and must be analysed by the social, economic and cultural characteristics of the involved communities. Any single method must be conducted in a practical way and should place a strong emphasis on ecosystem management and participatory decision-making. To manage well you need not only to know the fish, but also the fishermen and the fishery system.

Fishery management characterises itself by studying a considerably variety of factors, such as: limitation of the natural extractive production; complex relationships between the stock and fishing effort; low efficiency of the fisheries, in virtue of the free access exploitation; unsafe prognosis; offer and demand relationship of fish products; high risk for capital inversion; lack of qualified staff; and dispersion of social organisations of the agents directly involved in the activity. The problems facing fisheries management is that the objectives – fish stock conservation – are generally established in economic, social and political basis, rather than biological and ecological ones. In formulating fishery management plans and measures it is fundamental to take in consideration the biological cycle of the exploited species, with the simultaneously knowledge of ecological nature (Paiva, 1986), and it should include various modelling approaches, legal and economic instruments, and gear modifications to limit by-catch and marine protected area (Tegner and Dayton, 1999), because fisheries management involves making choices: without choices one can be an observer, but never a manager (Hilborn and Walters, 1992). For these authors, it is widely accepted that the fundamental purpose of fisheries management is to ensure sustainable production over time from fish stocks, preferably through regulatory and enhancement actions that promote economic and social well-being of the fishermen and industries that use the production.

Freire and García-Allut (2000) provided a quite interesting argument on fisheries management. They mentioned that it has been dominated, up until recently, by a school of thought based on the assumption that in-depth scientific research on the biological foundations of the exploited systems would allow for adequate management. Another line of thought, developed more recently, and pointed out by Hilborn *et al.* (1995) upholds the fact that the spatial and temporal scales of variability of many systems would make research be of limited value in management, while the design of management and monitoring systems would be highly beneficial. So the ultimate goal of management systems is not to obtain precise estimates of the population parameters by means of stock assessments carried out by scientists, but rather to design monitoring and management systems that will yield long-term catches without endangering the stock (Ludwig *et al.*, 1993). Moreover, another failure in traditional management systems has been the lack of attention paid to the dynamics or behaviour of the fishers as an integral part of the system (Hilborn *et al.*, 1995). Fisheries management science appears to have evolved from the early stages during which understanding the biological foundations of the system was considered the key factor in good management, to a state in which the intrinsic complexity of the exploited stocks and ecosystems, along with the technical and socio-economic factors involved, create the need for reorienting research and management strategies (Freire and García-Allut, 2000).

Thus, even if the objectives of fishing management are well identified theoretically, the application of such theories on a local basis are not straightforward and for fisheries managers are diverse and often contradictory. According to Lleonart *et al* (1999a), they could be to maximise fish production or revenue, to minimise catch fluctuations, to avoid the risk of collapse of the resource, to maintain employment, etc. The manager has two kinds of tools available: technical (limitation of the effort, meshes, legal size, etc.), and economic (subsidies, taxes, penalties, etc.). From the technical point of view there are two main methods to manage a fishery: to limit the catch (TAC's and quotas) and to limit the effort (licenses, time fishing, power, etc.). In both cases a process of monitoring and assessing the fishery is required (Lleonart *et al.*, 1999c). In a complex system, as fisheries can be, it is not always evident what will be the response from the system to a certain management measure. Furthermore, predictions of the indirect effects of a certain measure are still more uncertain (Lleonart *et al.*, 2003). There is a series of regulation systems with which the administrator can make use, all with advantages and disadvantages and, generally, fisheries management may encompass a combination of many of those mechanisms available. On the other hand, as an example of such difficulty the ICES[8] (Anon., 1991) reported which considers that a common fishing policy's Total Allowable Catch (TAC) approach does not work very well because it does not regulate discard. Even if the full extend of the ecosystem effects of fishing remains unclear,...the exploitation of the living resources ... undoubtedly affects the structure and functioning of the ecosystem and must, therefore, be viewed against other management objectives.

Adaptive management involves a continual learning process that cannot conveniently be separated into roles like "research" and "ongoing regulatory activities", and must be based on the assessment results and an empirical process of trials and errors (Hilborn & Walters, 1992). This consists of a cyclical annual process made up of the following steps: (1) the evaluation of the resource under different hypotheses (in order to model uncertainty); (2) the risk analysis under different management procedures (it is necessary to have a set of alternative hypotheses available and a set of management plans to examine the behaviour of different plans under different hypotheses); (3) recommendations of the measures to take according to the preceding analysis; (4) up-dating the regulations and control; and (5) updating the data which are necessary for the evaluation. On the other hand, Lleonart *et al.* (1999c) stressed that a non-adaptive management is that where the management steps are not regularly updated. The fishermen themselves, through fishermen's associations and based on gentlemen's agreements, play a significant role in such a management. In any case, the code of conduct has to be promoted and watched over by higher authorities since the fishermen have ways of not complying with the regulations.

For several decades, the management of stocks and fisheries has usually rested upon scientific advice based on assessment of individual stock, when the maximum sustainable yield (*MSY*) was the only mechanism of control of the fishing effort. But the single-species assessment models and the related policies have not served particularly well, because (1) the assessment results have often been ignored; (2) the assessment methods have failed in cases involving rapid stock decline; (3) there has been insufficient attention in some cases to regulatory tactics; and (4) apparently severe violation of the assumption usually made about compensatory responses to recruitment (Pauly *et al.*, 2002). Recently the fisheries management shows a trend for the classical methods used in single species assessment, to

[8] International Council for the Exploration of the Sea

incorporate the effects of multispecies, multifleet and multigear, i.e. the analysis of the catch of many species by different fishing gear and different types of boats. This is mainly because, in the evaluation of overall harvesting strategy, the traditional methods take no account of the effects that occur when several stocks are exploited concurrently in time and space at different levels of fishing (Rocha *et al.*, 1995).

The alarming situation of many fish populations demands an urgent reform of the fishing management method and more efficient conservation method, but it seems to be even harder when we consider that many fisheries exploit different stocks and populations. Management of shared fishery resources remains one of the great challenges on the way towards achieving long-term sustainable fisheries, because adult fish caught in one country may have been spawned and mature in waters of another. Munro *et al.* (2002) stressed that while there is not precise knowledge on the numbers and abundance of shared fish stocks, there can be little doubt about their prevalence and their economic importance in world fisheries. Although this problem reached world concern, in local fisheries shared fishery resources may present as many as difficulties to solve due to interest others than fishery.

These and others assumptions apparently leads to the need to develop models that allow a variety of inputs parameters and outputs results, incorporating multispecific characteristics and multidisciplinary approaches. Nowadays there is an increasing awareness for the management of fishing stocks and models have been developed since long ago. Dayton *et al.* (1995) considered that the principal challenge to the management of any wild resource is to incorporate the uncertainties and to allow maximisation of the catch in such a way that the exploited stock is neither wasted nor put at risk. In most cases the exploited fish stock experience recruitment uncertainties as well as ecosystem changes that alter growth productivity.

The problem to take management measures relies upon the knowledge on the stock under analysis, because assessment procedures may not be sensitive enough to detect extend of the perturbations. Although not directly interpreted in this sense, the problem and difficulties to implement management measures is of concern since long ago. Facing many problems due, mainly, to social, cultural and geographical aspects of the fishery, in Brazil, constraints were always posed dampening implementation of management measures. Paiva (1986) was among few Brazilian researchers that raised concern on such features, arguing that the high level of exploitation of most of the fishery resources led to the abandon of merely developmental strategies, favouring conservational approaches. As a result of this new conception, special attentions have been paid to resource management based only on the maintenance of *MSY*. The author suggested that correct management of fishery resources would only be possible in a wide social and economic context.

Beverton & Holt (1957) stated the importance of populational dynamics studies for the control and management of fisheries, and generalising what continues to be the central problem of fisheries research, the investigation must intend not merely to study the reaction of a particular populations to fishing, but also of the interaction between them and of the response of each marine community to man's activity. Gulland (1971) stressed that it is most unlikely, in an area where several stocks exist, that the overall pattern of fishing will be such that the maximum yield is taken from each stock. Among the heavily exploited stocks, even with good management, some are likely to be under-fished (the yield would be increased by greater fishing), and others over-fished.

Depending on the primary management objective, the concept of fishing method would appear to be of prime relevance if management strategy is based on input control and when adjustment to technological innovation appears to be necessary; problems of stock depletion would seem to be better addressed through the concept of fishery; management objectives geared essentially towards sustaining social tradition or local economies would benefit from an approach based on an appropriate breakdown of the fleet because it may help in determining or evaluating the impact of, or the need for, public intervention. Such an approach may reduce the variability of factors conditioning the dynamics of each segment and help to assess any interactions that might exist between segments (Hundloe, 2000).

Rosenberg (2002) pointed out that the history of fishery policy and management world-wide paints a bleak picture of overexploitation and decline of valuable resources in almost every part of the globe. Recent information indicates that the global fish catch has been declining for the past decade as basically all principal resources are currently exploited and many overexploited. The politics of fishery management may be changing, but slowly, and even if we have new science perspectives, but are struggling to implement precautionary management nationally and internationally. The author continues arguing that for many fisheries we have come to the end of the road in terms of delay and inaction allowing overexploitation, and what needs to be done is to fish less, because although conscious of the hard work that must be done, time is running out. For Pauly *et al.* (2002) one of the reasons for such a picture is that overcapitalised fisheries can continue to operate after they have depleted their resource base only through government subsidies.

For Clark (1990) the concept of optimal resource management must be based on the standard cost-benefit criterion of maximising present values of net economic revenue. This criterion is relevant to both private and public management decisions, although the specification of costs and benefits is not necessarily the same in both cases. Private management is normally concerned only with actual, internalised costs; public management is often concerned with social and external costs as well. For this author, however, it should be noted at the outset that few biological resource stocks, historically speaking, have been managed on the present-value criterion. Most marine fisheries, for example, have hardly been "managed" at all, in any strictly economic sense of the term.

The point being raised today is that in a complex system such as fishery, optimum management system does not exist in the context of the economic and biological theories developed to understand a fishery exploitation, because the optimum economic yield is at a point where the fishing effort is catching less than could be caught sustainably, that is below the optimum biological yield. Notwithstanding this pessimistic view of the environmental impacts of fishing and the difficulties to define indicators for fisheries policies, biology and economic sciences can play an important role for fisheries management. For Hannesson (1993), fisheries management is indeed a multidisciplinary subject, but obviously it must be based on sound biological expertise, but the ultimate objective is economic, because fisheries management that disregards economic aspects may succeed in preserving fish stocks, but it will waste others resources such as investment funds and labour, and it is likely to be distinctly unhelpful for the fishing industry. The following items will try to conjugate ideas towards an adequate management system and the sustainable development of the fisheries.

I.4 - REVIEW OF BIOLOGICAL FISHERIES MODELS

Biological fisheries models were developed and have been improved aiming at studying the dynamics of exploited fish populations, which means the conduction of comprehensive studies on the aspects related to fish growth, recruitment, reproduction and mortality, being it individually or as the biomass of the population fish belongs. Myers (1995) detached that in natural ecosystems there is a non-linear relationship between resource exploitation and population growth with respect to many other natural resource stocks, notably fisheries.

At this introductory note, it is essential to point out the ways in which biological fisheries models evaluated, especially for the studies of population dynamics for fisheries and in the use of mathematics, which made possible the development of equations, models, and computational programs. Beverton and Holt (1957), in their well known book *On the Dynamics of Exploited Fish Populations*, mentioned the importance of mathematics and that many fishery naturalists, and many workers dealing with population problems, generally accepted that mathematics is an indispensable tool in any population dynamic study.

The objectives of the fishing biological models is the analysis of a particular fishery, inasmuch as the level of fishing pressure under which it is submitted, and permit the evaluation of a particular fish population under study. There are many ways to evaluate a fish population that, to some extent, is far away from the methodology of population dynamics theories that one may consider for the quantitative study of the fisheries. They must become relatively useful as for the attainment of rapid evaluation, to contrast results from different methods or to diversify the source of information. Models to be applied to a specific fishery must be as simple as possible concerning mathematical formulas and data input, and must be flexible to allow changes and adjustments of parameters, considering a particular fishery. As pointed out by Willmann and García (1986), the main objective of a model is to provide decision-makers and administrators with a straightforward instrument that can assess the possible consequences deriving from the adoption of important political decisions.

It is important, thus, to have in mind how the current knowledge for the analysis and understanding of the dynamics of a particular fish population, submitted to a specific fishing pressure, was achieved. So, for brevity's sake, an attempt overview on how those models developed will be conducted. Concerning the detailed procedure chosen to describe fishing biological models theories, the focus is on the development rather than the construction and utilisation of theoretical procedure. In this sense, it seems that biological fishing models developed from the assumption on how an organism grows and the utilisation of growth curves, developed for others animals, adjusted for fishes.

Generally two kinds of models are known: the analytic or structural and the global or production models. The global or production models are based on the theories developed by Schaefer (1954), which study the mechanisms taking in consideration the inputs (fishing effort) and the outputs (yield, production or catch). Production models represent the combinations of the many factors to which any stock is submitted, adding information on quantitative biology. As stressed by Farrugio (1993), they allow the representation of chronological variations in the total biomass of a stock in equilibrium (and of the volume of the corresponding catches) in relation to chronological variations in fishing effort. These informations, according to Paiva (1986), constitute the main biological parameters necessary to correctly manage the fishery, and the main components of these models are: stock, recruitment, growth, mortality and production. Following Lleonart (1993), for any exploited population there is a stable equilibrium relationship between catch and effort, and is described by a curve with a maximum called Maximum Sustainable Yield (*MSY*), representing an optimum from a management point of view.

The analytic or structural models are based on the yield-per-recruit theory developed by Beverton and Holt (1957), which allow simulations through the intrinsic analysis of the fishery, because it is well known that the yield that can be taken from any fishing stock year after year must, in some way, depend upon natural processes such as growth, mortality, recruitment and reproduction. The yield that is possible to take from an annual year class is dependent on the number of recruits, the growth pattern, the natural mortality, the fishing effort, and the first age-at-recruitment. Such relationships allow the estimation of the yield-per-recruit (*Y/R*), a very important parameter for population dynamic studies, because a maximum *Y/R* leads to a maximum total yield.

According to Farrugio (1993), analytical modelling of stocks of marine animals makes a much finer description of their possible dynamics, and also of the main mechanisms which regulate them. In other words, it takes into account the relations between spawners, recruitment, age, growth in length and weight, death rates (natural and due to fishing), the structure of the stock and its biomass (often confused with that of the total population). Lleonart (1993) stated that, knowing the natural and fishing mortalities at age, and the length-weight and the length-age relationships, the yield (in biomass) of a recruit can be obtained. The most interesting feature of this method is the computation of a set of *Y/R* values varying the fishing mortality vector. These variations can consist in multiplying every value of the vector by the same factor (simulating effort changes), or modifying some particular values to simulate selectivity changes.

Basic books and papers on which population dynamics theories are based on analytical or structural models are: Baranov (1918), Russell (1931), Beverton and Holt (1957), Ricker (1969, 1975 and 1979), Csirke (1980), Laurec and Le Guen (1981), Pitcher and Hart (1982), Gulland (1983), Sparre *et al.* (1989), among others.

The basic principles on the dynamics of an exploited fish population are based on Russell's (1931) work, and may be considered as a starting point for the development of the following theoretical population models. As described by Beverton and Holt (1957), the axiom taken by Russell is that the weight of a population remains stabilised if, over a given period of time, the weight increments are equal to the weight decrement – another way to stress what Pütter[9] suggested 11 years before. But as for Beverton and Holt it is self-evident, the significance arose when applied to fisheries problems and the value of considering populations in a steady state, being true for the whole population or part of it made up of individuals between any two ages. An important axiom of Russell work states the primary factors contributing to the balance of weight increments and decrements in any phase of a closed fish population, that is, one in which there is no emigration or immigration, as being: (a) *recruitment* of individuals to the exploited phase of the life-cycle; (b) *growth* of individuals in the exploited phase; (c) *capture* of individuals in the exploited phase by fishing; and (d) *natural death* of individuals in the exploited phase.

Primarily considerations of growth was originally suggested by Sachs[10] (Ricker, 1979), to whom within any stage of growth, increase in size may follow an S-shaped curve, the lower part may – or may not – approximate to an exponential curve, while the upper asymptotic part may reflect preparations for the next stage – unless the fish is already in the final stage. A metabolic theory on how an organism grows was advanced by Pütter[9] (Ursin, 1967), the first to realise the usefulness of the truism that what remains in the body is the difference between what comes in and what goes out, and was the first who introduced growth curve on biology studies (Ricker, 1979). Brody (1945) applied it to the growth in weight of domestic animals beyond the inflection point and, applied to length, it has had the contribution of von Bertalanffy (1934[11], 1938 and 1957), who distinguished three metabolic types in the animal kingdom: (1) where metabolism is proportional to surface area or to the ⅔ power of weight; (2) where it is proportional to weight; and (3) where it is intermediate between these two situations.

von Bertalanffy then endeavoured to establish *a definite and strict connection between metabolic types and growth types, in consequence of a general theory which establishes rational quantitative laws of growth and indicates the physiological mechanisms upon which growth is based*. Since then von Bertalanffy's growth formula has been widely used for fish

[9] Pütter, A. (1920) Wachstumsähnlichkeiten. *Pfluegers Arch. Gesamte Physiol. Menschen Tiere,* **180**, 298-340.
[10] Sachs, J. (1874) Über den Einfluss der Lufttemperatur und des Tageslichtes auf die stündlichen und täglichen Änderung des Langenwachstums der Internoden. *Arb. Bot. Inst. Wurzburg* **1,** 99-192.
[11] von Bertalanffy, L. (1934) Untersuchungen über die Gesetzchkeit des Wachstums. *WilhelmRoux' Arch. Entwicklungsmech. Org.* **131**:613.

population dynamics studies (described in Chapter III, item III.2.2). This relates the asymptotic size in length or weight, the growth ratio and the age of a fish, which has the form:

$$L_t = L\infty\{1 - \exp[-K(t - t_0)]\}$$

for length, and

$$W_t = W\infty\{1 - \exp[-K(t - t_0)]\}^{\theta}$$

for weight.

When choosing a growth curve, and therefore a biological model, one should take into account, according to Ricker (1979), that any of those curves for fish can give reasonable fits to both length and weight data, but not necessarily on the same species, and not necessarily for the complete range of ages. The only criteria for choosing a model that have proved valid are goodness of fit and convenience. This author exposed that, historically, most of the curves in use have been proposed along with some mathematics-physiological theory as to how growth might be regulated, and much ingenuity has been expended in trying to relate them to growth processes.

While the analytic fishing models are derived independently, based on the equations before mentioned, the descriptive ones, the constants are calculated from changes in the numbers of the population itself, and are associated with the development of the logistic equation of Verhulst[12] by Schaeffer (1954a), that describe population growth based on the mathematical expression of Graham (1935):

$$\frac{dB}{dt} = rB(t)(1 - \frac{B(t)}{K})$$

where r is the intrinsic rate of population growth, $B(t)$ is population biomass in time t and K is the carrying capacity of the environment. Population behaviour through time is described as a sigmoid curve, where the unexploited biomass increases until a maximum level $B\infty$, constrained by K. It is built on annual increment of catch data and has the disadvantage that causes of failure must remain unknown but the advantage that the chance of failure by growth overfishing or recruitment overfishing is minimised. The distinction between descriptive and analytic models is a didactic one to point the contrast between a model of the Schaeffer form and that of the yield-per-recruit (*Y/R*) in the consequences for management; management can only come slowly into being with the first, but quickly with the second, because the great

[12] Verhulst, P. F. (1838) Notice sur la loi que la population suit dans son accroissement. *Corresp. Math. Phys.*, **10**:113-121.

advantage of the analytical model is that management advice could be given quickly once a fairly small quantity of information become available (Cushing 1975). (for details the suggested literature on the theories of global or production models are: Graham (1935 and 1939), Schaeffer (1954a), Pella and Tomlinson (1969), among others).

The scientific advantage of the Beverton-Holt model, according to Cushing (1975), lies in its analysis of growth and death by age from age/length keys and the market statistics of stock density. Instead of a single observation of catch and stock density in each year, as demanded in the Schaeffer model, there are observations of stock density by age; so the annual information is increased by the number of age groups in the stock. But this numerical advantage is trivial as compared with the independent estimates of growth, recruitment and mortality. In the descriptive models the contributions of growth and recruitment were not distinguished and the model improved year by year as additional data were added.

Each ecosystem has a limited and fixed carrying capacity, which determines the maximum size of the fish stock, due to natural factors (Paiva, 1986; Kula, 1992). The biomass grows as a result of new fish entering the stock, as well as infant fish growing in size. Growth, which is a function of stock size, is slow in the early stages because of a relatively small number of fish in the fishery. It speeds up to a maximum level, than moderates to reach the maximum carrying capacity, which is also the saturation level, where the population, in the absence of fishing activity, is stabilised (natural equilibrium of population level). The change in the fish stock over a small interval of time will be given by the difference between the biological growth function and the level of fishing activity in that time (Kula, 1992). But growth rate may be negative below some minimum population size, in which stock exploitation will not be viable. If for some reason stock is reduced below such a critical level, the net effect of recruitment, individual growth, and mortality is negative and so stock size shall actually decrease (Anderson, 1977).

The stock-recruitment relationship represents the relationship between parental stock size and the subsequent recruitment in numbers, or year-class strength. Ricker (1975) discussed a number of desirable principles for stock-recruitment curves, and listed four basic properties that, it were felt, should be generally applicable:

- a stock-recruitment curve should pass through the origin when there is no parental stock there is no recruitment (this assumes no immigration);

- the curve should not fall to the abscissa at higher levels of stock, so that there is no point at which reproduction is completely eliminated at high densities (this accords with observations);
- the rate of recruitment (recruits-per-spawner) should decrease continuously with increases in parental stock (reasonable where only compensatory biological mechanisms are present); and
- recruitment must exceed parental stock over some part of the range of possible parental stocks (realistically only applicable to semelparous species which spawn only once).

Hilborn and Walters (1992) pointed out that not only the curve for the stock-recruitment relationships should be fitted, giving the average recruitment at any stock level, but also that the uncertainty associated with the fitting process to actual data needs to be assessed.

Being pertinent the interrelationship between age and growth, leading studies considered that age determination in fishes and, consequently, the determination of the growth and mortality indexes, are parts component of modern fishing sciences. According to Paul (1992) a great variety of techniques is used and continues to be developed, and discrepancies between different authors continue to happen. This situation occurs because growth rates of one specie can vary temporal and geographically. The validation procedures of each technique are complex, not being, therefore, possible the use of a technique in any type of study, or in other words, data should be validated before a given technique is applied.

In Pauly (1980) a reasonable and quite comprehensive explanation of natural mortality on fishes can be found. For this author, in fish population dynamics, the exponential coefficient of natural mortality (M) certainly is one of the parameters for which it is most difficult to obtain good estimation. Defined as all possible causes of death except fishing, in theory direct estimates of M can therefore be obtained only from completely unfished stocks. First attempts to estimate M were conducted by Beverton and Holt (1957) and Ricker (1975), through the values of total mortality (Z) minus fishing mortality (F), or by a plot of Z against contemporary effort data (f). Improvement on such estimation was explored by Beverton and Holt (1959), who attempted to relate M to some easy-to-estimate parameters, whose value could then be used to predict M. Thus, Pauly (1980) attempted to demonstrate that three variables significantly affect natural mortality: (1) the size of a fish, as expressed by its values in asymptotic length ($L\infty$) or weight ($W\infty$), which very significantly (negatively) correlates with M; (2) the growth rate of a fish, as expressed by the magnitude of K; and (3) the mean environmental temperature, which reflects maturity of a given ecosystem and the physiological aspects related to fish metabolism.

As the estimation of natural mortality is an important factor for population dynamics study, Francis (1974) discussed the relationship of F to M, at the level of maximum sustainable yield (*MSY*). He then mentioned that many publications (Tiurin, 1962[13]; Alverson and Pereyra, 1969; Gulland, 1971) assumed that for many fish stocks the instantaneous fishing mortality rate – referred to in the usual context generally as a biomass rate – is approximately equal to the instantaneous natural mortality rate – generally a numbers rate – at the point of *MSY*, under the assumption of the logistic form of the general stock production model (Schaefer, 1954), when values of M and standing stock biomass are estimated under the unexploited equilibrium condition. Francis concluded that under this assumption this approximation is applicable only under very limiting conditions, if and only if the level of recruitment which occurs at the unexploited equilibrium level is equal to that which occurs at the population level which produces the *MSY*, e.g. if recruitment is density-independent and the spawner-recruitment relationship density-dependent.

As well summarised by Pauly *et al.* (2002) fisheries science advanced over a time when fishing stocks were released from fishing, due to the possibility to population recover, and due to the attempt made to equate the concept of sustainability with the notion of optimum fishing mortality. Fishing mortality can be understood as the interaction of two systems: the fishermen, or the fishing effort, and the fish. This allowed the construction of models of single-species fish populations whose size is affected only by fishing pressure, expressed either as a fishing mortality rate (F, or catch/biomass ratio), or by a measure of fishing effort (f) related to F through a catchability coefficient (q): $F = q \cdot f$. In this sense the catchability represents the fraction of the population caught by one unit of effort, directly expressing the effectiveness of a gear. Thus q should be monitored as closely as fishing effort itself, if the impact of fishing on a given stock, as expressed by F, is to be evaluated. Technology changes tend to increase q, which quickly renders meaningless any attempt to limit fishing mortality by limiting fishing effort. The conclusion is that adjusting fishing effort to some optimum level should generate maximum sustainable yield.

[13] Tiurin, P. V. (1962) Factor estestvennoi smertnosti ryb i ego znachenic pri regulirovanii rybolovstva (The natural mortality factor and its importance to regulate fisheries) *Vopr. Ikhtiol.,* **2**:403-427 (Trans. From Russian by Fish. Res. Board Can. Transl. Ser. Nº 558, 1965).

Anderson (1977) clearly stated that at any point in time, catch or fishing mortality will be a function of (1) the amount of fishing effort that fishermen applies to the fishery and (2) the size of the stock. For any given population size, the higher the effort the larger will be the catch; and for any given level of effort, the larger the population, the larger will be the catch. Since catch varies with the level of effort, a different equilibrium population size will result at each level of effort. This is important because effort is a variable controlled by man. Catch is a function of stock size and effort, but since equilibrium stock size is a function of effort, then sustainable yield is a function of effort only. In other words, at lower levels of effort each additional unit of effort applied to the fishery will add a positive increment to the catch, although the size of this increment decreases as the total amount of effort is increased, and that beyond *MSY*, each additional unit of effort will actually decrease catch. At a sustainable yield, catch equals growth; but when effort is changed, the size of the catch varies from that equality. Therefore, population size will change until a new equilibrium is established at the point where growth again becomes equal to catch.

One of the main objectives of biological fisheries models is the definition of the Maximum Sustainable Yield (*MSY*) of a fish stock. This may vary as a function of age class (length) of the recruited individual to the fishery. To each level of a given variation will always correspond an optimal effort, applied at the same unit at time. Optimum catch of an overexploited stock will be as smaller as higher will be the wish to recuperate it along the time. Nevertheless, as mentioned by Paiva (1986), *MSY* is only known when overfishing arises, demanding a correction process that involves economic waste.

According to Clark (1990) the management of renewable resources, where it has been practised at all, has generally been based on the concept of *MSY*. For this author it is perhaps the simplest possible management objective that accounts for the fact that a biological resource stock cannot be exploited too heavily without an ultimate loss of productivity. The concept of *MSY* is itself based on a model of biological growth that assumes that at any given population below a certain level, a surplus production exists that can be harvested in perpetuity without altering the stock level. If this surplus is not harvested, on the other hand, a corresponding increase occurs at the stock level, which ultimately approaches the environmental carrying capacity, where surplus production is reduced to zero. Since surplus production equals sustainable yield at each population level, it follows that *MSY* is achieved at the population level where surplus production is greatest.

An advance on the study of population dynamics was the development of virtual populations analysis (VPA), an ingenious stepwise procedure developed by Gulland (1965) to calculate, for a year-class, the instantaneous fishing mortality and population at each age, given a knowledge of the catch at each age and the natural mortality (Pope, 1972), and generally relies upon commercial catch-at-age trustful data to reconstruct past stock abundance. VPA and sequential population estimation techniques are widely used to reconstruct abundance of fish stocks. This reconstruction is an important component of standard procedures of many fisheries management agencies for estimating stock size, forecasting catches, and evaluating the success of past management schemes. Detailed description can be found in Gulland (1965 and 1983), Murphy (1965), Pope (1972), Rivard (1983), Pope and Shepherd (1985), MacCall (1986), Rivard and Foy (1987), among others. Pope and Shepherd's paper shall be highlighted considering the effort done to compare the performance of various methods for tuning VPA.

VPA has commonly been used on catch data sets that include periods of increasing *F*. According to Lleonart (1993), VPA rationale starts from the number of individuals caught at age of a cohort, and the minimum number required at age, and the corresponding fishing mortalities are obtained. Hence, from a table of numbers caught at age and year, the corresponding tables of numbers of individuals at sea and the fishing mortalities are obtained.

However, Cushing (1975) reports that the study of a virtual population has a long history, developed from the catch equation and based on the assumption of the sum of catches throughout the life of a year class. According to this author, Derzhavin[14] published a study of the sturgeon based on year class data from the first half of the last century. The sum of catches within a year class from recruitment to extinction represented a least estimate of stock or virtual population. Fry[15] applied it to the stock of trout of Lake Opeongo, in eastern Canada, and, in 1957, Fry wrote that the virtual population represented *the sum of the fish, belonging to a given year class, present in the water at any given time that are destined to be captured in the fishery in that year and all subsequent years*. Otherwise, it should be emphasised that the well known problems with VPA is that it have simulated the development of non-sequential statistical fitting methods of estimating abundance, which are now gaining wider acceptance as plausible alternatives to VPA (Lapointe and Peterman, 1989), because it can create overoptimism, considering that VPA depends upon estimates of current fishing mortality rates to provide a "reconstruction" of historical stock trends. Catch-at-age data is the

[14] Derzhavin, A. N. (1922) The stellate sturgeon (*Ascipenser stellatus* Pallas), a biological sketch. *Bihll. Bakinskoi Ikhtiologichesakoi Stantsii,* **1**:1-393.

indispensable information if any age-structured stock assessment model is intended to be applied. For example, the acquisition of catch-at-age data with known natural mortality rate, stock size and fishing mortality rate can be therefore estimated using VPA models. Catch-at-age data can be derived from catch-at-size data by using age-length relation, age-length key or other length-age conversion algorithm.

In the last decade, discussion on the evolution of population dynamics models went through the incorporation of intrinsic aspects of a specific population and the incorporation of environmental factors that contribute to aggravate anthropogenic impacts, specially overfishing, and attempts to understand the complex relationship of the food web. Such concern advanced from the general theories of the dynamics of fish production, specially those formulated by Beverton and Holt (1957), which show that greatest catch is taken with a moderate fishing mortality, combined with protection of the smaller fish. Taking into account the natural, non-fishing, deaths before reaching the size at first capture, the potential catch is likely to be no more than half the total fish production, and a portion of this production of the lower trophic levels no longer used by fish must go somewhere, but may well never appear in a form usable by man (Gulland, 1971).

One essential aspect of the development of population dynamics theory, considering the rates of changes in weight and numbers of populations under fishing pressure, still the recognition of a fish population or community of populations as a self-maintaining *open system,* exchanging material with the environment and usually tending to a steady state. According to Beverton and Holt (1957), the significance of open systems in biology has been discussed in details by von Bertalanffy (1950a, 1950b and 1951), who notes the role of feed-back in homeostatic processes, making reference to the work of Frank *et al.*[16]. The development of this paper may be regarded, in von Bertalanffy's terms, as a step in the transition from the view of an exploited fish population as an open system exhibiting physical independence of the variations of the elements comprising it, to one in which that system – behaving as a unit through the interaction of the primary processes of birth, growth, mortality and movement because of their mutual dependence on age and population density – is itself but one element in a higher system comprising all the others inter-dependent biotic groups, including man and other predators, competing animals, species at others levels in the food chain and so on. In this sense, Pauly and Murphy (1988) book on the theory and management of tropical fisheries is a quite good work to be quoted on the importance that nowadays

[15] Fry, F. E. J. (1949) Statistics of a Lake Trout Fishery. *Biometrics,* **5**(1):27-67.
[16] Frank, L. K. *et al.* (1948) Conference on Teleological Mechanisms. *Ann. N. Y. Acad. Sci.* **50**(4):187-278.

population dynamics must incorporate environmental parameters for the correctly implementation of management and regulation measures.

A number of packages are now available to the fisheries biologist for the analysis of exploited marine populations, based on the methods and models of population dynamics. Often, the large amount of data needed to run such programs restrict in practice their use, as is the case in many fisheries, where long historical series are not available or are of poor quality. At this point, the fisheries biologist may choose to wait until a good-quality data set becomes available, or use whatever data is at hand and try to ascertain something about the fisheries under study with less restrictive models and programs (Maynou, 1999)[17].

So, the understanding is that model validity must accomplish the assessment through a correspondence that exists between the results, i.e. a curve, and the observed data of catch and effort. Should official data be utilised to validate a model? Lack of sufficient data and trustworthy statistics make the validation of models particularly important in developing countries, where systematically assessment of fisheries is extremely difficult and demands a correspondent advise for political matters, in case of possible errors in the applied parameters. Nowadays, sensibility analysis is an indispensable tool to overcome this situation.

I.5 - REVIEW OF THE ECONOMICS OF THE FISHERIES

As has been the pattern during writing, it must be understood that the context of this introductory note on fisheries economics procedure must be to outline questions of comprehensive force and general and well treated theory in the economic literature.

According to Anderson (1977), economics can be defined as the study of the optimal allocation of scarce resources among unlimited wants. It investigates how the limited amounts of land, labour, capital, natural resources, and entrepreneurial ability available at any given time can be combined to best satisfy the desires of society. Individuals, families, and society normally all face the same puzzle: how to allocate limited means or resources among unlimited wants, given the state of technological knowledge, in such a way that their welfare or happiness, however measured, is maximised. Thus, considering the way that must conduct

[17] Maynou, F. (1999) VIT for Windows (version: 1.2): Software for fisheries analysis. Original program and MS-DOS version by J. Lleonart and J. Salat. *FAO Computerized Information Series – Fisheries,* n. 11. – 1997.

maximisation of fishing production, fishery economics can be defined as the study of the optimal allocation of a fishing stock to a fishery, because proper use of a fish stock requires that resources be utilised to exploit it such that the present value of future net returns is maximised. Such maximisation is not an end in itself; rather, its achievement means that society's resources have been properly allocated.

In the fishery process, the economic factor may be regarded to the biological development, but is self-stimulating by the increase of its own volume to a limit that produces a downfall of fishing products value and thus decrease the economic stimulus to continue to invest in fishing effort. Undoubtedly, the optimum is not in the superior limit but where the direction of the increment changes its sign. The factors that affect the economic development may be of two classes: primary factor (man, gear, boat, etc.) and secondary factor (market, communication, infra-structures, etc.) (Bas, 1987).

Economics is one of the disciplines most poorly understood by lay people. Most what is conveyed by economic information is in fact financial information. The crucial difference between financial data (and financial analysis) and economic data (and analysis) is that the former is based on the individual or corporate/private perspective – taking as 'given' the whole array of taxes, subsidies, commercial practices and regulations which influence prices – whereas the latter is concerned with society's economic welfare. It is by pursuing what is know by economic activity that humans feed themselves (Hundloe, 2000).

Economics can explain to us the socio-economic network as a conditioning factor of fishing activity; the use of fisheries resources by men; to improve the productive chain, such as capture, transport and conservation techniques, aiming to follow market rules; and also help in the understanding on how and why the use of the resource has a given evolution. Not only is it necessary for the resource to exist biologically, but there must also be an economic interest in exploiting it. Economics needs not only to explain the reason for and why a given process takes place, but also to generate correction mechanisms and solutions for problems that could arise when exploitation becomes unsustainable and, with other disciplines, has reached solid conclusions in some aspects and still asks important questions about others that should be answered with accuracy.

Aiming at ascertaining the fisheries resource, population dynamic studies must be carried out, as resumed in the previous item, by the utilisation of fisheries biological models. The evolution that experienced the analytic and production biological fisheries models made them complex models that may induce simplifications for the economic analysis, and, on the other hand, those simplifications may limit a reliable analysis. As stated by Surís and Varela (1995), the utilisation of such a biological approach and such a straightforward approximation afforded its wide utilisation by economists aiming at the economic analysis of a given fishery.

This relationship can be better understood through the concept that a production function is the relationship between the amount of resource used (input) and the amount of resultant product (output). In terms of a fishery, it is the relationship between the effort applied and the fish caught. As explained by Anderson (1977), the production function in a fishery depends on the reproductive biology of a fish stock, and the growth of the fish stock is assumed to be a function of its size in weight. Further assumptions can lead to the understanding of the basic economic model of a fishery, which relates revenue and cost with catch, and their marginal functions; if a greater intensity of fishing develops, the marginal catch per unit of effort decreases. Marginal revenue can be understood as the change in revenue produced by a change in the number of a fish sold, while marginal cost, the change in total cost due to a change in the production of fish. Marginal catch per unit of effort, thus, is a change in catches due to a change in effort.

Concerned that *MSY* is only known when overfishing arises, demanding a correction process that involves economic waste, as already mentioned in item I.4, from an economic point of view, seeking maximum catches must be avoided. In establishing a maximum economic catch as the objective of any fishery, the result will be the maximisation of the economic yield, by the difference between catch values and operational costs, which tends to *zero*, when such a catch is surpassed (Paiva, 1986). *MSY* gives no consideration whatsoever to the cost of catching fish, thus, a high cost situation, the cost of maintaining the level of activity at *MSY* is much higher than the corresponding revenue. So, the importance to note that the economically optimal level of fishing is below the point that is suggested by biological models is pointed out by many economists. In other words, economic models establish a more conservative perspective and push for a reduction in the level of fishing activity to maintain a larger stock of fish.

Nevertheless, the use by economics of those biological models as a base for economic models has been very limited. In spite of having introduced in the analyses powerful mathematics instruments, it was not possible to reach satisfactory analytical solutions in the economic studies, especially of multi-species fisheries. The development, and consequent utilisation, by economics took place through the understanding that the increase of the fishing pressure on a given fish population induces an increase in catches up to a maximum that correspond to a level of the fishing effort (f) at the maximum sustainable yield (MSY). This level of f is the guarantee of the population stability and also the maximum catches in space and time, which means that any increase in f will correspond to a decrease in the population level and sustainable catches.

The living, or renewable natural resources, are those whose reproductive rate is considered economically significant, or sufficiently rapid to support economics decisions, and the conditions on which the exploitation of such resources occurs depends also on institutional circumstances, and specially on the many forms of properties that they are historically exploited and that define the human activity on them. There is, even today, many cases in which the situation of property rights are not well defined, deriving from the typically competitive or under a monopolist character, common property, free access, etc., which implies different conducts of the economic agents and different solutions for the emerging problems (Surís and Varela, 1995).

According to these authors, for the scope of economics analyses of the fisheries resources, the required biological information should be resumed as:

- The intrinsic per capita growth rates (maximum);
- Offspring renewal period;
- Number of survivals per unit of parental stock that reach next progeny;
- Maximum capacity of allowed (possible) population in a determinate space;
- Data on accessible nutrients and the corresponding environmental factors; and
- Knowledge on population movement, if in stratum of the same progeny or if it form inter-progeny groups.

For the review of the economic theories also there are some basic books and papers, not as vast as if we compare with those of population dynamics studies, that are useful for a more appropriate understanding of the economics of the fisheries. The orthodoxy application of economic analysis on fisheries resources started with the static models developed by Gordon (1953 and 1954), Scott (1955a and 1955b) and Schaefer (1954a, 1954b, 1957 and 1959). After those original works, the economic discussion centred on the static and dynamic characteristics in theoretical bases. The former introduced the classic microeconomic analysis and incorporated essential questions as the property and decision regime for natural resource exploitation. The later incorporated, besides the aspects before mentioned, a temporal factor in the basic structure of the models, which allowed studies on the dynamic adjustment of fisheries biological and economic variables.

Static economic models (that relates *f* with input capital and work force, and where the total costs and the production value are functions of *f*) and dynamic economic models (which assumes that fish price – unit cost of *f* – and the discount social rate are independent of time), were mainly based on the Gordon-Schaeffer model. Seijo *et al* (1998) explain that the Gordon-Schaeffer model is based on the logistic equation of Verhulst[12], described in the previous item.

When the temporal factor was incorporated in the basic structure of economic models it was possible to study the dynamic adjustments of the fisheries biological and economic variables. As reproduction and growth of commercial fish species do not happen instantaneously, it is evident that from the biological point of view may last years to return to previous biomass equilibrium or to achieve a new one. It also sounds clear that from the economic point of view the monetary fluxes have a temporal component that may be translated by brought values up-to-date through a discount rate (Surís and Varela, 1995), i.e. through catch and effort limitation, population size must be controlled and net income shall be maximised. Additional detailed information on the complexity of such models can be found in Crutchfield and Zellner (1962), Plourde (1970 and 1971), Quirk and Smith (1970), Royce (1972), Anderson (1977), and Naredo (1993). One of the basic assumptions is that through such models a product of the marginal investment on the resource or the intrinsic rate of interest of the resource shall indicate that society must invest in the natural resource till the intrinsic rate of interest equals the discount social rate. The discount rate is a market-orientated view of people living today.

As reinforced by Anderson (1977), the essential difference between static and dynamic economic analysis, is the treatment of time. Static analysis considers revenue in all periods to be the same, and therefore the proper goal is to maximise revenue in each period. The more complete dynamic analysis gives different weights to revenues in each period according to the discount rate, and the proper goal is a maximisation of the present value of the net revenues for the life of the fishery. But it is not the maximisation of the net revenue *per se* that is the goal of proper management; rather, it is the efficient use of all of an economy's resources. In the static analysis, effort should be expanded until the last unit yields a catch equal in value to the opportunity cost of producing it. In a dynamic sense, yearly effort should be expanded until the last unit adds the same amount to the present value of the stream of future revenue, which includes a once-and-for-all raise as the stock is reduced, as it does to the present value of the stream of future costs.

In a more simplified form: increases in effort will both increase cost and decrease sustainable catch, because each additional unit of effort catches progressively fewer fish, and so, as catch expands, each extra unit of fish caught will require more effort than the previous one, which means that the average cost of fish will increase as the catches gets larger. Although it is useful to keep a firm understanding of the meaning and interpretation of static and dynamic economic models, a more comprehensive discussion is beyond the scope of this chapter, as already stressed, because the utmost perception is that both entail essentially the same principle, that of the proper use of fishing resources.

Natural resources, as a whole, have been and continue to be exploited under different institutional conditions, and particularly under different property regulation systems. Property may be defined as a set of rights and duties exerted on the natural resources during a period of time (Scott[18] *apud* Surís and Varela, 1995), which implies a social relationship where there is *accepted* and *excluded* in the decision making process for the resource management, utilisation and enjoyment.

Thus, economic structure fishery system may be defined by the institutional property characteristic on which fishing resource are allocated, because, according to Seijo *et al.* (1998), to have an optimal allocation of natural resources in a specific economy, non-attenuated property rights need to be specified. Marruh Filho (2001) searched for the concepts of fishing resource properties and resumed that from the theoretical point of view there are five categories of:

- *Common property*. There is neither proprietors nor property rights. Access to the resource is not regulated, being open and free for individual or collective groups. Such resources are considered as *free access*. Clark (1990) mentioned that competitive users of a common property resource fail to take into account the costs that their use may impose on other users, and such externalities do often lead to overexploitation and other undesirable outcomes. In this category, however, the situation of free access to the resources and the common property are differentiate by Stevenson[19] (*apud* Surís and Varela, 1995), as;
  - ✓ *Free access*. Or open access, the resources are not shared, and there are rivalries on their exploitation. A high rate of use may drive stock to extinction by reproduction inefficiency. Property or possession is obtained through

[18] Scott, A. (ed.) (1986) *Progress in Natural Resource Economics*. Oxford, Oxford University Press.

catches, which means that symmetric externalities arise, when each user affects and is affected by the others, as well as asymmetric externalities, when an agent decision affects the others but it is not affected by the others. Hundloe (2000) explains that externality is an economic cost or benefit that is not – does not have to be – paid by a producer or consumer, falling on someone else, being pervasive in modern economies. Clark (1990) stressed that from the theoretical viewpoint open-access exploitation can be treated as the limiting case of privately optimal management in which the rate of discount becomes infinitely large, but it must be clear that in a real world high interest rates are admittedly deleterious to conservation, but a zero interest rate, or some rate close to it that should benefit natural renewable resources, is a practical impossibility. In an unrestricted access base, fishing effort will expand uncontrollably, and the individual fisherman acting alone has no incentive to invest in or conserve the resource. The importance is to emphasise that undesirable results of an open access fishery arise not because of the naivety or irrationality of individual operators, but because of a market failure; and

- ✓ *Common users.* Resource may well be delimited by physical, biological and social parameters. Well defined users or group of users, by their own or in conjunction with an institutional body, define rights and duties, that may be implicit or explicit, as previously accorded. Negative externalities may occur, because there is competition for the resource. Seijo *et al.* (1998) explain that externalities are defined as every external effect cause by individual fishers but not included in their accounting system, and it have been associated with the *stock* (reduction of stock availability and hence the harvest cost of others caused by increasing effort), *crowding* (aggregation of effort in a specific fishing ground with the consequently increase of marginal catch costs), and *technological* (when a fishing gear changes the population structure through sequential externalities – competition among fleets – or incidental – interdependent fisheries). Ecological and techno-ecological externalities are

[19] Stevenson, G. (1991) *Common Property Economics: a general theory and land use applications*. Cambridge, Cambridge University Press.

nowadays receiving increasing attention, due to interactions between species, e.g. a predator-prey interdependency.

- *Private property*. Property rights pertain to individuals or collective groups that have exclusive rights on the resource use. As private resources are administrated by their owners that also has the right to keep for themselves or commercialise, the whole or a part, the resource itself as well as their fishing effort, with which it appropriates of such resources. Thus, the exclusivity and transferable condition, private real estate characteristics, are configured and belonging to the State to secure the private property rights;
- *Communal property*. Resources belong to a community or users that maintain a high level of interdependency among them. Resources are administrated collectively, and the rights of use are prohibited to outsiders. Inside the community does not exist exclusivity or transferable conditions, with the rights of use and access equal for the community members. Communal property rights may be secured and recognised by the State or simply exist in fact, due to traditions and ancestors rights. In general, the proprietor community associated with the State establishes, in greater or minor degree, the rules of resource use;
- *State property*. It is characterised by a decision power body on the level and nature of resource exploitation. The State, as the resource owner, may exploit it directly or allocate use of rights for its citizens and enterprises; and
- *Global or international property*. Resources that occur beyond the Economic Exclusive Zones (EEZ) are considered of common property or use by nations, prevailing, in principle, the free access system. Nevertheless, for resources of high economic and environmental importance, conventions, agreements or international treaties regulate the main exploitation approaches, trying to avoid the free access and the negative implications on stock health and the economic enterprise profitability.

From the economic point of view, such definition detached into a set of significant characteristics, according to Surís and Varela (1995), such as:

- *Exclusivity level*. Who may or may not own and use the same space, and which aspect exclusion is affected;
- *Capacity level*. How much and when to exploit to enforce the exclusive rights of use;

- *Transferable rights*. That must include the divisibility; and
- *Determined temporal and geographically*. Durability of rights and definition of the location and limit of the affected area.

Considering the importance on the fishing resource property rights, it can be defined and referred to as an entire range of rules, regulations, customs and laws that define rights over appropriation, use and transfer of goods and services. Kula (1992) emphasised that the establishment of property rights on resources is crucial for their rational and efficient utilisation, because on a situation of free access a “first come first served principle” will prevail. If all resources were owned by private or public bodies and property rights were fully enforceable in courts of law, then everybody would think twice before engaging in a “use as you please” principle, that would create a gross inefficiency and waste.

Aiming the sustainable development of a renewable natural resource and human welfare, there is a fundamental economic practice that can work against equity. According to Hundloe (2000) it is a matter of discounting. Discounting, more precisely the discount rate, is probably the most controversial – and unresolved – issue in economics, after the matter of distribution. Sustainable development does not discount the future. As general statement, ecologists would say that to achieve this outcome (generation after generation), there is a need to maintain the world’s natural capital, because it is humanity’s life-support system. However, there are some economists (probably a majority at present) who believe that, as a consequence of technological change, humans can continually substitute human-made capital (machines, etc) for natural capital. This is the ‘weak sustainability’ position. The ‘strong sustainability’ rule of limited substitutability is the preferred by ecologists. Under the weak sustainability rule, there is nothing wrong with a positive discount rate, even a high one – in fact, one high enough that a fish stock could be mined – as long as there is another more profitable investment available.

For fisheries management, however, this means such things are already done: use biological data and analysis to set management measures. Having set these limits, the maximum economic yield (*MEY*) can be accepted as a relatively safe level of effort as long as the discount rate is not so high that *MEY*>*MSY*. A *MEY* of a fishery can be more properly thought of as the optimal stream of yields over time. This stream can consist of a constant amount year after year, or yearly catch may vary widely, and this optimal stream can change over time with changing expectations as to cost, price, and rate of growth of the stock. Theoretically it can be said that, for any given level of activity, the more fish there are in the fishery, the more will be harvested. So, for any given level of stock, a larger harvest results. For any given fishery must be understood that it is only a small part of the fish market and level of catches that would not significantly affect the price of fish in the market. The cost is an inverse function of the biomass level.

Anderson (1977) stressed that revenues measure what people are willing to pay for the fish, and costs represent the value of the next best use of the inputs necessary to produce the effort use to catch the fish. Therefore, when marginal cost of effort is greater than marginal revenue, society is losing, since the additional fish are being taken at a cost greater than their value to consumers. Since returns represent the value the fish provided to society and costs measure the value of foregone alternatives, the widest spread between these two implies a proper allocation of inputs. In formal terms effort should be increased as long as the increase in current revenue compensates for the reduction in the present value of future revenues. When the net value of the last decrease in current catch is equal to the increase in the present value of future net revenues, a dynamic *MEY* will be obtained.

Overexploitation risk depends on the relations between the yield and costs functions. The cost function is directly dependent on the technologic progress, while the yield function on the market or the demand for fish products. The greater the technological progress and the demand for fish, the greater the risk of overexploitation. But such economic availability isn't the only factor that operates conducting to overexploitation of a natural resource, because economic and biological factors are directly related. The most susceptible species to overexploitation are those that belong to highly mature ecosystems, to high trophic levels and those sedentaries, as the bentonic ones, while the contrary is true for species less vulnerable to overexploitation, like the pelagics one. As the economic situation of a country has a direct influence on the evolution of a fishery, the economic administration has two choices: (1) a biological regulation; and (2) the technological progress.

Having these definitions clear in mind, some relatively solid overview from the economics theories related to the fishery system, thus, can be drawn, based on (Franquesa, 1997):

- *A resource that reproduces at a biological rate below the capital growth rate (interest) will tend to be exploited until its depletion.* Fortunately few fishery resources have these characteristics (whales, coral, elasmobranchs, etc.), but where this situation does arise, if man has developed technologies, if there is no regulation, then society will tend to deplete it. There are no economic mechanisms to stop the process and only political decision can avoid it. If a resource grows in the environment more slowly than it would in a bank transformed into capital (once caught and sold), it is of no economic sense to let it grow, since it is more profitable to deplete it completely and convert it into money. In this case it "grows" quicker in the bank than if it were a living resource. Evidently this conditioning factor shows how poorly economics resolves problems by itself: in this case, the monetary benefit is clearly separated from what would be a social optimum. As emphasised by Clark (1990), renewable natural resources that are incapable of replenishing themselves at sufficiently high rates, economically rational owners will tend to overexploit these resources;

- *Economic interest determines a social optimum below the potential biomass reproduction maximum (biological optimum).* For most living resources the biological rate of interest is far higher than the capital growth rate, therefore there is a trajectory of optimum use of a resource that permits its reproduction. In this sense the economic conditions behave parallel to the laws of nature that generate systems that do not normally work at 100% of their potential. The optimum relationship between fishing effort and yield obtained can be found at the point where the difference between revenue and cost is greatest. However, in order to reach this equilibrium it is necessary for access to be regulated; and
- *In the exploitation of fishing resources, the problem is normally presented as excessive use: overfishing.* In spite of the *MEY* being at a point where the fishing effort is catching less than could be caught sustainably, the competition between fishermen encourages them to exploit the resource beyond its economic and biological possibilities. The pressure towards overfishing is observed in all technologically developed fisheries: if the fishing equipment makes overfishing technically possible, this will happen. Thus, in the fisheries there is a high probability of the equilibrium point reaching the result of a free access regime, which implies always restrictions, but these are much smaller than the incentive to enter into an exploitation that generates extraordinary profits.

Finally, Anderson (1977) helped on the understanding of the development reached by the study of the fisheries resources from the biological and economic sciences, and their interrelationships, although emphasising the importance of economic analysis on a fishery system. This author stressed that economic analysis as a tool should be used to the fullest extend possible in any given circumstances. If other tools of fishery regulation such as biological and political analysis are unworkable, and if economic, biological and political data are incomplete, then economic analysis cannot be expected to yield its fullest result. But it still can, and should be, put to the best use possible in the structuring of fishery policy.

I.6 - STATE-OF-THE-ART OF BIOECONOMIC FISHERIES MODELS

Fish population size and abundance are traditionally correlated with the economics of the fishery, and the benchmark of such correlation analysis is named bioeconomics. Economic analysis of the exploitation of natural resources applied to the fisheries, highlighted on item I.5, is a relatively recent branch of economics, but it holds true that, until this moment, the multidisciplinary approach between biology and economic has not received much attention and has been constituted as a speciality with a recognised methodology.

Bioeconomic models appeared during the 50's, attempting to relate the reproduction of a renewable resource with its exploitation for economic purposes, trying to explain, on a simpler level, the relationship between *reproduction rate* of a living resource, and *fishing effort* as a cost and their relationship with *catches* expressed as revenue through sale of the resource. The use by bioeconomic models of such scheme, eventual consequences on the processes of fisheries exploitation when given regulations are implemented may arise. Even though the impact of regulation measures most frequently used in fisheries shall be modified, paradoxical situations will still arise, wherein the measures apparently aiming to increase profits for the sector may in fact reduce the revenue obtained (Franquesa, 1997).

The initial estimates of bioeconomics were based on some models that were later further developed and made more sophisticated, sometimes too formally to be used operatively. Bioeconomic models developed from the basic studies conducted especially by Gordon (1954) and Schaefer (1954a), where detailed information is available, denoted Gordon-Schaefer Model, which considers the marginal and average production and the effort levels employed. Otherwise, other important mechanisms that helped in the development of bioeconomic models were the perception of the utmost importance of the monitoring and the studies of fleet dynamics also known as Smith Model (Smith, 1969), which considers that the durability of a fishery would be proportional to the incomes obtained; the yield-mortality model, which intends to generate a biological production model; and the dynamic age-structure model, which considers the factors that affect the biomass with time, such as growth, recruitment and mortality, in a population distributed homogeneously in time and space. The behaviour of the Gordon-Schaefer Model simulates how *total revenue* is balanced with *total cost* in an exploitation of a renewable natural resource. Cost and revenue functions are measured in a homogeneous dimension: money. This allows to hypothesise about how they will inter-relate.

Although the first consideration on bioeconomic dated early as the 1950s, as point out by Franquesa (1997), bioeconomic management models in fisheries have been developed since at least the early 1970s. Bioeconomic models designed for management purposes include, in addition to the usual biological and economic variables such as, species, stocks, fishing fleets, geographic distribution of the fleets, the degree of industrial integration and so on, certain management instruments or tools. Apart from these general features each model is designed with regard to the specific biological and economic situation and the available instruments.

Quirk and Smith (1970) mentioned that bioeconomic models for fisheries analysis must deal with the stock-flow dynamics, externality in production, the relation between man and his natural environment, social control of regulation, public investment, and the economic significance of property rights. A bioeconomic model may be generally described as follow:

$$maxVA\prod = \int_{t=1}^{n} \left[p(Y) - c(Y) \right] Ye^{-it}\, dt$$

$$Y = f(E, S)$$

$$\frac{dE}{dt} = f(\bullet)$$

$$\frac{dS}{dt} = f(\bullet)$$

where *Y*, *E* and *S* are respectively the amount of catch, the level of effort and the dimension of the stock, and the parameters *p*, *c* and *i* are, respectively, the price of landing, the cost of effort and the social discount rate.

For Clark (1990) the “discounting” effect associated with capital opportunity costs always has the effect of pushing the optimal population level below the MSY level, whereas cost-efficiency considerations have the opposite effect. When both effects are considered, the profit-maximising optimum may turn out to be on either side of MSY, depending on the relative strengths of the two effects. It is interesting to observe, however, that the clash between these two effects does not ordinarily lead to some form of oscillatory harvesting in which one effect and then the other dominates. Although some harvest policies are sometimes employed, the author maintains that this phenomenon arises from a different bioeconomic cause associated with efficiencies of scale in the harvesting process.

Nowadays there are some bioeconomic models whose frameworks consider the complexity of the fishery, or fisheries, and the diversity of stocks, fleets and fishing activities, which allow examining the technical, biological and economic interactions, whatever is the level of knowledge and data collection system. The description of a number of them can be found in Laloë and Samba (1991), Laurec *et al.* (1991), Eide and Flateen (1992), and Placenti *et al.* (1992), for particular case studies, and Grant *et al.* (1981), Sparre and Willmann (1993), and Ulrich *et al.* (1999), for more generic and large range fishing studies.

For the Mediterranean bioeconomic fisheries models, development were mainly designed by the Gabinete de Economía del Mar from the University of Barcelona - Spain (GEM-UB) since 1994 within the framework of the EU Directorate General XIV funded project *Quantitative Analysis of the relationships which condition the North Occidental Mediterranean Fishing System*, acronym HEURES, an instrument for fishing management based on effort control to evaluate management strategies and to analyse the feasibility of implementing an adaptive management (Franquesa, 1994; Franquesa, 1996; Lleonart *et al.*, 1996). It's a clear ancestor of models like MECON and MEFISTO, which improved the outcome of the Heures model, especially MEFISTO, with participation of other research institutions, mainly the Institut de Ciències del Mar (ICM), from the Consejo Superior de Investigación Científica (CSIC) - Spain.

MECON is a simple bioeconomic fisheries global model. Its main purpose is to illustrate the dynamics of a fish stock subject to fishing by an economic agent. The fishing fleet has certain economic and technical characteristics (capital, fishing power, effort, etc.) which inflict a fishing mortality (F) to the fish stock. The fishing process results in catches that are then sold and transformed in revenues. A fraction of these revenues will directly be used to increase or diminish the capital or the effort of the fleet. The fishing mortality is dynamically changed at each time step, by virtue of the relationship of F with q (catchability) and E (Effort). Catchability can be held constant or made function of the capital and/or time. MECON can be used to study the changes produced in the fishing system by technical or economic measures imposed by the user, either as start-up conditions or at given periods of the simulation horizon (events) (Franquesa and Lleonart, 2001).

MEFISTO is a quite more powerful bioeconomic model, and the biological functions follow an analytical model. The first objective of the model is to reproduce the bioeconomic conditions in which the fisheries occur. The model is, perforce, multi-species and multi-gear. The main management procedure is effort limitation. The model also incorporates the usual fishermen strategy of increasing efficiency, in order to increase fishing mortality, while maintaining the nominal effort. This is modelled by means of a function relating the efficiency (or technological progress) with the capital invested in the fishery, and time. A second objective is to simulate alternative management strategies. The model allows operating with technical and economic management measures and in the presence of different kind of events. The final users of the product are three: the scientist, the decision-maker, and the fisherman. The model should contribute to increased comprehension of the usefulness or uselessness of certain management measures, and establish the difference between short and mid term regarding earnings and losses (Franquesa and Lleonart, 2001).

Another quite interesting model developed for the Mediterranean Sea is MOSES, designed by the Insituto Ricerche Economiche per la Pesca e l'Acquacoltura – IREPA, under the scope of the Italian fishery structure, based on biological, economic and technical approaches (IREPA, 2002). It is specifically built to consider aspects in the Italian fishery context, in order to represent a management instrument to be employed by public administration. It is a catch-effort model for multi-species and multi-gear fisheries, developed using time series of data of catch and fishing effort. It can be used both for simulation and optimisation analyses. In the former case, the model offers a description of catch and effort data through the estimation of parameters for biological and logistic models. In the latter case, it provides the optimal distribution of fishing effort over areas and gears according to different scenarios (each combining economic objectives and biological and inertia constraints).

A recent effort for the development of bioeconomics models, based on a specific fishery, is the one conducted for the Nor-western Mediterranean Region. These models are based on peculiarities and distinct realities, but rationally it should consist of an adoption of measures to modelling and to use them as an important tool for bioeconomic analyses of small-scale coastal fishing. According to Lleonart *et al.* (1999a), the purpose of these tools is to facilitate analysis of the consequences and risks of different management measures applied to particular stocks, as already mentioned. The highlighted concepts permitted to deepen effort for the adoption of bioeconomic theories through the scopes established under the Project BEMMFISH[5], which defined as a priority of such studies as follows:

- Development of an appropriate theoretical background appropriate for the application of biologic, economic and bioeconomic fisheries models, through actions such as;
  - ✓ Review the current management practices applied and to examine the state-of-the-art of the biologic, economic and bioeconomic models relevant to local realities;
  - ✓ Verify the possibility to characterise a conceptual fishery model, integrating the actual qualitative relationships among different actors involved in the activity, including the biologic stock, the fishing structures, fleets and gears, market, fishermen and the technological progress, and the time scale at which each of those elements act; and
  - ✓ To indicate parameters for future actions aiming the building of a numerical and quantitative model.
- Elaboration of simulation tools allowing the potential end users (fishers, scientists and managers) to simulate the effects of different management measures.
- Development of user-friendly computer software to input the facts of particular fisheries and for simulations purposes.

Bioeconomic models are composed of two or more modules, the most important being the biological and the economic ones. These two components are linked together by equations through the inputs of value parameters. In the case of inputs, fishing effort measures the human pressure applied to a determined resource. Each effort level corresponds to a cost level. Considering outputs, each catch level corresponds to a specific value. This correspondence between biological (biomass) and economical (revenue) sides is linked by prices. Of course their characteristics and design depend on the biological and economic structure of the fishery where they have to be developed, but it is possible to take into account some useful ideas of these models and adapt them to a specific region and fishery where a bioeconomic analysis is to be applied. Among the biological contributions to the bioeconomic models, recognised works shall be deserved to Fox (1970), Pella and Tomlinson (1969), and Schnute (1977). Contributions from the economic point of view may be deserved to Crutchfield and Zellner (1962), Smith (1969) and Clark (1976 and 1990).

As it holds true for economic models, static and dynamic bioeconomic models are to date considered a theoretical tool for the establishment of management measures for the sustainable use of fishing stocks, in virtue of the existing peculiarities of the fishing activity. These models are based on peculiarities and distinct realities, but rationally it should consist of an adoption of measures to modelling and to use them as an important tool for bioeconomic analyses of diverse fisheries. The purpose of these tools is to facilitate analysis of the consequences and risks of different management measures applied to particular stocks. Based on these concepts and others quoted by Lleonart *et al.* (1999a), modelling management strategies consists of using a stock simulator (operating model) and a simulator of the assessment process, both provided with different errors sources. Concerning the methodologies implemented, the models can be classified into simulation models and optimisation models. As mentioned above, the first ones can simulate the effects that may be caused by the public management choices, while the second ones are implemented to find the optimal solutions. There are also some models that include both simulation and optimisation methodologies.

Using this procedure, the whole process of stock dynamics, fishing activity, fishery assessment and fishery management as an adaptive process can be simulated, i.e. the possibility to define an optimum management system for a specific fishery. However the establishment of a conceptual framework is not an easy task and sounds reasonable to reinforce the argument raised in item I.5 that an optimum management system does not exist in the context of real fishery exploitations, that is, a system that maximises the objectives pursued through regulation at a minimum cost for all. Conversely, what sounds reasonable is to define an optimum management system for each fishery model.

Bioeconomic management models are really a subset of bioeconomic models in general. This means that there are bioeconomic models that are not management models, i.e. they do not contain a management module. Bioeconomic simulation models are clearly a subset of bioeconomic management models. Not all bioeconomic management models can simulate the effect of management measures, but bioeconomic optimisation models are a subset of bioeconomic simulation models. Not all bioeconomic simulation models contain a maximisation module while bioeconomic optimisation models must contain a simulation module as already pointed out.

For Haraldsson and Arnason (2002), with regard to basic methodological approach, bioeconomic management models can broadly be classified into simulation models and optimisation models. The first class of models merely simulates the effects that may be caused by certain application of management tools. The second attempts to find optimal solutions in the sense of locating the maximum of an objective function. Thus, basically, the optimisation models are more comprehensive than simulation models. They include everything in simulation models but add an objective function and a maximisation algorithm. Some models are designed to perform either simulations or optimisation depending on the choice of the user. Such models are essentially optimisation models with the optimisation part turned off when they are used for simulation only.

As was already emphasised, bioeconomic model is a powerful management tool related with the biological and the economic characteristics such as, species, fishing fleet, the geographic distribution of the fleet, industrial integration degree, and others. Furthermore the models are developed regarding the management targets and tools that want to be used. Bioeconomic model can also be classified in theoretical, empirical and numerical. Theoretical models consist in a set of equations that describe the biological and the economics interactions. This kind of model can be used to analyse the sign of the effect of some management tool. Empirical models are characterised by a quantification of the relationship among variables. Finally numerical models concerns simulation algorithms (Coppola and Placenti, 2002).

New trends in fisheries sciences focused on integrating various intrinsic relationships within and between the different components of the fisheries, i.e. the resources and the fishers, whose relationships should be biological, economic or social (Ulrich *et al.*, 2002). These authors mentioned that according to Mesnil and Shepherd (1990) interactions may be of two types: the inter- and intra-specific biological interactions, such as predator-prey and competition relationships; and the technical, or technological, interactions. For the main technical interactions Ulrich *et al.* mentioned Rijnsdorp *et al.* (2000), for whom there are ground interactions, where the presence of one fishing unit displaces or interfere with another fishing unit's operation. The other is resource interactions, where different fishing units are exploiting the same stock, in which situation individual revenues are linked. Interactions occur both actively, when the level of the mean revenue of all other fleets is strongly dependent on the level of effort of one specific fleet, and passively, when the level of revenue of one specific fleet also depends on the mean level of effort of all other fleets.

All these aspects allow the estimation of the positive or negative impacts of any management policy applied to one given part of the fishery on other related species and fleets, both in terms of catches and revenues. These interactions, however, are sometimes poorly understood, especially in some small-scale fisheries, where qualitative informations are available, but lacked quantitative data to accurately analyse interactions among species and fishing activities involved in the whole fishery, because they all rely on a preliminary precise description and delineation of fishing activities.

Another important element which must be considered is that bioeconomic models suppose that, whether profit exists or not, there is an automatic adaptation (the following day) of the effort. Reality also indicates that it is much easier to enter than to leave and that overcapitalisation induces depreciation not to be evaluated as a cost. Therefore, in practice, the equilibrium effort will be greater that could be supposed when simply comparing total cost with total revenue, since very often the costs are underestimated. Anderson (1977) explain that although many different combinations of effort and population size could lead to a bioeconomic equilibrium, when a simple dynamic analysis is conducted, it is of course entirely possible that the biological and the economic systems may never reach a simultaneous equilibrium, and that it can be a long and painful process and that resources devoted to a fishery in the meantime may earn less than a normal return.

The total cost of a fishing operation can be understood as the relation between resource availability and fishing effort: as the resource population density goes down, the effort needed to capture it goes up. In a simplest way the cost of effort is proportional to the fishing effort: the more effort used, the higher the cost and a particularity is that one unit of effort (a man, a boat, a fishing day, a horsepower of steam, etc.) has a given implicit price in order to determine the total cost. This cost would be the product of this price multiplied by the quantity of effort. In reality this relationship may be more complex: the cost per unit of effort may go down if the capture capacity goes up (if there are economies of scale); however, just for the sake of the criteria followed since the beginning of this chapter, aiming not to deepen on one specific aspect of biological, economic and even bioeconomic theories, the simplest form may be kept, that cost is *proportional* to effort, because well satisfy the needed understanding of the bioeconomic tools for fisheries management. For details other than the already mentioned recommended books and papers are: Anderson (1977), Hannesson (1993), Naredo (1993), Seijo *et al* (1998), among others.

This section overview dealt with a state-of-the-art of bioeconomic management models and thus left for the previous sections several interesting aspects on the ecological, biological and economic aspects of the fishery, or fisheries, and it should be noted from the outset that this overview, and the previous one, is not intended to provide a broad description of the models and corresponding theories. Its aim is merely to provide quite elementary comments on the most relevant aspects of bioeconomic modelling, the cornerstone hypothesis that made possible their development and construction and a short account of the nature and content of the most relevant aspects for the proposed bioeconomic study. That is why a wide bibliography was supported aiming to contribute for the development of a bioeconomic science branch.

As emphasised by Leonart *et al.* (1999c), the exploitation of natural resources will not allow an indefinite growth. These growth limits in the exploitation of resources appear to be in contradiction with what some economists recommend, which is precisely growth. The sustainability of fishing resources is then an economic and not biological problem. Biologically, a sustainable exploitation is a goal which can be assumed, the problem is if it is economically acceptable to plan a growth level of zero in fish production. Recent history has shown that it has not been possible to obtain sustainable fisheries. The causes can be attributed to the limitations and uncertainty of the evaluation techniques and to the economic pressure on the world fishing.

Although it is extremely unlikely that in any particular case an maximum sustainable yield (*MSY*) harvest policy should prove to be optimal in an economic sense, because management policies based solely upon the achievement of *MSY* will almost inevitably lead to severe difficulties arising from the economic irrelevance of the concept, from an economic perspective three relevant stages on the bioeconomic study of a fishery may be considered. This lead to suppose that the exploitation will tend to be situated on two of them, according to the surrounding conditions, based on Franquesa (1997). An initial stage indicates the *maximum sustainable biological yield (MSY)*. It is on the vertex of the revenue function and represents the level of exploitation that generates a greater physical volume of captures and greater revenue, but does not represent maximum profit. The economic objective is not to increase revenue, but profit, which indicates the maximum difference between income and costs. As stressed by Anderson (1977), the goal of management should be to maximise profits and consumer surplus, and not just to maximise profit only.

The next stage represents *maximum profit*, and indicates higher cost and income differences. This maximises the distance between total revenue and total cost, between the money that we deposit and the money that we spend; therefore the profit is maximised. Any business wishing to maximise its profits will move towards this stage if it can prevent another from increasing the effort, and is also called *maximum economic yield (MEY)*, the condition that access to exploitation is regulated or property rights allocated must be fulfilled.

Finally, it can be stressed that fisheries scientists are cursed by the uncertainties that swathe their work. At best their models of dynamics of fish populations produce imprecise estimates of the maximum catches that can be taken without driving a stock to extinction. Factors such as varying climate can exert dramatic influence on fish population dynamics, obscuring the effects of fishing pressure (Schiermeier, 2002), because the links between fishing pressure, environmental changes and fish behaviour are not sufficiently understood.

CHAPTER II - CHARACTERISATION OF THE COASTAL FISHERY

II.1 – INTRODUCTION

The world-wide food production, in general way, has not followed population growth, especially in developing countries. This is also the context in which the world-wide and Brazilian fishing productions is inserted in. For instance, a decrease in the growth rates of the fishing production is observed in the last three decades, accentuated since the 80's, when it became clear the overexploitation, or even depletion, of 69% of commercial fish stocks, according to FAO (FAO, 2000). It is interesting to point out that the great producing fishing areas correspond to approximately 3% of the total area of the seas and oceans of the world, which answer for about 90% of the total world fishing production, what could explain fishing resources exhaustion.

World fisheries catches greatly increased since 1950, when FAO began reporting global figures. The reported catch increases were greatest in the 60's, when the traditional fishing grounds of the North Atlantic and North Pacific became fully exploited, and new fisheries opened at lower latitudes and in the Southern Hemisphere. But recent studies show that catches of world fisheries are in general decline. The present trends of overfishing and wide scale disruption of coastal habitat seems to threaten food security (Watson and Pauly, 2001).

As well explained by Gulland (1971), this sudden end to the period of expansion may be due to the fact that until the catch approaches the potential yield of the resource, the stock and hence the catch per unit effort, is not much reduced by the fishery. Also, any slight reduction in stock may be more than balanced by improved techniques and more experience of the fishery, e.g. knowledge of the best grounds and seasons. The maintenance of high levels of catch and effort is directly related to high levels of catch per unit effort and demand, which induces investment. Considering the apparent inexhaustibility of fisheries resources, with means that catches will increase to a high proportion of the stock and so reduce appreciably the stock, and the catch per unit of effort, the incentive to increase effort will subsequently decrease, because increasing effort probably would not increase total catch.

II.2 – CONCEPTUALISATION OF THE BRAZILIAN ARTISANAL FISHERY

In spite of the apparent Brazilian good environmental conditions always stressed, that leads to the belief of the potential expansion of the fishing sector, due to the privileged littoral extension (approximately 8,000 km), the existing river basins and estuarine areas whose magnitude contribute to enrich the continental shelf and the territorial sea, and its Economic Exclusive Zone - EEZ of two hundred nautical miles, the Brazilian fishing production seems relatively stabilised, and does not significantly participate in the world fishing production and is still markedly artisanal even if we consider governmental effort and incentives to develop the industrial sub-sector. Those seemingly unplanned actions do not succeed due to the social and cultural characteristics of the fishing communities along Brazilian coast, more expressively represented in the Brazilian North and Northeast Regions, with high dependency on social and economic neighbourhood relationships.

The fishery sector in Brazil faces a sustainability crisis, showing decreasing productivity and also decreasing rates of increment in total production, as a consequence of the unskilfully planned expansion process undertaken, which led to an over-dimension of fleets and processing plants, as well as overfishing. Moreover, inadequate utilisation and occupation of coastal areas affected negatively these aquatic ecosystems, reducing the expected capacity of the fishing activity to create food, employment and income, and of course the fishery sector either at the Northeast Region of Brazil or Pernambuco State follows this same panorama. As expressed by Perrings (2000) the change in land use in many coastal areas has already caused the collapse of habitats and ecological services that affect marine capture fisheries, but considering that the linkages between terrestrial activities and the state of marine coastal system are complex, such relationship will not be deepen in the present context and characterisation.

Assessment of fish stocks and implementation of management measures was always difficult due to lack of knowledge on the existing fishing stocks potentialities, and unreliable fishery statistics. In the Northeast Region of Brazil, situated ca. from 2ºS-40ºW to 13ºS-36ºW, from Maranhão to Bahia States, with narrower shelves and predominance of rocky bottom, and the productivity is low, which favoured the establishment of small-scale and artisanal fisheries. The inshore banks are considered as being heavily over-fished and the offshore banks are increasingly exploited. Estimates of potential were always extremely rough, and subject to a wide range of possible error.

In accordance with Timm (1978) the PESCART[20], in virtue of the legal undefined policies that seemingly assaulted the artisanal fishery when the elaboration of the Brazilian Code of Fishery (*Código de Pesca*), defined this activity as that one developed by isolated individuals or small crews, whose partnership relations of work prevail, constituting the substratum of the fishermen associations and fishing co-operatives. This was the first attempt to differentiate it from the industrial fishery, even recognising that this difference does not obey precise limits. The PESCART then concludes that artisanal fishery is an activity not composed by society capital, defined as artisanal fisherman, and, as a consequence, those that are not partners or employees of enterprises and fishing companies.

The PESCART started from the premise that the small-scale fishing form of production, the technological base, and the commercialisation system were primitive and cause of fishermen impoverishment. Thus, based on the principals of technical assistance and rural extension, meant fishermen modernisation, teaching them new production technologies, and boat modernisation; above all shifting from old sailing boats to new motorised ones. Hence, sought to organise fishermen on business co-operatives, which led to the rupture of their single way of life.

Although it is a general rule to define one specific economic activity for its conceptualisation, SUDEPE[21] (1988) also pointed out the difficulties of such a conceptualisation for the artisanal fishery and the involved producer, having as some criteria the use of the work forces and resources availability, in which participate many economic agents who created a context for a stratified dynamics of the productive unit, revealed in different places and times. It must be pointed out, however, that the artisanal fisherman forms a non-dissociated and essential part on this complex system of production and its efficiency depends on the dynamic and integrated way he operates in space and time, but submitted to a condition of extreme dependence on the exploitation of the commercial and enterprise-capitalist capital.

Buzeta (1987) defines the artisanal fishing community as a complex and closed social and cultural organisation that has defined geographic limits and interrelationships, not only in the productive scope, but also with an evident descriptive and cultural structure that has strong influence in the socio-economic process. SUDEPE (1988) defines the activity as the one

[20] Plano de Assistência à Pesca Artesanal (Plan of Assistance for the Artisanal Fishery)
[21] Superintendência do Desenvolvimento da Pesca (Superintendency for Fishery Development)

promoted by small producers (fishers), in which the social production relations characterises, mainly, by the participation of familiar workforce or neighbourhood groups.

More recently Marruh Filho (2001) defined that the artisanal fishery is characterised for using technologies with relative low level of environmental impact, being all the productive process presided over by a *savoir-fair* based on the traditional knowledge of the marine environment dynamics and their living creatures, comprising from the process of fish finding to the methods and techniques of capture appropriate for some species, at certain times of the year, and having the maritime environments of its communities as the maximum radius of action of its fishing operations. The use of machines is restricted to the propeller engine of the boat not having, instead for trawlers, considerable implications in the relation fishermen-exploited environment.

In a wider context, Freire and García-Allut (2000) stressed that the concept of artisanal fishery is rather ambiguous and variable in terms of the unit of analysis used, and, in their study in Galicia, North-western Spain, they employed five different types of definition to establish limits and scopes: (1) from a political and administrative standpoint, which develops ambiguous classification mainly as a consequence of the different powers that governments have on the management of the fisheries; (2) from an economic and social strategies used for the exploitation of ecosystems and stocks, characterised by familiar structure and system of profit sharing; (3) from a technological point of view, with the use of low and medium technological equipment, insofar as the operating chain is simple, consisting of gears handled by one or two peoples; (4) considering the pattern of the activity in respect to the species exploited, location of fishing grounds, and gears used, which is based in the flexibility; and (5) from a biological standpoint, characterised for the exploitation of coastal waters.

Artisanal fisheries have been for long subject of interest for social scientists and national planning agencies because it represents one of the last example of activity for sustenance based on the hunting of the wild resource (Diegues, 1983; Buzeta, 1987). Recently, this interest has increased because the importance of the artisanal fishery as fresh food supplies for human consumption and because of the overexploitation of coastal resources (Buzeta, 1987; Mattos, *et al.*, 2001b).

At present the concept of artisanal fisheries is not standardised, and various criteria are used to define it, including fishing tradition, vessel length, type of métier and socio-economic environment. Bozon (2000) recognises that these criteria tend in most cases to characterise what is not artisanal fisheries rather than what is. A consequence is that some métiers are classified as artisanal fisheries in some countries but not in others.

Artisanal use of the fishing resources may be described thus as the use referred to subsistence exploitation of near-shore, coastal ecosystems by human culture with relatively simple watercraft and extractive technologies that varied widely in magnitude and geographic extend. In this type of activity the word *fishing*, in the original and most general term in the English language, sounds appropriate because indicates the process of hunting and gathering all kinds of organisms in the oceans, including plants, invertebrates, and vertebrates.

II.3 – PERNAMBUCO STATE FISHERY SECTOR

Pernambuco State fishery sector is predominantly artisanal, which contributes with 97% of the total fishing production. The maintenance and strengthens of the artisanal fishery is due to two general causes: (1) the overexploitation of coastal ecosystems, on the one hand, decreased considerably the productivity and the individual income, making possible the exploitation of such areas only by means of subsistence or small-scale activities, pushing the semi-industrials and industrials activities to oceanic areas, which is dedicated, mainly, to satisfy the external market; and (2) on the other hand, the social, technological and economic characteristics of the artisanal fishery, surprisingly strong, contradicted diagnoses of a transitory and extinguishing activity, face to the necessity of *modernisation* and *rationalisation* of the fishing sector, showing to be economic viable, desirable on the social point of view and ecologically adequate.

The small-scale coastal fishery of Pernambuco, urgently needs the implementation of management measures that shall make possible the exploitation of fisheries resources at biological, economic and ecological sustainable basis. It catches a great diversity of species being important the conduction of studies to identify aspects related to biological aspects (reproduction, growth, etc), oceanographic parameters (biotic and abiotic factors), and fishery, aiming at adequately manage the activity. As a general condition for the fishery sector in Brazil, also in Pernambuco the apparent situation denotes an unsustainable activity. Seemingly, the fisheries resources off Pernambuco continental shelf are overexploited, and the sector is not able to improve fishing communities welfare conditions of employment and income, if compared with other primary economic sector of the Northeast Region of Brazil. Importations seem to supply approximately 90% of the State demand for fish products.

Unplanned development induced an accented production decline and economic stagnation leading, as a consequence, to political and institutional weakness, and a massive fishermen migration to other economic activities, may be an appropriate diagnose for the artisanal fishery sector in recent years. The major problem may be the fact that official reported data was mainly based on extrapolations, because of inefficiency of data collection system. Gulland (1971), discussing trends in world catches, pointed out that prediction by extrapolation cannot reasonably be expected to be more reliable in the long run than the prediction of catches from individual stocks, with the exception of the uncertainty in the later due to the diversion of fleets from one stock to another. He assumed that the later prediction is highly reliable, while the former is likely to be equally unreliable, at least in the long run. Inconsistencies arise from the fact that predictions – global or for a particular stock – are, in the short run, concerned with the two different sets of problems. The prediction by extrapolation will only hold true as long as there remain unexploited stocks which can be effectively harvested with existing technology.

Causes for such a stagnation may be diverse, amongst which can be remarked: a) poor life conditions and lacking of defined structure for the establishment of safety at work system of artisanal fishing communities; b) high illiteracy degree; c) low efficiency of the fishing techniques devices; d) very restrictive access to financial loans; e) deficient storage and commercialisation infrastructure; f) land use conflicts and economic speculation of coastal areas, with the consequent destruction of mangrove and estuarine areas, a process that favoured the dismantle of the fishing villages; and g) urban, agricultural and industrial pollution of coastal areas.

II.3.1 - THE COASTAL ZONE AND THE FISHING GROUNDS

The study area, the continental shelf off Pernambuco, as well as the continental shelf off North-eastern Brazil, where the State is located (Fig. 1), is relatively narrow where small-scale pelagic and demersal fisheries are constrained off a small band adjacent to the coast. The limits are the parallels 7º32’S e 8º49’S and the meridians 34º49’W e 35º11’W, through the coastline, and the same parallels and the meridians 33º58’W e 34º51’W at the continental slope. The continental shelf off Pernambuco has an area of 1,524 nm^2 (SUDENE, 1976), c.a.

20 nm width, and its coastal line has 187 km, which represents, approximately, 5.1% and 2.2% of the Northeast Region and Brazilian coast lines, respectively.

According to GERCO[22] (PNMA[23], 1995), the littoral zone has an area of 4,410 km^2 and, in some regions, it presents height below sea level. This littoral zone presents many productive ecosystems, considered the "green region", enclosing segments of coconuts trees plains, estuaries with large mangrove areas, coral reefs, algae beds, islands, and sandbanks. This diversity reflects the absence of torrential rivers.

In accordance with Coelho and Torres (1982), in the early 70's the estuarine areas of Pernambuco had 25,044 hectares, with 7,672 hectares covered with water and 17,372 hectares of mangroves, with 6 identified estuarine systems: (1) estuary of the river Goiana, with 4,792 hectares, at northern most region of the State; (2) estuarine complex of Itamaracá Island, with 4,732 hectares, at the north region; (3) estuarine complex of the Metropolitan Region of Recife, with 2,083 hectares, at the central region; (4) estuarine complex of Suape, with 4,901 hectares, at the south region; (5) estuary of the river Sirinhaém, with 2,814 hectares, also at the south region; and (6) estuary of the river Formoso, with 3,143 hectares, at the State southern most region.

The State is located in the inter-tropical zone with average annual temperatures of 25ºC and little thermal amplitude (Silva, 1982). Has a diversified climate, varying from hot to humid and semi-arid of low latitudes, due to its geographic location, with two delimited climatic periods: the dry season, from September to February, and the rainy season, from March to August (Cavalcanti and Kempf, 1970). According to Hazin *et al.* (1995), in the study area winds from NE to S prevail, being predominantly NE/E during January and February and E/SE during July and August. Annual variation of the rainy index seems to be directly related with wind intensity, oceanic evaporation and proximity of the inter-tropical convergence zone.

Informations on the hydrologic mechanisms of the continental shelf off Pernambuco are scarce. Considering the Northeast Region of Brazil and the prevailing oceanographic conditions, this ocean space has the influence of two marine current which are resultant of the Subequatorial Current that, coming from Africa, bifurcate approximately at 5ºS resulting in the Brazil North Current, flowing North-westward, and in the Brazil Current, flowing Southward. Both are high temperature and nutrients poor currents which associated to the high thermocline depth do not favoured primary production, thus conditioning the low marine productivity of this region.

[22] Programa Nacional de Gerenciamento Costeiro (National Program of Coastal Management)
[23] Programa Nacional de Meio Ambiente (Environmental National Program)

The Brazilian Navy had led the first oceanographic studies in the late 60's and early 70's. Some fragmented data had been got by Cavalcanti and Kempf (1970), Silva (1982) and, more recently, by Hazin *et al.* (1995). The shelf area off this region has the influence of the warm Brazil Current, and offshoot of the South Equatorial Current turning to the south. Off the coast area, Hazin *et al.* (1995) identified a coastal northward stream, with concomitantly modification of its intensity due to the intensity of the winds and season. The direction of this current normally follows the direction of the wind or presents deviation to the left until 90°. In general there is a uniform water mass, with mixed layer extending until the edge of the continental slope. The State presents an oligotrophic marine environment due to the influence of tropical waters from the Brazil Current.

The surface water temperature varies between 24 and 29ºC, with minimum values observed in July and August and maximums between January and February (Laborel, 1967 *apud* Silva, 1982; Cavalcanti and Kempf, 1970; Hazin et al., 1995). According to the Brazilian Navy (DHN[24]), the thermocline in this region is situated around 100 meters depth, therefore beyond the edge of the continental slope, justifying the stability of the water masses. Conductivity ranged from 32.2 ups and 36.6 ups, being higher during dry season and lower during rainy season.

According to Kempf (1970a), the State shelf is relatively plain, with bottom covered by biogenics carbonate sediments. The carbonate level of this sediment is extremely high, always superior to 90% (Kempf, 1970b). Algae, specially ramified Chlorophyceae, is also present in the sediment, being able to dominate in certain areas (Mabesoone and Coutinho, 1970). Quartzy sand and mud bottoms occupy great part of the littoral domain. These sedimentologic studies permitted the division of the shelf in 3 distinct zones: (1) internal shelf - from 0 to 20 m depth, with presence of reef and moderate relief; (2) median shelf - from 20 to 40 m depth, with an irregular relief; and (3) external shelf - from 40 m until the continental slope, with moderately to irregular relief and covered with biodedritic sand.

Studies developed by SUDENE (1976) on the potentiality of the fisheries resources of the Brazilian Northeast Region identified a low and disperse biomass (0-2.5 t/km^2) off Pernambuco, whose species composition is mainly of small reef fishes. At deep areas of the shelf and at the continental slope the biomass varied between 5 and 10 t/km^2, which can indicate an occasional aggregation of bigger demersal fishes, probably due to a reproductive or trophic migration.

[24] Diretoria de Hidrografia e Navegação (Directorate of Hydrography and Navigation).

The total biomass of aquatic organisms on the continental shelf was estimated, by the acoustic method, at 15,000 t, excluding the estuarine communities of vertebrates and invertebrates and the pelagic biomass of tuna and tuna like fishes that was not detected by this method, due to their migratory behaviour. From this total, 5,682 t are of specimens with more than 20 cm in length. The exploitable sustainable biomass was estimated to be around 3,000 t/year, of innumerable species of fishes and crustaceans (SUDENE, 1976).

II.3.2 – TECHNICAL ASPECTS AND FISHERY STATISTICS

A ten years fishing production of the State of Pernambuco was analysed, from 1993 to 2002, through the official fishing statistical series published by CEPENE[25], a research centre under IBAMA[26] co-ordination. Taking into consideration that one of the main objective of the present study was to follow and analyse the characteristics of the small-scale coastal fishery, two fleets were chosen: the gillnet fleet based at Brasília Teimosa, Recife City, and the hand-line fleet based at Candeias, Jaboatão dos Guararapes City.

In 2002 the coastal and estuarine fishery statistic registered a production of 5,884.5 t of fishes (3,923.4 t, representing 66.7% in weight and 50.9% in value), crustaceans (600.3 t, representing 10.2% in weight and 37.7% in value) molluscs (690 t, representing 11.7% in weight and 7.9% in value), and others (670.8 t, representing 11.4% in weight and 3.5% in value). Figure II.1 shows the historic data series since 1993 to 2002, with the relative participation for each group of species. It can be observed slightly increasing trends on total and groups production, the exception being crustaceans that slightly decreased. Informations from the official statistical institute indicates that crustaceans (lobsters and shrimps) are heavily exploited, which may explain such production decrease, but the increase of the other groups may be related to an improvement on data collection, leading to a trustful data system.

For Brazil and the Northeast Region the statistic for 2002 is not yet available but, approximately, Pernambuco fishing production represents 1% and 10% of national and regional productions, respectively. The main caught species in weight in 2002 were: anchovy (manjuba), *Anchoa* spp, (752.7 t – 12.8%), shellfishes (species of the Family Verenidae)

[25] Centro de Pesquisa e Extensão Pesqueira do Nordeste (Research and Fishing North-eastern Extension Service Centre).

[26] Instituto do Meio Ambiente e dos Recursos Naturais Renováveis (Environment and Renewable Natural Resources Institute).

(664.1 t – 11.3%), and the spotted goatfish (saramunete), *Pseudupenaeus maculatus*, (493.7 t – 8.4%). However, in value the most representative species were: the lobsters (24.8%) *Panulirus argus* (18.0%) and *P. laevicauda* (6.8%), followed by anchovy (9.3%), and shellfishes (7.5%) (IBAMA, 2003). Considering the production of fishes, during the period analyzed it was observed the highest catch of 4,145.6 t in 2000 and the lowest of 2,328.9 t in 1993. In relative proportion of total State production, the group fishes reached the highest percentage of 82.3% in 2001, when 3,590 t were captured, and the lowest in 1994 with 62.3%, when 2,473.6 tons of fishes were caught.

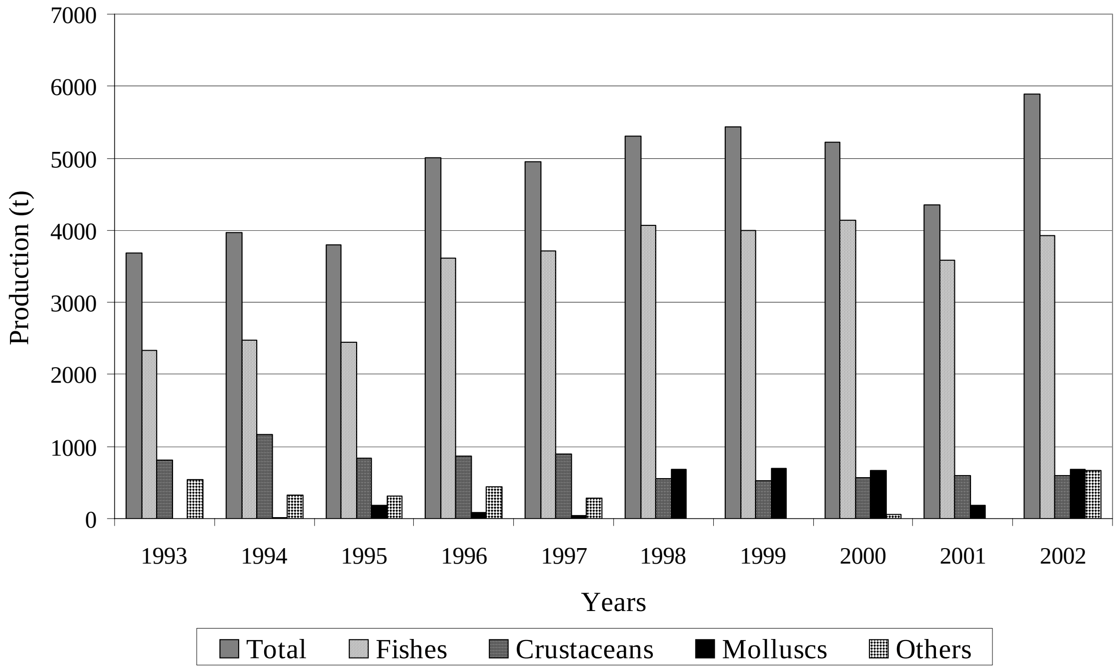


Figure II.1 - Historic data series of the total fishing production of Pernambuco State (Brazil), by group of species, from 1993 to 2002.

In the State 16 fishing gears are used off estuarine and coastal areas. During 2002, the most representative fishing gear used was gillnet, which caught 1,456.9 tons (24.7% of the total State capture), followed by traps with 1,117.3 tons (19.0%), beach-seine with 975.5 tons (16.5%), and hand-line with 840.3 tons (14.3%) (IBAMA, 2003).

Gill-netters and hand-liners, the objective of the present study, are essentially used by the small-scale artisanal coastal fishery, with no industrial purposes. Gillnets have proportionally high profitability, mainly because of the obviously unnecessary use of bait, but with the inconvenience to difficult handling at adverse climate. Considering the hand-line fishery, the most utilised baits are sardine, small amberjack and flying fish.

Concerning coastal hand-line and gillnet fisheries, and the coastal region under study, the methods of fishing depend on the topography of the fishing grounds and the target species. In regions of broad continental shelf much of the artisanal catch is taken by bottom-set gillnets, mostly manufactured of monofilament, some constructed of multifilament, which take a wide variety of teleost and elasmobranch species, as well as lobsters, with small differences depending on the target species; and simple bottom-set long-lines, such as hand-line or hook-and-line, targeting the most valuable species of fishes. In regions of narrow continental shelves, where deep waters off continental shelf are readily accessible, the artisanal fleet use surface-set long-lines and drift-nets to target coastal pelagic teleosts and sharks species. This last feature of the artisanal fishing is not common off Pernambuco State. Although small semi-industrial boats may operate in such a way, it is specially found in others State of the Northeast Brazilian Region, where semi-industrial and industrial fishing have developed accordingly.

The average catches of the hand-line fleet, during the analysed period, was 917.6 t, with the lowest catch in 1995, when 746.6 t of fishes were caught, which represented 19.7% of total State production and 30.5 % of fishes production; and the highest in 1996, when 1,144.4 t were caught, which represented 22.9% and 31.7% of the total State and fishes productions, respectively. For the gillnet fleet the average catch was 939.4 t, with the lowest catch in 1995, when 555.9 t were caught, representing 14.6% and 22.7% of the total State and fishes productions, respectively; and the highest in 2002, when 1,456.9 t were caught, which represented 24.8% of total State captures, and 31.7% of fishes production. In 2002 the hand-line fleet caught 840.3 t of fishes, which represented 14.3% of total State captures and 21.4% of fishes production, which means that 58.5% (2,297.2 t) of the total capture of fishes was took by these two fishing gears. Figure II.2 shows the evolution of the catches, from 1993 to 2002, of the hand-line and gillnet fleets, showing relative participation.

The hand-line fishing boats may be defined as a métier, usually defined by the use of a given fishing gear in a given area, in order to target a single specie or group of species. Otherwise the gillnet boats cannot. The hand-line boats, making this its main fishing gear, fish in a given area defined as the Pernambuco State Continental Shelf, and target coastal reef fish species. Although the gillnet boats fish in such a defined area, they sometimes may use hook-and-line to fish during the period in which net is settled, and target a variety of species, e.g. semi-pelagic (i.e. blue runner), small pelagics (i.e. Spanish mackerel), reef fishes (i.e. lane snapper).

Gulland (1971) described that fishing along the northern and central coastal of Brazil was mainly pursued by small crafts and sailing rafts using various types of seine-nets, long-lines and traps. Among the diversity of boats used in the local fishing activity, three groups can be identified: motorised boats, that respond for the majority of the catches, and in 2002 caught 2,605 t and represented 44.3%; canoes, with 2,111.7 t (35.9%); and rafts, with 490.7 tons (11.5%). The number of total boats in operation fluctuated along the study period, from a minimum of 1,411 in 1993 and a maximum of 2,457 in 2001, which means an increase of 74.1%. A lot of small floating devices are used by poorest fishing communities and fishermen, and in the State statistics are grouped as not identified, that was incorporated in the statistical data system since 1997. These devices caught, in 2002, 677.1 t, that represented 11.5%. Concerning fleet composition, in 2002 there were operating 2,457 boats in the State, being 32.7% of canoes, followed by motor boats (26.7%), rafts (25.6%), and not identified boats representing 15%.

It might seem fruitless to speculate about seemingly unknown problems, but in what extend can be said that an increase on fishing effort occurred? Considering that the data collection system was being improved in the past decade and even more during last years, it is not reasonable to conduct any analysis which could lead to biased results, and is beyond the scope of the present study and Chapter. A trustworthy statistical data preclude an analysis of such fluctuation and not necessarily means that fishing effort increased same fold. In this specific case, there was an incorporation of not identified crafts that can be understood as an improvement on data collection, and that could have apparently increased fishing effort. This occur because, as stressed by Watson and Pauly (2001), at lowest level (individual fishers), catches are under-reported.

Motorised fishing boats are artisanal manmade crafts, with wooden hull, central engine with an average power of 30 hp, and length that vary between 6 and 10 m. They are locally called *botes* or *lancha*, with half-open cabin located at the stern, leaving the middle of the boat and the bow free for the drudgeries of fish. Instead of having caverns, most are used for the storage of fishing gears and tackles, such as anchors, ropes, lines, hooks, etc., and the fishing yield are stored in icebox. Canoes are also handcraft built, with wooden flat hull, moved by oars and/or sail, having no cabin or deck, and ranging from 3 to 9 m long. Rafts are locally called *jangada*, moved by oars, pole or sail, flat wooden hull and ranging from 3 to 6 m long.

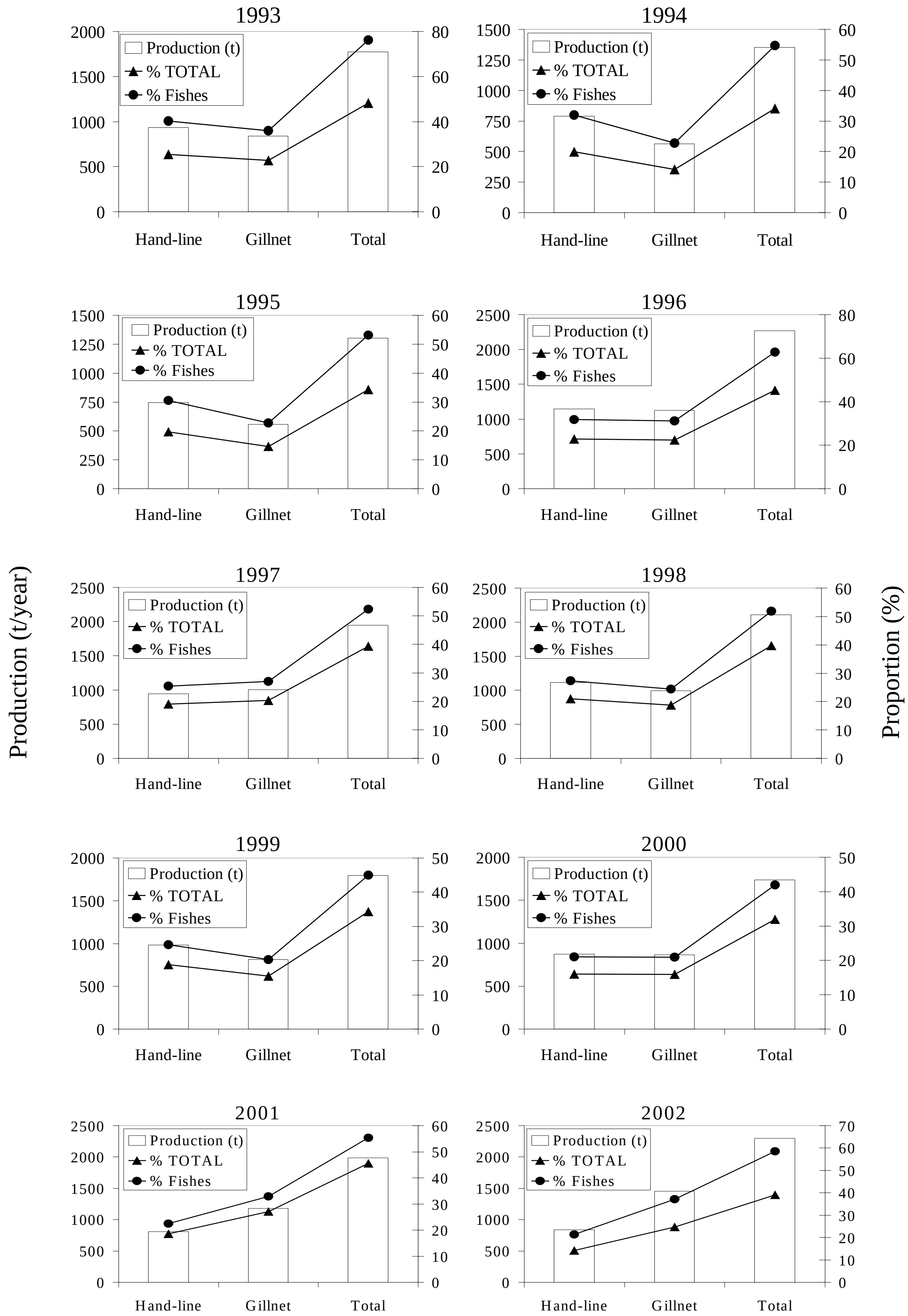


Figure II.2 - Evolution of the catches (t), from 1993 to 2002, of Pernambuco State, North-eastern Brazil, hand-line and gillnet fleets, with the respective relative proportion (%).

First rafts were constructed with a special tree wood, which has a high buoyancy index, found in the Brazilian Atlantic Forest, but deforestation and uncontrolled overexploitation for such objective reduced substantially the number of these trees and a special law was enforced prohibiting exploitation. Being the main source of material good for most fishing communities in the middle of the last century, insofar the collection in such a particular area exceeded the capacity of the local tree stock to replenish itself through re-growth, fishing communities perhaps first faced with an economic problem of changing habit and knowledge to replace the adequate material for raft manufacture. Nowadays rafts are manufactured with polystyrene, covered with wooden board, the same used for motorised boats and canoes, from more productive trees or cultivated ones.

Although it is clear that an increase in fishing effort does not means, necessarily, an increase in catches at the same time, and even more improbable an increase in catch per unit of effort (CPUE), informations from the official statistical institution concerning data collection, and the available data show that, for some years, an increase in numbers of boats lead also to an increase in productivity per type of boats, because total production increased considerably, maybe indicating that effort is relatively stable, while data collection is being improved. Figure II.3 shows the productivity per type of boats for the analysed period. It can be seen that the lowest CPUE was obtained in 1997, when motorised boats[27] caught 3.20 t/year/boat, catches of fishes was 3,719.8 t, and 671 boats operated. The higher CPUE was reached in 1999, when motorised boats productivity was 5.28 t/year/boat, an increase in the CPUE per boat of 65%. In 1999, 3,993 t of fishes were caught, an increase of 7.3%, and 434 motorised boats were in operation, a decrease in the number of motorised boats in operations of 35.3%.

As data system is highly dependent on officials collectors and boat owners informations, it seems that in some years, specially those of higher production and productivity, boat owners do not inform their total operations, as in number of fishing trips or volume of catches, trying to hide the finding of new productive fishing ground. It sounds reasonable to especulate that nowadays knowledge still scarce to identify and define interactions among groups of interest in the fishery system, especially in localities with high social and economic conflicts, let alone describes their working across the board.

[27] In this specific analysis concerning the relationship of fishing effort and catch per unit of effort (CPUE), in productivity (t/year) per type of boats, it was only considered motorised boats, because the scope of the present study is the analysis of the coastal fishery of two specific fleets, the hand-liners and the gill-netters, that mainly operates with motorised boats.

It is of concern that the marine fishing fleet is obsolete, being composed by old small boats with few technological advances, low autonomy and, in some cases, using predatory fishing methods. This small-scale fishing, although operating in higher productive fishing grounds, such as coastal and estuarine areas, if compared with the medium- and large-scales fisheries, in most cases fish on juveniles of commercial stock species. In general, these boats are not adequately dimensioned, hence prevailing the traditional, and some times old, knowledge on fishing boats design. In most of the cases the engine is not compatible with displacement, causing fuel over-consumption. Handling and conservation of fish on board is inadequate, losing quality, and labour conditions are beyond the required regulations of safety at sea.

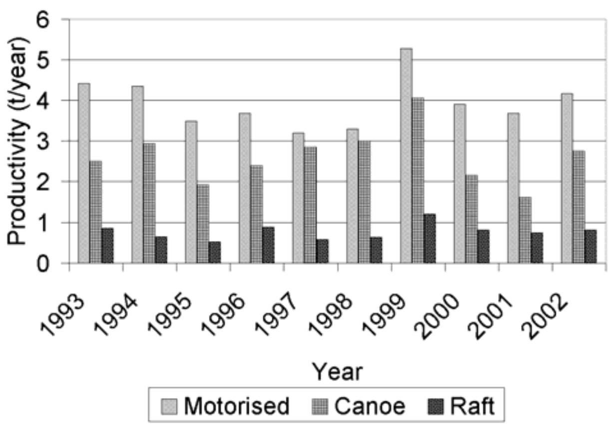


Figure II.3 - Productivity per type of boat (t/year) of Pernambuco State, North-eastern Brazil, coastal fishery from 1993 to 2002.

Regarding electronic fishing device, only three equipment’s are utilised, such as: the radio VHF, the echo-sounder, and the GPS - *Global Positioning System*. However, despite the familiarity of some fisherman with these devices, these are utilised by very few boats, and there are difficulties to operate, mainly the GPS, due to illiteracy of fishing master and lack of technological teaching.

Coastal infrastructure, when existing, is insufficient and inadequate, as a consequence of planning mistakes. These infrastructures were over-dimensioned, on the belief of the inexhaustibility of fishing resources, aggravated by the fact that there was very little information, or no information at all, on stock availability and sustainability, on local infrastructures such as roads, electricity, etc., and social and cultural characteristics of fishermen and fishing communities, resulting in non-acceptability and/or incapacity to operate and manage fishing warehouses and ports.

II.3.3 – THE FISHERY SYSTEM

In the Brazilian maritime fishery system, understood as an assembly of natural, physical and biological conditions, befitted to determinates forms of production social organisation, there is differentiated productive ways that, although representing relatively different historic periods, articulates and interrelates among one another, establishing a very particular dynamic for the national fishing development model, represented by the artisanal and small-scale fishing, and the capitalist production, such as the boat owners and the entrepreneurial one.

Until the mid of the 1960’s, the Brazilian fishery sector presented a low development of the productive force. Although the capitalist/industrial fishing sector had just been established, the small-scale fishery, considered a subordinated sector, presented a hegemonic social relationship with which objectives and stability of the productive process and relationships with the environment and their resources could be established. Paradoxically, on the fragility or almost entirely absence of the State regulation measures to control the use of the fisheries resources, this existing scenario of a low development of the productive forces, was one of the basic factor for the maintenance of certain level of equilibrium between the fishing effort and the resource sustainable yield.

Nowadays the Brazilian fishery sector is under administrative co-ordination and management of two distinct institution: the Instituto do Meio Ambiente e dos Recursos Naturais Renováveis – IBAMA (Institute of Environment and Renewable Naturals Resources), organisation belonging to the structure of the Ministry of Environment; and the Secretaria Especial de Aqüicultura e Pesca – SEAP (Special Secretary for Acquaculture and Fishery), under the direct supervision of the Brazilian Presidency. The IBAMA dedicates to the sustainability of the use of heavily exploited fishing stocks, while the SEAP to development programs based on the scope of fisheries biological, social and economic sustainability.

According to the Brazilian *Magna Letter*, in its Art. 225, the fisheries resources are non-alienable stocks of public property, owned by the Union, and on this way constitute an environmental macro common good. Nevertheless, may be allowable to private property part of a stock, as a micro common good necessary for the satisfaction of individual and collective needs, and on this sense must be regulate under the State enforcement measures to ensure the required sustainability, either on the environmental/ecological point of view or on the social and economic.

Considering the utmost importance to apply management fisheries models aiming at the activity sustainability, potentialities and fragility's must be identified, because any intention of intervention on the dynamics of the small-scale coastal fishery must consider local and current realities, to strengthen advantages to define regulation and management measures. Thus, the main potentialities of the coastal fishing, adapted from Bonzon (2000) and Anonymous (2001), can be listed as:

- Fisheries, as a whole, are of small-scale, artisanal or of subsistence, local and traditional, making possible a total, temporal or partial occupation of an innumerable fishing communities members, a support to these communities and maintenance of local traditions;
- Most of the fishing stocks are locally confined to coastal, estuarine and insular environments, not shared;
- Diversity of fishing stocks may contribute to spread fishing effort and to the supply of a wide variety of valuable marine fish products, commercialised mainly fresh at local markets. This makes for a low price elasticity of demand which allows small-scale fishing operations to remains relatively profitable against a background of diminishing yield;
- Instead of increasing demand for frozen and processed products, still exist a preference for high quality fresh fishes;
- The diversity of fishing techniques and gears applied in space and time may, at some extend, contribute to dispersion of the fishing effort;
- A reduced fishing activity is done by medium and large size boats at industrial scales, contributing to the activity socialisation, preventing production concentration in large entrepreneurial clusters;
- A wide variety of fishing grounds and the physic nature of such environment, in general ways, with shallow and irregulars shelves and protected coastal areas, favour stocks conservation; and
- Existing production agents organisations (fishermen, boat owners, entrepreneurs, etc.) is a guarantee of representativeness and voice.

Otherwise, coastal fish stocks seems to be fully or over-exploitated, mainly because of a high fishing effort, use of non-selective fishing gears, and coastal and estuarine ecosystem degradation, and although legal instrument to abolish such practices do exist, the control is difficult. Thus, the activity fragilities, adapted from Bonzon (2000), Anonymous (2001) and Mattos *et al.* (2001b) must be listed as:

- Fisheries diversity and the predominance of multi-species stocks in a marine ecosystem subjected to environmental changes, although poorly understood, makes it difficult to identify ecosystem boundaries for uniform local areas or management measures;
- Fishery legal instruments, although longstanding, are difficult to apply, thus not enforced and respected, particularly technical measures applicable to the utilisation of selective fishing gears and legal minimum catch size of some commercial species;
- General informations on the biology of exploited species and the state of fishing stocks are commonly scarce, and statistics (catch and effort data) are trustworthy;
- High fishing effort and lack of effective method to stop fishing mortality lead to depletion of most of the exploited fishing stocks, habitat degradation, biodiversity reduction, and considerably affects sensible areas of the aquatic substrate, i.e. the natural nursery areas;
- Stock assessment seldom takes into consideration ecosystem parameters and limits, or does not consider species interaction, and in lesser degree between fisheries and species of mammals, chelonians and sea birds;
- Tendencies to generate subsidies to fleet modernisation, that promotes the introduction of more efficient boats and increases fishing effort, do not take into account the limited environmental capacity and the sustainable yield of the exploited fishing stocks;
- Urban development and domestic and industrial polluting activities contribute to degradation of some fishing areas, committing fish quality;
- Fish catch below minimum size limits, during closed season, or caught as by-catch has been increasing;
- Lack of co-ordination of public agencies responsible for the activity management, and also between these and research institutions, leads to inefficiency to harmonise and prioritise data collection;
- There is a fragile identification of fisher groups within fishing territories, with implications on non-collective adoption of technical innovations and management

measures. Social, cultural and economic discrepancies lead to centralisation of actions, disfavouring organisation co-management;

- In many localities there is limited interactions between fishermen, administrators and researchers;
- There is a high fishermen dependency on wholesalers commercial impositions; and
- Instead of officially prohibited, the open access system prevails, in virtue of lack of control of the responsible governmental institution.

II.3.4 – THE SOCIAL DIMENSION OF THE FISHERY

Social and economic analyses on the inter- and intra-relationships of artisanal and industrial fisheries are now priority studies, although it still far from being adequate if the fishery sector dimension is considered. Lack of organisation and management and co-management processes are even more aggravated inside the complexity of the small-scale productive chain.

The social organisation of the artisanal productive sector are defined internally the system. Its distribution in the littoral is regulated by the expansion of the process of production goods, and by the capital spread in the production social division. These organisational structures were constructed with practically no interference from outsiders, because there is a relevant importance of the familiar unit or neighbourhood groups, although not predominant, in the labour relationship. Otherwise, this leads to a definition of hierarchies and individual properties of the fishing methods and instruments, aiming at increasing productivity.

The reproduction of the work force, of the production instruments, and of the own social-production relationships depends on the articulation-established process presently existing among the various forms of fishing organisation. As the cultural characteristics of *freedom* to fish whenever they want prevail among artisanal fishing communities, it does not stimulate organisation, and many fishermen don't have the interest to register at fishermen's associations, especially because this is not enforced by government regulations, and individual control does not occur. Alternation from an independent fishing pattern to a system of production and fishing as a member of a crew took place during the 70's represented a highly rational adaptation to local ecological conditions. However, at the same time incentives to industrialise the fishery sector exceed rationalisation expropriation of the work force and was strongly evinced.

In Brazil there is an estimation that the fishery sector generates 800,000 direct jobs, totalling 4,000,000 direct and indirect ones, 5,000,000 are directly engaged in sport fishing, and an innumerable inhabitants of rural communities practise subsistence fishing for own consumption or complementary income. In Pernambuco State littoral, there are 33 fishing communities where 7,000 fishermen are registered, and it is accounted that a similar number of fishermen are not registered, rising up this number to a total of 14,000 artisanal fishermen in the State. Otherwise, as stressed that official statistic is not reliable, there exist non-governmental estimation that the number of coastal artisanal fishermen may raise up to 25,000, and that 125,000 directly depends on the coastal fishery activity, which represents, approximately, 1.6% and 3.1% of coastal and total State population, respectively.

One of the main problems found is the low social and scholar level among artisanal fishermen, with high index of illiteracy, mainly among older fishermen. Hazin *et. al.* (1995) found that, in average, 25% are illiterate or half-illiterate, 52% have an incomplete primary education, 20% has a complete primary education, 2% have an incomplete secondary education, and only 1% have a complete secondary education.

According to Mattos *et al.* (2001b), the existing social relationship are extremely fragile, where the majority of the fishermen has a high dependency on external agents, either public or private, and the productive chain is poorly known, which difficult appropriate investments. Three main impediments to adequately plan and implement management measures are identified, such as:

a) <u>Management Measures</u>

- ✓ Less participation in the decision process;
- ✓ Lack of knowledge of the legal instruments;
- ✓ Lack of political and technical assistance;
- ✓ Fishermen are poorly organised and highly dependent on wholesalers; and
- ✓ Lack of supervision of the fishing activity as a whole, both by the government and by the fishermen organisation.

b) <u>Administrative Features</u>

- ✓ Lack of legal instruments to guarantee the whole access to subsidies;
- ✓ Lack of adequate educational governmental programs;

- ✓ Governmental and non-governmental interference on organisational processes; and
- ✓ Manipulation of the legal instruments by politicians and financial powers.

c) <u>Environmental Factors</u>

- ✓ Subjected to conflicts due to the open access characteristic of the resource;
- ✓ Lack of codes and arrangements to regulate the occupation of estuarine and coastal areas;
- ✓ Pollution and degradation of estuarine and coastal areas; and
- ✓ Isolated actions during the implementation of fishery and acquaculture projects.

Diegues (1983) pointed out that in the Brazilian artisanal fishery system two production relationships can be distinguished: (1) the technical production relationship is a modality of control that agents may exert directly on the production instruments and in general on the work process. These are related to the co-operation established forms among production agents during the process of material appropriation or environmental domain. Co-operation may be simple, when work division is reduced, and complex, when work process holds a series of activities exerted by many workers which ends with a final common product; and (2) the social production established relationship among the production agents through ownership or propriety of the means of production.

The labour system is characterised by partnership, where each fisherman has his knowledge on the production means, on the environment and the work process, i.e. the accumulated knowledge on fishing gears, on the fishing resources, etc. In this labour system, the payment of the work force takes advantages in the way that partnership is emphasised, because there is no excess of capital or if so, it is very small, whose result can be the impossibility to replace fishing instruments, which in most of the cases is under wholesalers dependency, or may lead to dispossess fisherman from his production means and his transformation on wage-earning work force. As stated by Marx (1970[28] *apud* Diegues, 1983), *its annihilation, the transformation of the individualised and scattered means of production into socially concentrated one, of the pigmy property of the many into the huge property of the few, the expropriation of the great mass of people from the soil, from the means of subsistence and from the means of labour, this fearful and painful expropriation of the mass of people forms the prelude of the history of capital.*

[28] Marx, K. (1970) The Capital; historical tendency of capitalist accumulation. In: Worsley, K. *Modern sociology; introductory readings.* Pelican Books.

The kind of existing co-operation in the small-scale fishery system occur, *vis-à-vis* to groups homogeneity, because when the level of development of the productive forces is extremely low, it is not possible to occur a group division into differentiated socials classes. At this technical level and social productivity, the group solidarity is a material and physical indispensable condition for the community survival. This may occur because the exploitation of the natural renewable resources is conducted through an easy access means of production by those that acquired traditional knowledge through generations.

II.3.5 – THE PRODUCTIVE CHAIN

A productive chain is defined by a set of action and processes that has as final result the merchandise (Gereffi and Korzeniewics, 1996). Throughout such chain there is the interaction of the participant agents who, from this common relation, establish the competitiveness and the subsidies so that the activity continues its process of transformation, becoming relatively more or less efficient. Erroneously, through the years, efficiency approach of a particular economic activity was based on the isolated analysis of the performance and the economic characteristics of the participant agents of each strata without taking in consideration the form and the nature of the relations inside and among each one of these strata (Croccia, 2002).

Pernambuco State fishery productive chain is characterised by a complex activity, since fishing until commercialisation, with great part of the production destined for the domestic market. This process is highly informal and consolidated due to lack of government control and developmental policies directed to the artisanal fishery sector. Fish handling chain, according to Barros (2000), can be divided in 12 stages before reach final consumers: catch; handling on board; storage on board; onshore transportation; onshore handling; onshore storage; transport to wholesalers; storage on wholesalers; handling by wholesalers; transport to retailers; handling by retailers; storage by retailers. Of course that during this chain sporadic consumers may arise, since stage 4.

The productive fishery structure may be divided in three strata: the pre-fishing, or the preparation to fish; the fishing operation, and the post-fishing, the commercialisation, or the market. Boat owners are responsible for the expenses to fish, such as food, fuel, bait (when it is the case), ice, etc., which are acquired in local market, and generally fishing gear is either fishermen belongings or responsibilities, meaning that mending is taking from fishermen earns. As fishing port infrastructure is deficient, or do not exist at all, loading is always done helped by small boats called *catraia*[29] and by beach workers, called *luteiros*[30]. These expenses are generally high, because few organised communities purchase goods and fishing needs through fishermen associations.

Boat crews are composed by a skipper (fishing master) and by 1 to 3 fishermen, which depends on the type of fishing and boat size. Displacement to fishing areas are carried through coastal navigation, using visible points ashore to define route and boat positions and the different fishing grounds. Fishing operations are realised off Pernambuco State shelf, having as external limit the edge of the continental slope, called *paredes* (walls). Depth and bottom substratum is defined through a manual gear, called *sassanga*, composed by a nylon line (Ø 90 mm), with lead at its end, which possesses small cracks at the base to allow the penetration of the substratum. Fathom is the usual measure, defined as in the distance between hands of a fisherman with the arms extended perpendicularly to the body, whose length is generally equivalent to 1.8 m. Fishing effort is directly related to crew size, due to the handling characteristic of fishing operations, with low mechanical processes.

It is a fact that uncontrolled increase of exploitation of fishing resources, beyond the sustainable maximum limit, resulted greatly in the reduction of the main marine commercial species, with some clearly overfished (Mattos *et al.*, 2001). That is why, for the fishermen, production uncertainty is always high considering the diversity of variables that compose the fishing activity, making the traditional knowledge of the fishing master a remarkable consequence, being the main productive vector of this activity and a direct responsible for the success of fishing.

Generally an informal 50% share is pre-established between boat owner and crew. Owner pay according to each fisherman production and price is defined according to local market. This form of work and payment may be interpreted as salary, which means that the fisherman is not the owner of the means of production.

The fishing master has advantages among the crew, as by choosing the best place to fish onboard, also allowed to decide the effort, which is the case for individual fishing, like hand-line. In this activity each fisherman is paid according to his production, like working by himself, marking the fish he caught with a special cut that indicates his property. Another way of differentiating the fishing master from the crew is by assigning to him a greater amount of

[29] Small flat raft used to tansport fishermen, fishing equipments, the production and goods to and from the boats.

the production, which is the case of fishing activities where the work as a group is important and indispensable, like nets. In gillnet fishing the share system sometimes occurs as by dividing the production and each fisherman take responsibility to commercialised his production, which seems to often occur in more distant fishing communities from urban areas or, as exposed by Diegues (1983), in this production system of the artisanal fishermen, the net or boat share takes the form of monetary income, in the way that share only occurs after selling the production by the production instruments owner.

The fishing master is that who has a natural leadership, and has acquired sufficient traditional knowledge as for being recognised by the community. It may be said that he is in a managerial position, organising the crew and determining where and when to fish. This person labour and managerial skill warrant payment, or fishermen wages. Few had the opportunity to be trained for a fishing master or boat captain, as because there is lack of training courses or because they do not trust on the transmitted theoretical knowledge in such courses more than their traditional one. The skippers, aiming at justifying his greater amount on the fishing production, use this traditional knowledge, a secret passing from generations. A rudimentary knowledge of reading, writing and simple arithmetic helps them differentiate from the illiteracy class, from which they themselves have arisen.

The market, although considered the space of exchange relationship, is hence considered as an external component of the productive process, due to the social relationship assembly at community basis, which support and guide such productive process, and to the relationships with the environment and the fishing resources (Marruh Filho, 2001).

As well explained by Ivo (1975[31] *apud* Diegues, 1983), commercialisation is the axial point in the regional fishery, considering the historic structure of the fishing activity and the existing entailing between the commercial capital and fish exploitation, in whose process becomes clear the inappropriateness of the natural fisheries economy, which reduce all artisanal fishermen into a dependent work force, and day after day kept out by those productions owners who, at the same time, control all products commercialisation.

The boat owner, when a dealer, sell the production direct on the local market or transport it to higher demanded fish markets. When there is a middleman, boat owner and fishermen earnings decrease. Some more organised fishermen organisations established

[30] A local word that comes from "luta" that in Portuguese means "fight", that is to say, *to fight for the eachday bread.*

[31] Ivo, A. B. L. (1975) *Pesca, tradição e dependência: um estudo dos mecanismos de sobrevivência de uma atividade tradicional na área urbano-industrial de Salvador.* Tese de Mestrado. UFBA.

recently modern processing plants that allow them to export to other States or even other countries, seeking better markets and prices. Middleman still taking advantages on the deficiency of the productive chain to compete with fishermen organisations in the direct purchase of the fish production, acquiring it for a lesser price and re-passing to retailers for up to three times the initial value.

According to (Barros, 2000), in the State of Pernambuco can be identified two fish market: large and small retailers. Large retailers are supermarkets and large fish store specialised on the commercialisation of fish products, while the smaller are beach small fish shops and street and public fairs. Consumers may also be categorised by those that frequent these two kinds of markets, with a characteristic that those that visit larger store although very choosy for high quality fish, do not demand freshness and commonly buy frozen fish products; and those who visit the small markets demand fresh fish, but quality is very questionable, due to poor handling and infrastructure conditions.

II.4 - THE BIOLOGICAL RESOURCES

The standard distribution of marine organisms are influenced and delineated by three-dimensional barriers, as much in the vertical direction of the water column, as in the horizontal direction along the continental shelf. These sea barriers, however, are difficult to detect, because of the continuous nature of the seas and oceans, but allowed to assume that regions characterised by marked alterations on the intensity of ecological factors, as it is the case of coastal regions, generally represent biogeographic limits. The limits of a species distribution are established by the integrated action of the totality of the biotic and abiotic factors of its vital cycle.

Three fish stocks were chosen for the conducted analysis, considering the frequency on the following fishing fleets, the significant importance for the State coastal fishery and regarding the biodiversity found off the continental shelf (occurrence and representativeness in accordance with the existing ecological niches), 3-dimensional distribution (pelagic, reef, bottom, shallow and/or deep shelf, etc.), the abundance and representativeness on catches (commercial aspects, and value and costs of production), and biological aspects (reproduction, growth, etc.). The description of each group and the main potentially important species for conducting the proposed studies are described below, inasmuch it would not be reasonable to describe the overall State biological resources.

II.4.1 - COASTAL PELAGIC FISHES

Coastal pelagic fishes, or small pelagic, are those species whose biological cycle develops in the water column, bottom-independently, and their distribution are mainly at continental shelf waters. Among its biological common characteristics are: small and medium size fishes; hydrodynamic body shape; short life span (3 to 7 years); age-at-maturity in the first or second year of life; high fecundity; feed mainly on plankton; heavy schoaling behaviour; and usually live in highly productive but dynamic and highly variable system. According to FAO[2] statistics, approximately 35% of the world total catches (38.8% of the total marine captures, and 47% if only marine fishes are considered) are composed by this group of species, represented mainly by the following families: Clupeidae, Engraulidae, Carangidae and Scombridae. At Pernambuco State, in 2002, ca. 25% of total captures are composed by this group, and if only fishes are considered, this percentage raises up to 38.3% (IBAMA, 2003).

Off Pernambuco State, the most representative coastal pelagics communities of fishes are blue runner (guarajuba), *Caranx crysos* (Mitchill, 1815), with catches in 2002 of 155.2 t, representing 2.6% and 3.9% of total and fishes State productions, respectively; king mackerel (cavala), *Scomberomorus cavalla* (Cuvier, 1829), with 95.8 t, and representing 1.6% and 2.4%, respectively; dolphin fish (dourado), *Coryphaena hippurus* Linnaeus, 1758, with 60.1 t, representing 1.0% and 1.5%, respectively; ; and the Spanish mackerel (serra), *Scomberomorus brasiliensis* Collette, Russo, Zavala-Camin, 1978, with 41.8 t, representing 0.7% and 1.1%, respectively.

Although some evidence of variability and particularly long term changes in the total abundance of some important mid-size pelagics has been reported, this is not as accentuated and strongly evidenced as for small-pelagics. There are far less long term abundance estimates for coastal mid-size pelagics stocks, and total catch statistics are less reliable indicators of stock abundance when the stocks are lightly exploited, or when the stocks have a wider distribution range and most of the fishing is limited to the coastal areas. As longer lived animals, this group of species seems to be less exposed to the adverse effects of changing environmental conditions and unrestrained fishing. For the coastal pelagic group concerned, there is not much reason to expected short term abundance variability, as is commonly evinced for small pelagics, although total catches can still be highly variable if the fishery is not able to follow possible shifts in the distribution range of the stocks (Csirke, 1995).

Local fluctuations concerning yearly group production seems to be related to the migratory pattern of these species, but no information is available and it is beyond the present study purview. Figure II.4 shows the production of the group and for each specie separately, considering the analysed period, the lowest production being informed in 1994 (197.5 t), and the highest to 1996 (478.2).

These species are pelagic migratory and their stocks present a distribution area that extends along the entire Brazilian coast. The effort of conservation of coastal pelagic species in the Atlantic Ocean, given its migratory nature, has been led by ICCAT[32]. These species are grouped as small tunas with the Atlantic little tuna, *Euthynnus alletteratus* (Rafinesque, 1810), the frigate tuna, *Auxis thazard*, (Lacépède, 1802), and the Atlantic bonito, *Sarda sarda* (Bloch, 1793), the most important commercial small pelagics under the scope of ICCAT, in virtue of its economic importance and stock condition, due to the high fishing effort that are sustained. They are distributed for considerable oceanic and coastal areas, occurring, not rare, in all world oceans.

The family Carangidae is a group of species well represented in Pernambuco State captures, but economically is less valuable than the species of the family Scombridae, as well as others reef communities fishes, like the families Lutjanidae and Serranidae[33]. According to Ferreira *et al.* (1998), the family Carangidae does not present resident species in reefs, but feed on the fishes that inhabit it. They are commonly found on reefs, with indices of abundance relatively high, and reach reasonable commercial value in the State.

According to Hazin *et al.* (1999), none of the teleosts pelagic species here considered are under risk of biological extinction, even with some stocks being exploited at levels above their maximum sustainable yield. Undoubtedly, if this situation were to last, a commercial extinction of the resource would result. Studies conducted by Collette and Russo (1979), Zavala-Camin (1983) and Lubbock and Edwards, (1981) quoted by Hazin *et al.* (1999), informed that the king mackerel, *Scomberomorus cavalla*, occurs from the North coast to the neighbourhoods of Rio de Janeiro and São Paulo States, Southeastern Brazil, with occurrence in the Archipelago of São Pedro e São Paulo (St. Peter and St. Paul). The specie is epipelagic

[32] International Commission for the Conservation of Atlantic Tuna.
[33] The description on the species of such Families is in item II.4.2 – Coastal Reef Fishes.

and neritic, being frequently found in reef areas, and is also estenobiont, the salinity being the most important factor influencing distribution, limiting its approaching to coastal areas where fluvial runoff is high (Furtado-Jr, 1997 *apud* Hazin *et al.*, 1999), especially juveniles (Carvalho Filho, 1999). According to this author, they can occur from the coast to offshore waters, from the surface to 80 m depth.

According to IBAMA (1994), these species occurs beyond the 20 m depth and according to Collete and Nauem (1983) it occurs in the Western Atlantic, from Massachusetts (USA) to Rio de Janeiro (Brazil). It inhabits off the coast to approximately 150 m depth. It prefers clear waters and is more frequently found offshore, where small shoal of young fishes can form, or is solitary, in the adult phase. During reproduction it forms large shoals searching for shallow waters (Carvalho Filho, 1999). The species is commonly highlighted for its economic value and importance for the artisanal fishery in the Northeast Region of Brazil.

The king mackerel is the species of highest commercial importance in the State of Pernambuco and the Northeast Region of Brazil, with no marked seasonality. The main fishing area of the species off the State continental shelf is beyond the 5 nm offshore, being able to reach limits next to the continental slope, at approximately 20 nm. The fishing gear commonly used is gillnet, which catches young fish, and trolling, that catches larger individuals. Concerning the State artisanal and the small-scale fishing statistics, annually registered by IBAMA, trolling is mentioned as the main method of catch.

Also in accordance with Collette and Nauen (1983) and Hazin *et al.* (1999) quoting Collete and Russo (1979) and Zavala-Camin (1983), the Spanish mackerel, *Scomberomorus brasiliensis*, occurs throughout the Brazilian coast, is an epipelagic and neritic species, with no indications of high migratory movements. According to IBAMA (1994), it occurs in more coastal zones. In the Northeast Region, the reproduction happens all year round, even with a reproductive peak between July and September (Gesteira, 1972 *apud* Hazin *et al.*, 1999; Carvalho Filho, 1999). Is one of the most commercial important species, being caught throughout the year. It is often caught with surface gillnet (IBAMA, 1994).

In Brazil, the Spanish mackerel is caught mainly in the Northeast Region where 78% of the national total landing occurs. First studies in the Region have been carried out by the Laboratory of Marine Sciences - LABOMAR of the Federal University of Ceará - UFC, during the 60’s and 70’s, considering studies on age and growth, reproduction, fishing gears selectivity, mortality and abundance. However, since then, less is known on the exploitation pattern and current stock conditions. The fishery and biology of this species have never been

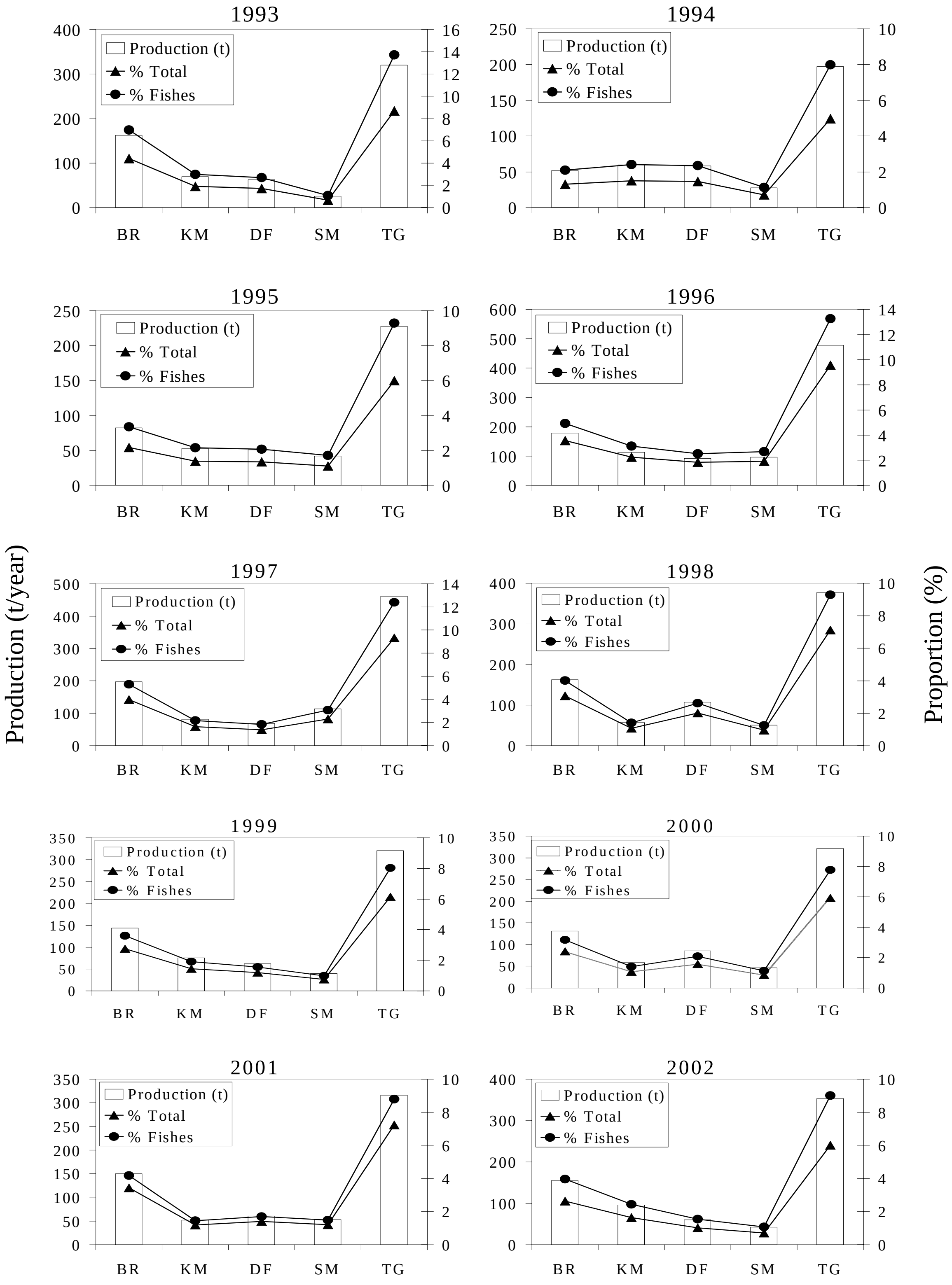


Figure II.4 – Captures (t) and relative proportion (%) of coastal pelagic fishes of Pernambuco State, North-eastern Brazil, total and fishes productions, from 1993 to 2002. BR - Blue Runner (guarajuba), *Caranx crysos*; KM - King Mackerel (cavala) *Scomberomorus cavalla*; DF - Dolphin Fish (dourado), *Coryphaena hippurus*; SM – Spanish Mackerel (serra), *Scomberomorus brasiliensis*; TG – Total of the Group coastal pelagic fishes.

analysed considering the other areas of the species distribution (only one stock had been considered) and information are restricted to the adjacent areas of the State of Ceará (Lucena *et al.*, 2001).

Lucena *et al.* (2001) considering studies and biological references of several other authors remarked that the Spanish mackerel stock is overexploited and the fishery should be managed. These same studies lead to the belief that this stock presents a highly exploitable pattern, with the current catch composition significantly distinct from that registering for the 60's and 70's, since the average size of the individuals caught decreased 33% and individuals larger than 86 cm are no more available to the fishery. According to the estimate of length at first capture (L_{50}) found by these authors, there is an intense exploitation of juveniles, due mainly to gillnet, which operates at low depth regions, habitats of juveniles. This stock is being exploited close to its maximum sustainable yield – MSY, because the biomass is less than 50% of the one in the initial exploitation.

For Nóbrega *et al.* (2001b), 85.31% of the population is composed by specimens between 2 and 5 years, being more representative in the year-class 2 (37.44%) and 3 (24.99%). In accordance with Nóbrega *et al.* (2001b), 74.8% of the Spanish mackerel in the Northeast Region of Brazil are caught by gillnets, followed by beach-seine (19.1%). The beach-seine is responsible for a significant catch of young fishes, in virtue of the reduced size of the used mesh, considering inadequate for the maintenance of this stock in the Region.

The dolphin fish, *Coryphaena hippurus*, is epipelagic with juveniles concentrating in shoals that could reach coastal areas, while adults congregate in pair, groups or schools offshore. Extremely migratory, this specie feed mainly on pelagic species of fishes, during the day, and crustaceans, during the night, and are preyed upon by tuna and tuna like fishes and sharks. No seasonal reproductive cycle was, until now, identified (Carvalho Filho, 1999).

II.4.2. - COASTAL REEF FISHES

Reefs zones are characterised for being a clearly defined habitat from other coastal areas, presenting a high biodiversity, quantitatively and qualitatively, with available food and serving as shelter for many species, especially during their juvenile phase. Such environment is directly influenced by climatologic and hydrographic condition and, indirectly, by geographic conditions. The State of Pernambuco continental shelf is relatively narrow, with barriers reef along almost the entire coast, favouring the occurrence of the species in question.

According to Cergole (1999) the species that inhabit these areas can be characterised as: (a) species that pass all their life cycle in the place; (b) species that pass only one period in the reefs, especially during juveniles phases; and (c) species that are only passing. Economic importance and stock conditions can be the main aspects that justify the study of such group, considering the strong fishing pressure which are submitted, due to the high fishing effort and environmental impacts caused by illegal fishering and coastal pollution, that significantly affects the marine substratum in the continental shelf.

The family Lutjanidae is composed of 17 genera and 103 species of mostly reef-dwelling marine fishes collectively know as snappers. These species are the main group caught by the coastal fishery off Pernambuco and, although frequent in coastal zones, can be found at depths from 2 m (juveniles) to 50 m (adults), and carry out small migrations from shallow regions to the edge of the slope, probably influenced by reproductive and/or trophic patterns.

Groupers (family Serranidae) are frequent in reef zones, with strong territorial habits, but reproductive and/or trophic migrations may occur between regions of different depths (continental shelf and slope). Especially for *Mycteroperca bonaci* (Poey, 1860), a migration from deeper regions of the slope to shallow regions on the shelf is well known among fishermen, although the reasons are not scientifically understood.

Fishing on species of the family Lutjanidae, known locally as *vermelhos* (red fish), assumes important economic and social role in the Northeast Region of Brazil and are distinguished as one of the main products for export. They are considered those that attain the highest commercial values amongst reef fishes, with some species apparently overfished, showing a significant reduction of its natural stock, due to the high fishing effort applied. It may turn the exploitation of such species economically unfeasible, because of the increasing costs of production, and the decreasing abundance index.

As an example, a recent study led by Ribeiro *et al.*, (2001) on *Lutjanus purpureus* (Poey, 1876) fishery on the State of Ceará, located in the Northeast Region of Brazil, reported the depletion of fishing areas once productive and its consequent abandonment, fetching for new more distant areas, magnifying production costs and not always reaching the awaited profit. Historical data series indicate that overfishing increased the proportion of juveniles in the catches to up to 42.6%, during the 80’s. The basic problem in the study of these or other populations of snappers is, basically, to establish regulation and management measures.

The most frequent species catch composition in 2002 of Pernambuco State captures, are: mutton snapper (*cioba*), *Lutjanus analis* (Cuvier, 1828), with catches of 160.9 t, representing 2.7% and 4.1% of the total and fishes State productions, respectively; lane snapper (*ariocó*) *L. synagris* (Linnaeus, 1758), with 119.9 t, representing 2.0% and 3.0% respectively; yellowtail snapper (*guaiúba*) *L. chrysurus* (Bloch, 1791), with 69.7 t, representing 1.2% and 1.8%, respectively; and dog snapper (*dentão*) *L. jocu* (Bloch and Schneider, 1801) with 20.9 t, representing 0.4% and 0.5%, respectively.

Fluctuations concerning yearly group production seems not to be as accentuated as was observed for the coastal pelagic fishes, and this pattern seems to be related to the endemic characteristics of reef fishes, but as for the previous group, no information is available and it is not on the scope of the present study. Figure II.5 shows the production of the group and for each species separately, considering the period analysed, the lowest production being reported in 2000 (227.8 t), and the highest in 2002 (371.4 t).

The most abundant species in number, the yellowtail snapper, *Lutjanus chrysurus* (Bloch, 1791), inhabits coastal waters at depths between 10 and 70 m, mostly around coral reefs. Usually found well above the bottom, frequently in aggregation. Young fish are usually found over weed beds, and are zooplankton feeders. Adults feed on a combination of plankton and benthic animals. Mutton snapper, *L. analis* (Cuvier, 1828), is found most commonly over vegetated sand bottoms and in bays and estuaries along mangrove coasts, and also occurs around coral reefs. It forms small aggregations, which disband during the night. Feed both day and night on a variety of items. Adults of dog snapper, *L. jocu* (Bloch and Schneider, 1801); are commonly found around coral reefs, and young specimens in coastal waters, particularly estuaries and occasionally entering rivers. They feed mainly on fishes and invertebrates. The smallest of all snappers caught off Pernambuco, lane snapper, *L. synagris* (Linnaeus, 1758), is found over all types of bottoms, but mainly around coral reefs and on vegetated sandy areas. They range from shallow coastal waters to depths of 400 m. They often form large aggregations, especially during the breeding season, and feed at night on a variety of items (Allen, 1985).

The reproductive pattern of these species are very similar, with most reproducing during spring and summer, in pelagic waters, mainly during sunset and early at night, with pelagic eggs and planktonic larvae. They feed mainly on molluscs, crustaceans and small fishes. During daylight they are found in shelters and during the night can be found in small shoals. Adults generally are solitary and territorial (Carvalho Filho, 1999). Among these

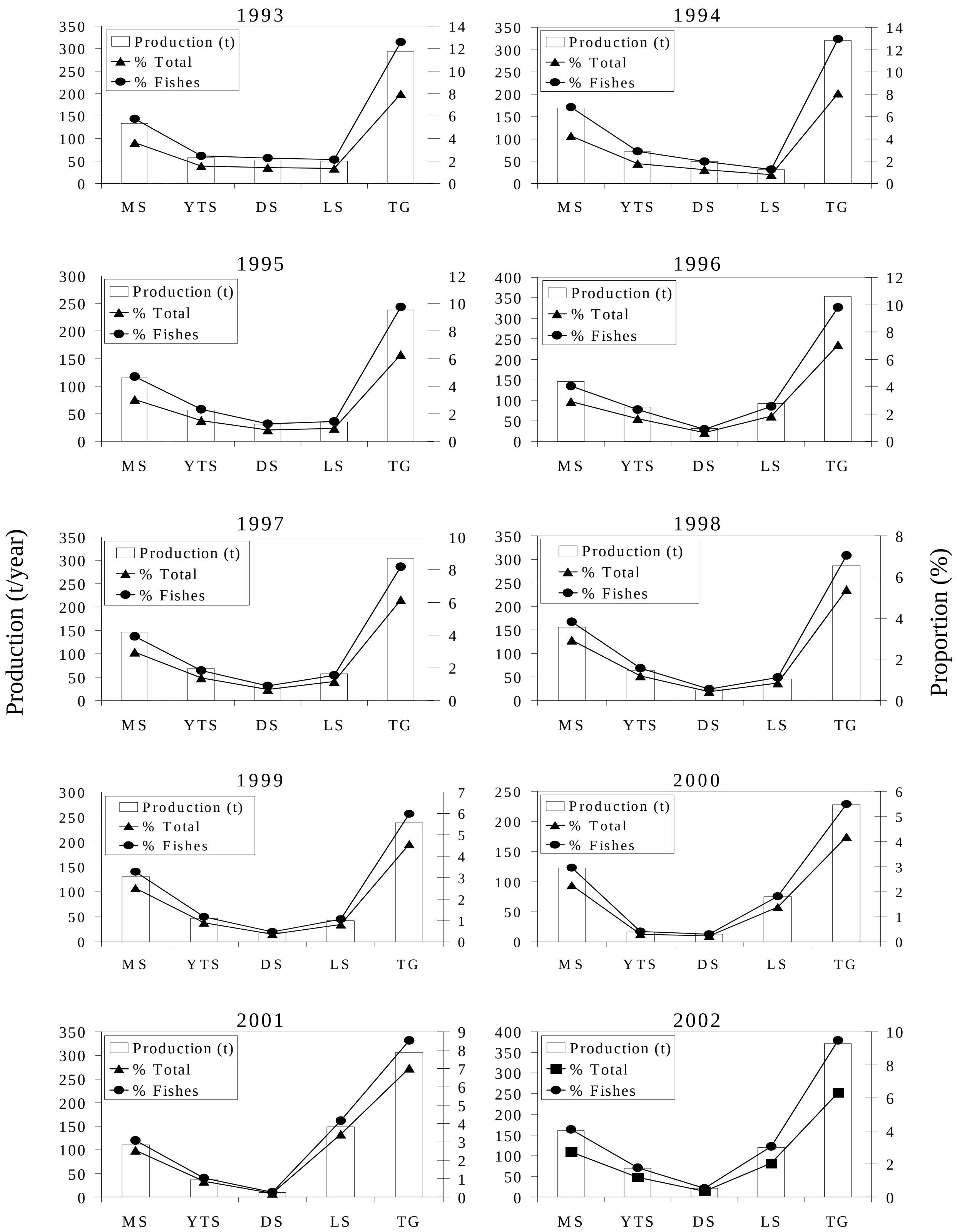


Figure II.5 – Captures (t) and relative proportion (%) of coastal reef fishes of Pernambuco State, North-eastern Brazil, total and fishes productions, from 1993 to 2002. MS - Mutton Snapper (cioba), *Lutjanus analis*; YTS – Yellowtail Snapper (guaiúba) *L. chrysurus*; DS - Dog Snapper (dentão) *L. jocu*; LS - Lane Snapper (ariocó) *L. synagris*; TG - Total of the Group coastal reef fishes.

species, the dog snapper reach the biggest size in length and weight, the mutton snapper has the higher proportion in weight in the State capture, and the yellowtail snapper has the higher in number. Further details on family and species can be found in Allen (1985).

II.4.3 - SMALL COASTAL SHARKS

Sharks are an integral and important component of marine ecosystems, playing important role for their maintenance, and are now a major conservation concern. They have a world-wide distribution and, as apex predators, the intensification of their fishery, due to a significant nutritional value of their meat and commercial value of their fins, is a matter of concern, considering that the great majority of the species present late maturation, low fecundity, slow growth and high longevity, which make them highly vulnerable to overfishing (Holden, 1974 and 1977), and many shark populations are now depleted and some are considered threatened. According to Last and Stevens (1994), although research on the ecological role of sharks is still scarce, it is know that some shark species play vital roles in marine ecosystem and are therefore crucial indicators of marine health. The depletion or removal of sharks may lead to increases or declines in others species, with unpredictable consequences for ecosystems. Sharks maintain the “genetic fitness” of their prey by removing the sick and the weak and help to keep their population sizes in check. As emphasised by Anderson (1990 *apud* Casey and Myers, 1998), elasmobranch experience low natural mortality when compared with teleost fish species and, at low population levels, are not able to compensate, for example, with increased fecundity or reduced natural mortality. Consequently, the end result of increased mortality due to fishing pressure could be extinction (Casey and Myers, 1998)

The use of shark and other chondrichthyan products pre-dates recorded history, and every part of these animals have been used for some purpose. Shark meat is an important food rpoduct consumed fresh, dried, salted or smoked in many countries. The demand for fins of sharks is growing such that they are among the world’s most expensive fishery products, and recently demand has been increasing for shark cartilage and other products for medicinal purposes. In some fisheries only the meat is retained, while the rest of the animal is discarded. In other fisheries, only the fins, or liver or skin are retained; few fisheries utilise all parts of the animals. Given the growing demand for shark products while many stocks are in decline, there is an urgent need to rationalise current patterns of usage (FAO, 2000).

Chondrichthyans fisheries require careful and specialised management, as they are more susceptible to overfishing than most other fisheries. Sharks and rays are generally slow growing and late maturing; many species do not reach sexual maturity until they are 10-12 years old. Their reproductive strategy of producing relatively few well-developed young means that the number of young produced is fairly closely linked to the size of the adult population. Most bony fishes, on the other hand, produce millions of eggs very few of which survive; it is possible to fish the adult population to a very low level and the survivors will still produce enough eggs to replenish the population (Last and Stevens, 1994).

Fisheries taking sharks and other chondrichthyans are common throughout the world and, although the overall number of species harvested is relatively small, they are taken with a variety of types of fishing gear and vessels. Sharks are taken mainly by gillnet, hook or trawl in industrial and artisanal fisheries. Small amounts are taken in traditional and recreational fisheries (including game fishers and divers) and in beach gillnet and drumline fishing bather protection programmes. There are several fisheries directed at one or a small number of species of shark, but most sharks are taken in multispecies fisheries where the fishers tend to target more highly valued teleosts. In some fisheries part or the entire shark catch is discarded (FAO, 2000).

Although representing an important fishing resource, globally sharks populations are in trouble with estimations that populations of some commercial shark species had declined in the past 8 to 15 years by up to 86% (Baum *et al.,* 2003). Despite the boom-and-bust nature of virtually all shark fisheries over the past century, most shark fisheries today still lack monitoring or management, because not all countries involved in shark fishing and international trade have even the most minimal management in place, and there is no management of sharks fished on the high seas (Hall, 2003).

The level of exploitation of elasmobranchs, in general, is little known, mainly because the statistics of each fishing nation rarely report the products obtained from many species, such as skin, jaw, fish paste, fertilisers, liver oil, cartilage, or even fins. Salted-dryed products and others for local consumption produced by the artisanal fishery are also not registered in the national statistics and neither by FAO[2]. Such difficulties, in accordance with IUCN[34] (1997), are related, mainly, to the little availability of data on sharks, such as:

- ✓ The natural history of the majority of the species;

[34] IUCN - International Union for the Conservation of Nature

- ✓ The population dynamics;
- ✓ Fishery catch and effort specific and realistic;
- ✓ Statistics on shared fishery catch;
- ✓ Independent fishery;
- ✓ Fishing plans management; and
- ✓ Ecological studies.

Thus, shark resource management and conservation is considered extremely difficult due to lack of knowledge on its current population state and the trends of population dynamics studies (Baum *et al.*, 2003). Macias (1984), studying *Rhizoprionodon terraenovae* and *R. longurio* off Mexico, noted that small sharks contribute significantly to local economy, forming an important part of the diet of a great number of Mexicans. He also stressed the need of studies on the life history of those species that can support a better stock conservation and the sustainable development of the fishing activity. For centuries artisanal fishermen have conducted fishing for sharks sustainably in coastal waters, and some still do (FAO, 2000). It seems be the case for the entirely Brazilian coast, as the importance of small coastal sharks for poor artisanal communities in Brazil, both in the Northeast and in the Southeast Regions, is remarkable (Ferreira, 1988; Gadig, 1994; Mattos, 1998).

From the studies considered and according to a previous survey, 4 species of small coastal sharks occur in the small-scale fishing off Pernambuco (Mattos, 2002), such as: the Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), the Brazilian sharpnose shark, *Rhizoprionodon lalandi* (Valenciennes, 1839), the smalltail shark, *Carcharhinus porosus* (Ranzani, 1839), and the blacknose shark, *Carcharhinus acronotus* (Poey, 1860). Even considering its low proportion in the total fishery catch off Pernambuco State and being caught as by-catch, its study should be undertaken due to its importance for the coastal food chain, for the nutrition of low income populations, and the strong anthropogenic pressure which these stocks sustain.

R. porosus, the main caught coastal species, suffers with the intense coastal and estuarine environmental impacts. IUCN (1997) registered that amongst the diverse factors that influence shark populations there are the loss and the degradation of habitats that serve, mainly, as nurseries for many species, where neonates are vulnerable to predators and find their prey more easily. Besides the described environmental factors, the utilised fishing gear (gillnet) is less selective, capturing shark with a wide size spectrum, being worse while lacking administration control on the performance of such nets.

Annual data series for the period analysed and the relative proportion of small coastal sharks considering the total and fishes production of Pernambuco State are shown in Figure II.6. It can be seen that high fluctuations of landings occur, the lowest in 1995 when 4.6 t of small coastal sharks were caught, and the highest in 2002 when 28.8 t were caught. During data collection it was possible to observe that *R. porosus* is more abundant in the north region of the fishing area (Fig. 1), but no spatial distribution can be drawn, due to the small sample size and because three (*R. porosus*, *R. lalandii* and *C. porosus*) out of four small coastal shark caught off this region are locally identified by the fishermen as the same species, called *rabo-seco* or *rabo-fino*.

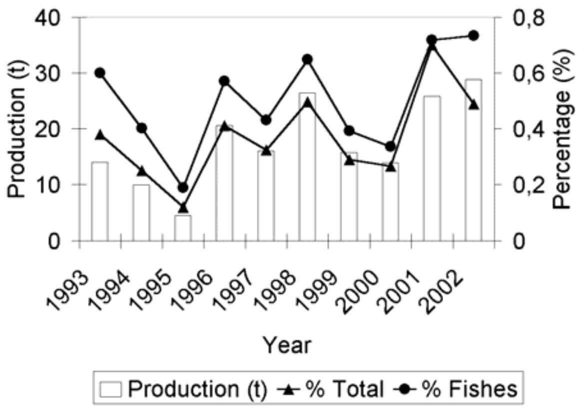


Figure II.6 - Captures (t) and relative proportion (%) of small coastal sharks on Pernambuco State, North-eastern Brazil, total and fishes productions, from 1993 to 2002.

These shark species occur from the intertidal zone to, approximately, 80 m depth, that defines the State continental shelf, including estuarine and reef zones. Despite the limited information on the shark fauna, it is known, however, that young-of-the-year of bigger size species inhabit coastal areas and are often caught by the artisanal fleet. However, considering the necessity to characterise the study habitat, only the 4 mentioned species were considered, in virtue of having all its vital cycle in coastal and continental shelf areas.

Abiotic and biotic factors probably have influence on deterministic patterns and biological rhythms of diverse shark species; however the up-to-date acquired knowledge does not allow conclusions, safe few consistent exceptions, which could explain a geographic distribution pattern of Brazilian coastal shark species (Lessa *et al.*, 1999).

Managers need to approach the management of fisheries for sharks somewhat differently from the approach they normally use in the management of marine capture fisheries. This is because sharks often have a close stock-recruitment relationship, long recovery periods in response to overfishing and complex spatial structures (size/sex segregation).

A major difficulty in assessing shark fishery stocks is that the number of species targeted is small and therefore they have not been intensively studied as a group. Furthermore, most of the shark catch is taken by fishers targeting teleost species which results in most of the catch reported as unidentified shark or mixed fish or not reported at all (FAO, 2000).

CHAPTER III – THE BIOLOGICAL ANALYSIS OF THE FISHERY

III.1 – INTRODUCTION

Nowadays there is an increasing awareness for the management of fishing stocks and models have been developed since long ago. When population dynamic studies of a particular fishing stock is to be conducted, questions that commonly flourish is 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.

Models to be applied in population dynamic studies, especially when stock assessment analysis is to be conducted, must be as simple as possible concerning mathematical formulas and input of data, and must be flexible to allow changes and adjustments of parameters, considering a particular fishery. As pointed out by Willmann and 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.

Considering that until recently fishing biological models were developed based on fisheries information of temperate regions and few are being adapted to tropical fishing conditions, the main objective of this chapter is to conduct a virtual population analysis (VPA), through the application of a model suitable for small-scale fishing, such as those developed for the North-western Mediterranean by Lleonart and Salat (1997).

As stressed in the introduction, the small-scales coastal fishery of Pernambuco State and that of North-western Mediterranean have similar characteristics. According to descriptions provided by Martín (1991), Lleonart *et al* (1999c) and Bas (2002) for the latter, both have a variable activity and highly multispecific catches and multi-gear utilization, and the seasonal activity of the fleets is related to the ecology of the different species, meteorological conditions, tourist season, etc., what is a quite good description for the Pernambuco State coastal fishery.

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.

Two groups of species were analysed, the coastal reef fishes and the small coastal sharks, caught off Pernambuco State continental shelf, located in the Northeast Region of Brazil (Figure 1). The former are represented by two species, the yellowtail snapper, *Lutjanus chrysurus* (Bloch, 1791), and the mutton snapper, *L. analis* (Cuvier, 1828), and the latter by one species, the Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861). These species comprise 4 stocks, one for each of the snappers and two for *R. porosus*, which were analysed separated by sexes.

Considering the importance of catch and effort data for the proposed analysis, it sounds clear that the choice of species was due to availability of the pertinent information to run a VPA study. Besides the relevance of fishing production as a source of income and protein for fishing communities, the two species of reef fishes are the most caught in the State coastal fishing regarding such a group, aside from their high commercial value, thus quite representative of the group and justifying the present study. In the following analysis, it was possible to compare these two stocks and infer on the necessity of regulation and management measures, even considering that both belong to the same fishery system. Unfortunately no sufficient information was available for any but all coastal pelagic fishes group of species, the other group that is under analysis on the scope of the bio-economic study.

For *R. porosus*, one should endeavour to ask why to conduct a VPA study on a species with very low level of abundance and representativeness on the State capture. Sharks represent a fishing resource of great importance in the whole world. Out of the availability of catch and effort data for the Caribbean sharpnose shark, the decision 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 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). In spite of its importance and common occurrence as by-catch in the local gillnet fishery, population dynamics studies on this species are scarce.

Thus, expecting to obtain a series of recruitment values and information on the demography of the study populations, and considering that studies on the dynamics of a single species' population subject to exploitation are necessary for fisheries management, a virtual population analysis (VPA) on the above mentioned species was conducted, taking into account the current situation of the stock under intense fishing pressure, the variations in the exploitation rate and the reaction of the population to changes in the exploitation pattern, aiming at generating information to rebuild the population and the mortality vectors.

III.2 - MATERIAL AND METHODS

III.2.1 - COLLECTION AND ANALYSIS OF FISHING DATA

During November 2001 to October 2002 the operations of 18 hand-line and 10 gillnet fishing boats had been followed. Fishery and biological information have been registered during landings, through interviews carried out with each fishing boat master and crew. Official data was utilised to permit a comparison and better analysis of this fleet operation (Chapter II). During this period, for the hand-line fleet, the following data had been collected:

- Catch in weight (total, per boat and species). Total capture in number was estimated using the calculated mean weight for a sample of the main species caught;
- Fishing effort employed (number of fishermen, number of hooks, area of net settled, annual days of fishing at sea, and hours of effectively fishing per day); and
- Catch per unit of effort (CPUE). To allow an estimation of the relative abundance index of each species, the adopted index in catch per unit of effort (CPUE) was defined as the weight of catches per 100 hooks (CPUE = kg of fish/100 hooks), per day of fishing (CPUE = kg of fish/day), per fisherman (CPUE = Kg of fish/fisherman), and per day and per fisherman (CPUE = kg of fish/day/fisherman). The monthly CPUE was calculated, considering the total production and each species separately.

For the gillnet fleet it was not possible to follow landings and, therefore, only sporadic information were collected. Nevertheless, for these occasional samplings, data gathering followed the same method as for the hand-line fleet. The only difference was that, considering the utilised gear (gillnet), the adopted CPUE index was defined as the weight of catches per 1,000 m^2 of net. The CPUE in kg of fish/day/fisherman was calculated averaging the comparison between gears. Effort was based on the estimation calculated by Mattos (1998) considering, on average, the number of boats in operation each year (226), the number of gillnets panels operated by each boat (10), the area of gillnets settled (1,600 m^2), and the number of effective fishing days (230).

For the hand-line fleet, two boats were chosen for the description of technical characteristics: *Estrela da Manhã* and *Lobo do Mar*. Its characteristics are appended in Table III.1. An overview of the Estrela da Manhã boat is shown in Figure III.1, whereas Figure III.2 shows the loading and landing processes, with boats anchored in protected artificial port, and the boats register on Port Administration is shown in Figure III.3 and III.4, respectively.

i) Easiness of access to the data of capture of these boats;
ii) Existence of relative good information on costs and expenses of fishing operations collected regularly by the owner of the two chosen boats (these information will only be analysed in Chapters IV and V);
iii) Ideal condition of accompaniment of all the strata that compose the productive chain; and
iv) Such boats can be considered as standard for the whole hand-line fleet that operates off Pernambuco State continental shelf. The same type of boats are used for the gillnet fleet.

Aside from the aforementioned collected information, the measures of each species total and fork lengths and eviscerated weight, aiming population dynamic studies of the target stocks, described in item III.2.2, was done. To enable the proper decision and analysis to be made, the physical units chosen were closely related to the actual effort placed on the stock both over time and among different types of fishing vessels.

III.2.2 – COLLECTION AND ANALYSIS OF BIOLOGICAL DATA

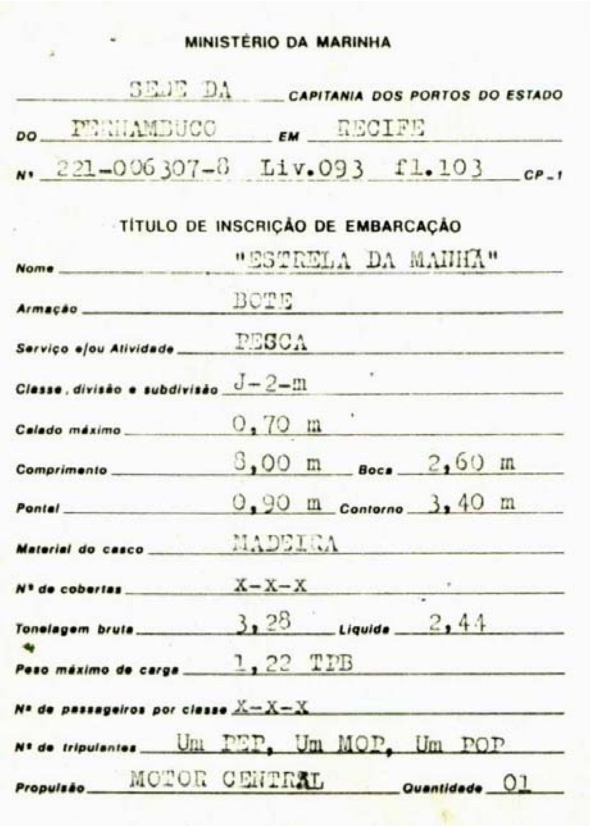
Identification of the caught species was conducted through the guides of fish’s species proposed by Compagno (1984), Szpilman (1992), Carvalho Filho (1999), and Lessa & Nóbrega (2000). From the hand-line fleet total and fork lengths and eviscerated weight for the most caught commercial species were collected from the *Estrela da Manhã* and *Lobo do Mar* boats. Linear and potential regressions between the main measures of size and weight were calculated, to facilitate future matching with specimens deriving from others fisheries.

Table III.1 – Technical characteristics of the *Estrela da Manhã* and *Lobo do Mar* boats.

Characteristics	**Estrela da Manhã**	**Lobo do Mar**
Engine	MWM D-222/2 (22 kw)	MWM D-225/3 (45 kw)
Length, over-all	8.00 m	9.00 m
Outline (contorno)	3.40 m	4.40 m
Depth or Ponton (Pontal)	0.90 m	1.20 m
Breadth, moulded	2.60 m	2.80 m
Displacement (GWT)	3.28 t	4.20 t
Fish-room capacity (urn)	1,000 kg	1,200 kg
Fuel	Diesel (60 l)	Diesel (100 l)
Maximum cargo capacity	1.22 t	1.26 t
Autonomy	8 days	8 days
Crew	3	4
Year of construction	1976	1988

Figure III.1 - Overview of the artisanal fishing boat *Estrela da Manhã.*

Figure III.2 - Loading and landing processes, with boats anchored in protected artificial port, showing the *catraia* and *luteiros*.



MINISTÉRIO DA MARINHA

SEDE DA CAPITANIA DOS PORTOS DO ESTADO

DO PERNAMBUCO EM RECIFE

Nº 221-006307-8 Liv.093 fl.103 CP-1

TÍTULO DE INSCRIÇÃO DE EMBARCAÇÃO

Nome "ESTRELA DA MANHÃ"

Armação BOTE

Serviço e/ou Atividade PESCA

Classe, divisão e subdivisão J-2-m

Calado máximo 0,70 m

Comprimento 8,00 m Boca 2,60 m

Pontal 0,90 m Contorno 3,40 m

Material do casco MADEIRA

Nº de cobertas X-X-X

Tonelagem bruta 3,28 Liquida 2,44

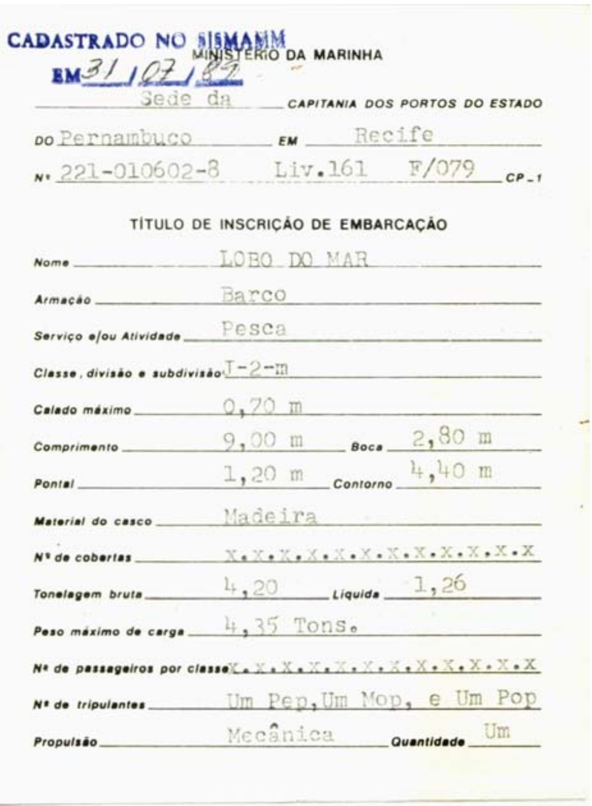
Peso máximo de carga 1,22 TPB

Nº de passageiros por classe X-X-X

Nº de tripulantes Um PEP, Um MOP, Um POP

Propulsão MOTOR CENTRAL Quantidade 01

Figure III.3 – Registration form on Port Administration of the artisanal fishing boat *Estrela da Manhã.*



CADASTRADO NO SISMAMM EM 31/07/89

MINISTÉRIO DA MARINHA

Sede da CAPITANIA DOS PORTOS DO ESTADO

DO Pernambuco EM Recife

Nº 221-010602-8 Liv.161 F/079 CP-1

TÍTULO DE INSCRIÇÃO DE EMBARCAÇÃO

Nome LOBO DO MAR

Armação Barco

Serviço e/ou Atividade Pesca

Classe, divisão e subdivisão J-2-m

Calado máximo 0,70 m

Comprimento 9,00 m Boca 2,80 m

Pontal 1,20 m Contorno 4,40 m

Material do casco Madeira

Nº de cobertas X.X.X.X.X.X.X.X.X.X.X.X.X

Tonelagem bruta 4,20 Liquida 1,26

Peso máximo de carga 4,35 Tons.

Nº de passageiros por classe X.X.X.X.X.X.X.X.X.X.X.X.X

Nº de tripulantes Um Pep, Um Mop, e Um Pop

Propulsão Mecânica Quantidade Um

Figure III.4 - Registration form on Port Administration of the artisanal fishing boat *Lobo do Mar.*

A 10 years historic data series was available, from 1993 to 2002, obtained from the Brazilian official statistical institution CEPENE[24]/IBAMA[25]. For the establishment of the von Bertalanffy's growth parameters, and consequently the determination of the growth curve in size (total length - Lt) and weight (eviscerated weight - We), when calculated for the collected data, the method of size frequency distribution was applied, according to the methodology described in Gulland (1969 and 1983), Ricker (1979), Santos (1978) and Fonteles Filho (1989). The equations are as follow:

$$L_t = L\infty\left[1 - \exp - K\left(t - t_0\right)\right] \tag{1}$$

for length, where:

- L_t = mean total length of the fish at any time *t*. In the text total length will be expressed as TL;
- $L\infty$ = asymptotic length or asymptotic value of the curve, defined as the mean size the fish of a given stock would reach if they were to grow indefinitely in the manner described by the formula;
- *K* = parameter related with the growth rate of a fish, and its magnitude has a direct relationship with the longevity of any fish;
- *t* = fish age; and
- t_0 = theoretical age at which the length of the fish (L_0) is zero.

Aiming at validating such an expression for any species, a Ford-Walford line was plotted (Walford, 1946), which relates the total length of fish at any time *t*, with this same length at time $t + \Delta t$, considering Δt constant. The graph is particularly useful for eliminating from a series of age-length data the points that do not fit the assumptions required for the application of the von Bertalanffy's growth curve.

With the expression validated, the parameters *a* and *b* of this linear regression were estimated, through the least square method:

$$L_{(t+\Delta t)} = a + b \cdot L_t$$

where:

- $L_{(t + \Delta t)}$ = total mean length at time $t + \Delta t$;
- L_t = total mean length at time *t*;
- *a* = linear coefficient of the line; and
- *b* = angular coefficient of the line.

The asymptotic value L_∞ was estimated through the formula:

$$L\infty = \frac{a}{1-b}$$

To estimate the respective values of length to the corresponding ages, relative ages had been attributed, through the mathematical expression:

$$L_t^* = \frac{\ln(L\infty - L_t)}{L\infty}$$

where:

- L_t* = corresponding length to the relative age $t*$.

Once verified the linear relationship between $t*$ and L_t*, graphic and analytically through the Pearson linear coefficient, the coefficients a' and b' of the regression $L_t* = a' + b'.t*$ were estimated by the least squares method, being possible to calculate the values of K and t_0, where:

$$K = -b' \qquad \text{and} \qquad t_0 = \frac{1}{K} \cdot \frac{\ln(L\infty - L_0)}{L\infty}$$

In accordance with the method described by Santos (1978), the parameters of the relationship between the eviscerated weight and the total length W_e/L_t can be thus established. This procedure allows to describe the relation between the two involved variable and to indicate the condition of the individuals through the estimate values of the condition factor ϕ, consisting also in one of the basic premises of the deductive method to attain growth curve in eviscerated weight of the individuals.

The expression of the empirical points was:

$$W_e = \phi \cdot L_t^{\theta} \tag{2}$$

where:

- W_e = eviscerated weight of fish at time t. In the text eviscerated weight will be expressed as EW;
- L_t = mean total length of the fish at any time t;
- ϕ = condition factor, related with the growth rate in weight of individuals; and
- θ = constant related with the type of growth, if it is isometric or allometric.

In a logarithmic transformation the expression takes the following form, with ϕ and θ values estimated by the least square method and applied to the linear relationship.

$$\ln W_e = \ln \phi + \theta \ln L_t$$

The growth curve in weight of a population is the relation between the mean eviscerated weight of the individuals and age *t*. The mathematical model of this curve was obtained through the deductive method described in Santos (1978), from the mathematical expression of the growth curve in total length and from the relation *eviscerated weight / total length*.

Substituting (2) in (1), the mathematical model of the growth curve in eviscerated weight can be expressed as follow:

$$W_e = W\infty\left[1 - \exp - K\left(t - t_0\right)\right]^{\theta}, \qquad \text{being} \qquad W\infty = \phi \cdot L\infty^{\theta}$$

where:

- $W\infty$ = asymptotic or the maximum eviscerated weight that, in average, fish can attain).

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, inserted inside of the computer program FISAT - The FAO[2]-ICLARM[35] Stock Assessment Tools. Such a method statistically separates normal distributions comprising a frequency distribution, assuming that each normal component represents one age group. Aiming at confirming the parameters $L\infty$ and *K*, the programs ELEFAN[36] and LFDA[37] were utilised, through FISAT. 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)[17], 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. As stressed by Maynou (1999)[17], this is clearly a very

[35] International Center for Living Aquatic Resources Management
[36] Electronic Length Frequency Analysis
[37] Length-based Fish Stock Assessment

restrictive hypothesis, because in general the population is not in equilibrium, as neither recruitment nor mortality is constant over time.

The program works with pseudo-cohorts, therefore suitable for analyses of non-historic series, that is to say a population analysis based on a limited time series of size or age frequencies. Others analysis tools and reporting options is 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), but basic equations for a better comprehension of the results are drawing below. Even considering the small sample size, a good amplitude of 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. For instance, the survival equation,

$$N_{(t)} = N_{(0)} \cdot e^{-Zt}$$

that can be expressed, for each class, in different form as

$$N_{i+1} = N_i \cdot e^{-Zi \cdot \Delta t}$$

and the catch equation

$$C_i = \frac{F_i}{Z_i}\left(1 - e^{-Z_i \Delta t}\right)$$

The process start with the last class and the number of individuals at the beginning of the last class is calculated using the catch equation with the terminal fishing mortality and the catch. Then, by replacing the survival equation in the catch equation, the following new expression is derived,

$$C_i = \frac{F_i}{Z_i} N_{i+1}\left(e^{Z_i \Delta t_i} - 1\right)$$

The equations that allow for the calculations of average values are the following:
Average annual numbers,

$$\overline{N}_i = \int_{t_i}^{t_{i+1}} N dt = \frac{N_i\left(1 - e^{-Z_i \Delta t_i}\right)}{Z_i}$$

Average age,

$$\bar{t}_i = \frac{\int_{t_i}^{t_{i+1}} t dN}{\int_{t_i}^{t_{i+1}} dN} = \frac{e^{-Z_i t_i}\left(t_i + \frac{1}{Z_i}\right) - e^{-Z_i t_{i+1}}\left(t_{i+1} + \frac{1}{Z_i}\right)}{e^{-Z_i t_i} - e^{-Z_i t_{i+1}}}$$

Average length,

$$\bar{l}_i = \frac{\int_{t_i}^{t_{i+1}} l dN}{\int_{t_i}^{t_{i+1}} dN} = \frac{L\infty}{e^{-Z_i t_i} - e^{-Z_i t_{i+1}}}\left(e^{-Z_i t_i}\frac{1 - Z_i e^{-K(t_i - t_0)}}{Z_i + K} - e^{-Z_i t_{i+1}}\frac{1 - Z_i e^{-K(t_i - t_0)}}{Z_i + K}\right)$$

Average weight,

$$\overline{w}_i = \frac{\int_{t_i}^{t_{i+1}} w dN}{\int_{t_i}^{t_{i+1}} dN} = \frac{aL_\infty^b}{\mu_i - \mu_{i+1}}\int_{\mu_{i+1}}^{\mu_i}\left(1 - e^{kt_0}\mu^{\frac{K}{Z_i}}\right)^b d\mu$$

The overall total (Z) and fishing (F) mortalities values are performed through the computation:

$$\overline{Z} = \frac{\sum_{i=1}^{n} Z_i \Delta t_i}{\sum_{i=1}^{n} \Delta t_i} \quad \text{and} \quad \overline{F} = \frac{\sum_{i=1}^{n} F_i \Delta t_i}{\sum_{i=1}^{n} \Delta t_i}$$

According to the survival equation this is equivalent to weighting the mortalities according to the time during which they act.

The catch equation can be rewritten as a function of the average annual number, in a way that fishing mortality per class indicates the proportion of individuals caught in each class.

$$C_i = F_i \overline{N}_i$$

This interpretation of fishing mortality can be extended to a pseudo-cohort, given that the total catch,

$$\sum_{i=1}^{n} C_i = \sum_{i=1}^{n} F_i \overline{N}_i$$

and the overall global fishing mortality F^* can be defined as,

$$\sum_{i=1}^{n} C_i = F^* \sum_{i=1}^{n} \overline{N}_i$$

or

$$F^* = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} \overline{N}_i} = \frac{\sum_{i=1}^{n} F_i \overline{N}_i}{\sum_{i=1}^{n} \overline{N}_i}$$

This is an overall value that relates the total annual catch with the average number of individuals in the population. Age class (F_{age}) and global (F_{term}) fishing mortalities were, then, established.

Once the population in numbers had been reconstructed, the transformation to biomass is done from the average numbers and weights for each class, being possible to obtain the critical ages and lengths (those corresponding to the points where the cohort reaches the maximum in biomass), for the present level of exploitation, by locating the class which provided the greatest biomass,

$$\overline{B}_i = \overline{N}_i \, \overline{w}_i$$

and for the virgin stock,

$$t_c = t_0 \frac{1}{K} \ln\left(3\frac{K}{M} + 1\right)$$

To run VIT-Program, ancillary parameters of the studied populations are needed, 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-structure population, it was necessary to proceed a conversion of size-structure composition to age-structure composition.

The length-at-age vector computed from the von Bertalanffy's growth parameters and the length-weight relationship were possible to establish, from the collected data, for two species of coastal reef fishes: the yellowtail snapper, *Lutjanus chrysurus*, and mutton snapper, *L. analis*. As data for the Caribbean sharpnose shark, *Rhizoprionodon porosus*, were available from Mattos (1998), they were used to run VIT Program.

The input value of fishing mortality as constant parameters for the whole population was calculated considering that the coefficient (*F*) is proportional to the stock density and the intensity of fishing defined as the fishing effort per unit of area or, more precisely, related with the stock density and the fishing effort, which can be expressed through the simplified equation: $F = qf$; where q = catchability coefficient and f = fishing effort.

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),

$$Z = \frac{K\left(L\infty - \bar{l}\right)}{(\bar{l} - l')}$$

where *K* and $L\infty$ are von Bertalanffy's growth parameters, $\bar{l}$ is the mean length of the fish in a sample representing a steady-state population and *l'* is the cut-off length or the lower limit of the smallest length class included in the computation. A constant value of *M* was considered. As it seemed to be of concern for Lleonart *et al.* (1999b), our result also 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 fishes.

Sizes-at-maturity for snappers were based on Froese and Pauly (2003), while for males and females Caribbean sharpnose shark were based on previous study conducted by Mattos *et al.* (2001a).

Further a yield-per-recruit (*Y/R*) analysis on the rebuilt population was conducted, as a follow up sequence proposed by VIT program. With the stock rebuilt by means of VPA, the selected method for computation of mean weights computed for each class (the default method is the exact one), was chosen. Yield-per-recruit analysis allows the user to get a more global vision of the population under study. Recruitment is defined as the number of individuals at the beginning of the first class, and yield as the total weight of the catch. Therefore, the *Y/R* is obtained by dividing the total weight of the catch by the number of recruits calculated from the VPA. The formula used in VIT is derived from the catch equation, expressed as the function of the average number of individuals per class:

$$\frac{Y}{R} = \frac{1}{N_i}\sum_{i=1}^{n} C_i \overline{w_i} = \frac{1}{N_i}\sum_{i=1}^{n} \overline{N_i}\,\overline{w_i} F_i$$

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. Transition analysis helps forecast the behaviour of the exploited population under changes in the pattern of exploitation by simulating its population dynamics, 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 changes in fishing patterns are incorporated in VIT as changes in the factor of effort or the fishing mortality applied to the various age classes and can be applied in several ways. The analysis of fishing regime shifts was done under conditions of deterministic or 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. According to Beverton and Holt, the equation that relates stock and recruitment is a monotonous asymptotic function that goes through the origin:

$$R = \frac{1}{a + \frac{b}{S}}$$

The assumption is that the new fishing mortality, given by the factor of effort (*f*), is a function of the value of *f* taken at each time period and for each age class. Although the changes in *f* can be applied during the first year of the simulation or all along the simulation, 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 function that relates the mean lognormal distribution is,

$$\mu = \ln(E(x)) - \frac{\ln\left(\frac{Var(x)}{E^2(x)} + 1\right)}{2}$$

and the variance lognormal distribution is,

$$\sigma^2 = \ln\left(\frac{Var(x)}{E^2(x)} + 1\right)$$

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 different conditions for *F* as of increase and decrease with the applied fishing gear, varied up to 100%. Also, was simulated the stock condition under the application of the maximum effort factors defined in the yield-per-recruit analysis for each species, the one that leads to the maximum sustainable yield (*MSY*). As for sake of clarity, a factor of effort equal to 2 means that the simulation considered that the fishing effort applied was the double of the current level of exploitation, and a given factor of effort of 0.5 means that the fishing effort was half. However, it must be understood and taken into account that it is a purely theoretical analysis, and that no one cannot avoid to strictly monitoring the exploitation changes of a real fishery.

The sensitivity of the parameters was also analysed, known also as risk analysis. 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). The sensitivity analysis is particularly important in developing countries where lack of sufficient data and trustworthy statistics frequently demands the assessment of the solutions and results obtained, and the correspondent advising on political matters in the case of possible errors in the applied parameters.

It was assumed that the sample distributions was representative of the catch for the period of analysis, and was used to estimate the effects of parameter variation or precision errors on the results of the *Y/R* analysis. The program computes a new run of *Y/R* analysis by changing each parameter by the extreme values: *parameter* · (*1+factor*) and *parameter* · (*1-factor*). The factor is constant for all the parameters selected in one-sensitivity analyses run, and they were treated homogeneously. The tested parameters were the 3 parameters of 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). It was performed an independent analysis of each parameter, and only the affected parameter is changed and all the others remain at their original value. The method assumes that the results obtained for any of the intermediate values will fall between the results obtained for the extreme values. Were tested changing in each parameter by a factor of 0.01 (1%), 0.05 (5%), and 0.1(10%).

III.3 – RESULTS

III.3.1 – THE COASTAL FISHERY ACTIVITY

Detailed description of boats and gears may be found in item II.3. Considering the caught species and the fishing gears under analyses, it seems that no interactions between hand-line and gillnet occurs, because notwithstanding the fact that these fleets target different species, the amount of the catch of each one fleet target species by the other is relatively low, as can be drawn from the analyses conducted in item II.4.

III.3.1.1 – THE HANDLINE FLEET

A total of 22 species were identified in the catch composition of the followed hand-line fleet (Table III.2), that represented a catch in weight of 28,184.25 kg and in number of more than 19,000 specimens (Table III.3). The main caught species, by groups of species, and their absolute and relative proportion in the catches are also shown in Table III.3.

The hand-line gear, locally called *linha-de-mão* or *pargueira*, is composed of a main line with one to four hooks, generally 2 (Figure III.5). In average, three fishing operations are realised each month, lasting 4 or 5 days each, with an average of 10 hours of effective fishing per day, if we consider that some boats fish only during the night and others (smaller in number) fish during the day and night. The monthly production, the fishing effort (days of fishing, number of hooks and number of fishermen) and the catch per unit of effort – CPUE (per day of fishing, hook, fisherman and day/fisherman) of the monitored hand-line fleet at Jaboatão dos Guararapes are shown in Table III.4.

Hand-liners crew range from 1 to 4 fishermen, generally 3, being a master and two fishers. The master is responsible for the boat[38], defines the area in which fishing will take place and has the right to choose its position where he would like to fish onboard. Although skilfulness must be taken into account, in the majority of the times such choice results in a higher productivity. Displacement until the fishing area is carried through coastal navigation, using visible points ashore to define the route and the positions of the boat and the different

[38] For the fishing master do not only behoove the boat command, but also take care of it maintenance.

fishing grounds. The fishing operations are realised throughout approximately 70% off the State continental shelf, from Itamaracá Island (northward) to Porto de Galinhas Beach (southward), having as offshore limit the edge of the continental slope.

Table III.2 – List of species caught by the monitored hand-line artisanal fleet based at Jaboatão dos Guararapes, Pernambuco State, North-eastern Brazil.

Portuguese Name	**English Name**	**Scientific Name**
Cavala	King Mackerel	*Scomberomorus cavala*
Serra	Spanish Mackerel	*Scomberomorus brasiliensis*
Dourado	Dolphin Fish	*Coryphaena hippurus*
Dentão	Dog Snapper	*Lutjanus jocu*
Cioba	Mutton Snapper	*Lutjanus analis*
Ariocó	Lane Snapper	*Lutjanus synagris*
Guaiúba	Yellowtail Snapper	*Lutjanus chrysurus*
Sirigado	Black Grouper	*Mycteroperca bonaci*
Garoupa	Red Grouper	*Epinephelus morio*
Guarajuba	Blue Runner	*Caranx crysos*
Xixarro	Bluntnose Jack	*Hemicaranx amblyrhynchus*
Bejupirá	Cobia	*Rachycentrum canadum*
Albacorinha	Blackfin Tuna	*Thunnus atlanticus*
Agulhão de Vela	Sailfish	*Istiophorus albicans*
Barracuda	Barracuda	*Sphyraena barracuda*
Arabaiana	Rainbow Runner	*Elagatis bipinnulatus*
Cavala Ipim	Wahoo	*Acanthocybium solandri*
Aracimbora	Horse-Eye Jack	*Caranx latus*
Bonito	Skipjack	*Katsuwomus pelamis*
Bico-verde	Midnight Parrotfish	*Scarus coelestinus*
Caranha	Sailor's Grunt	*Haemulon parai*
Agulhão Branco	White Marlin	*Tetrapturus albidus*

Each month, in average, 3 fishing cruises are carried out, lasting from 4 to 5 days, since during the full moon period (called *"Noite de Claro"* – clear night – by local fishers) the boats generally do not operate in consequence of the negative effect at which the excessive moon

Table III.3 – List of the main caught species by the monitored artisanal hand-line fleet, based at Jaboatão dos Guararapes, Pernambuco State, North-eastern Brazil, and their absolute and relative proportion in the catches.

Groups of species	**Portuguese Name**	**English Name**	**Scientific Name**	**Production (kg)**	**Relative (% - kg)**	**Production (n)**	**Relative (% - n)**	**CPUE (kg/100 hooks)**	**CPUE (n/100 hooks)**
Coastal Reef Fishes	Guaiúba	Yellowtail Snapper	*Lutjanus chrysurus*	4990.3	17.71	10,152	53.32	17.62	35.85
	Cioba	Mutton Snapper	*Lutjanus analis*	6366.1	22.59	3,749	19.69	22.48	13.24
	Dentão	Dog Snapper	*Lutjanus jocu*	3078.4	10.92	1,392	7.31	10.87	4.92
	Sirigado	Black Grouper	*Mycteroperca bonaci*	1783.7	6.33	231	1.21	6.30	0.82
Coastal Pelagics	Cavala	King Mackerel	*Scomberomorus cavala*	5882.5	20.87	1,986	10.43	20.77	7.01
	Dourado	Dolphin Fish	*Coryphaena hippurus*	2819.7	10.01	611	3.21	9.96	2.16
	Barracuda	Barracuda	*Sphyraena barracuda*	1119.8	3.97	224	1.18	3.95	0.79
	Bejupirá	Cobia	*Rachycentrum canadum*	615.3	2.18	45	0.24	2.17	0.16
Others	-	-	-	1528.4	5.42	648	3.40	5.40	2.29
Total	**-**	**-**	**-**	**28,184.2**	**100**	**19,038**	**100**	**99.67**	**67.23**

Table III.4 – Monthly production, effort and catch per unit of effort (CPUE) of the monitored artisanal hand-line fleet based at Jaboatão dos Guararapes, Pernambuco State, North-eastern Brazil.

Month	Production (kg)	Days of Fishing	CPUE (kg/Day)	N. of Hooks	CPUE (kg/100 Hook)	N. of Fishers	CPUE (kg/Fisher)	CPUE (Kg/Day/Fisher)
January	5,046.4	170	29.72	3,821	132.25	128	39.48	10.38
February	3,924.6	123	31.95	2,804	140.14	130	30.23	10.58
March	3,157.7	176	17.97	4,040	78.28	114	27.74	7.08
April	2,656.6	135	19.71	3,196	83.25	86	30.94	5.72
May	1,718.5	89	19.33	2,163	79.54	66	26.07	7.50
June	1,506.6	74	20.39	1,683	89.64	53	28.46	7.00
July	1,964.7	104	18.91	2,437	80.70	68	28.92	6.07
August	1,176.4	59	19.97	1,312	89.81	42	28.06	6.61
September	1,725.5	84	20.56	1,989	86.85	58	29.78	6.76
October	1,349.4	56	24.13	1,341	100.78	39	34.65	7.33
November	1,368.7	57	24.05	1,151	119.09	41	33.43	9.31
December	2,589.2	116	22.35	2,379	108.96	78	33.23	8.33
TOTAL	**28,184.2**	**1,243**	**22.70**	**28,316**	**99.67**	**903**	**31.25**	**7.21**

lights have on catches. The period of the fishing trips (days at sea) can vary in accordance with the weather conditions and fishing yield. The fishing effort applied (number of hooks) is directly proportional to the crewmembers, the type and size of the hook defined in accordance with the target species. Such relationship (hook X nylon line X target species) is established by the fishermen empirical knowledge. Two types of bait are used: sardine (*Opisthonema oglinum*, Le Sueur, 1818), acquired in the local market, and alive bait such as, the *"peixe-voador"* – flying fish – (*Hirundichthys affinis*, Günther, 1866) and *"garapau"* – bigeye scad – (*Selar crumenophthalmus*, Bloch, 1793). Live baits species are captured during the trips and placed in cages off-board so that they can stay alive during the fishing period.

Fishing takes place mainly during the night, from sunset until dawn, with the boat duly anchored. Very few boats, however, fish at the continental slope and remain adrift, and rely on the skilfulness of the skipper. During the day fishermen generally rest, leaving a floated line for the capture of coastal pelagic species. The caught fishes are marked at differentiated form as for identification of each fisherman production, through cuts in the extremities of tails and fins, on such a way that the production can be considered individualised. This method allows each fisherman to receive for its production, eliminating, thus, the risks of conflicts among crewmembers.

The caught species are placed on deck and later gutted and placed in isothermal ballot boxes. Harbour structure is highly inefficient, boats remaining anchored in protected natural or artificial bays, and most of the small-scale fleet land their production directly at beaches helped by *luteiros*[30] and through small boats called *catraia*[29] (Figure III.2). This labour force retains 10% of the production value for landing, being this value distributed with the total of *luteiros* that had effectively worked (this will be discussed in detail in Chapter IV).

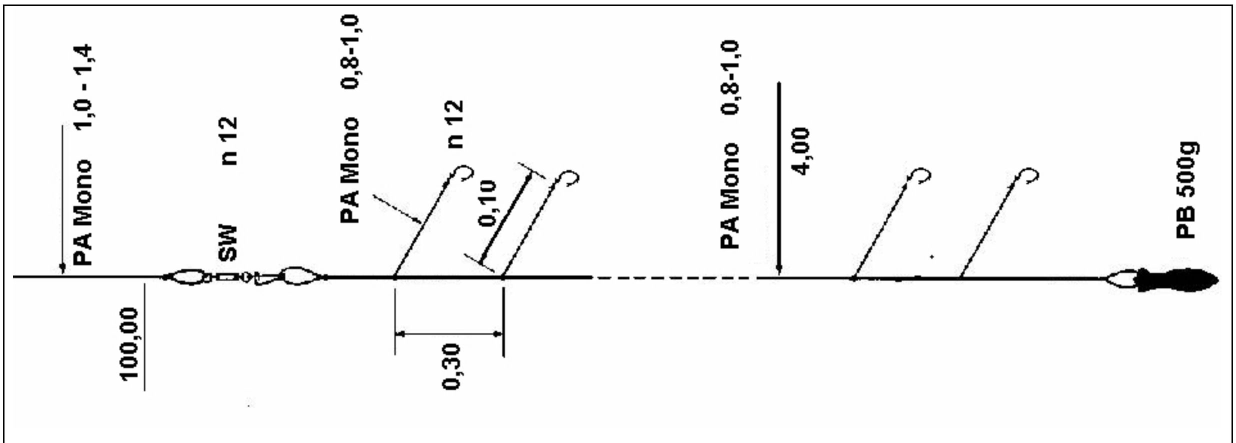


Figure III.5 – Characteristics of the fishing gear used by the hand-line fleet.

III.3.1.2 – THE GILLNET FLEET

For the gillnet fleet, it was not possible to follow landings. For a significant number of boats the effort in number of days, area (m^2) of nets in operation and number of fishermen, as well as the CPUE per 1,000 m^2 of net (12 kg/1,000 m^2), fisherman (8.96 kg/fisherman) and day/fisherman (8.83 kg/day/fisherman), was annotated aiming at comparison with the hand-line.

Fishing usually occurs off Pernambuco continental shelf, in depths between 10 and 30 m, and nets are set in mud and sand bottoms. As described by Mattos *et al.* (2001a), gillnets consisted of polyamide monofilament mesh measuring 80-120 mm between the knots (stretched mesh), up to 26 meshes in depth and hung at a ratio of between 0.5 and 0.6 on a buoyed headline. The gears are made of several panels of approximately 100 m in length (Figure III.6). Nets were set and retrieved by hand twice each night, with an effective fishing time of 10 hours. On average, the artisanal fishing vessels that took part in this fishery were small wooden boats, with 8.0 m mean length, 3.5 GRT displacement, and 35 kW engine power, without hydraulic winches.

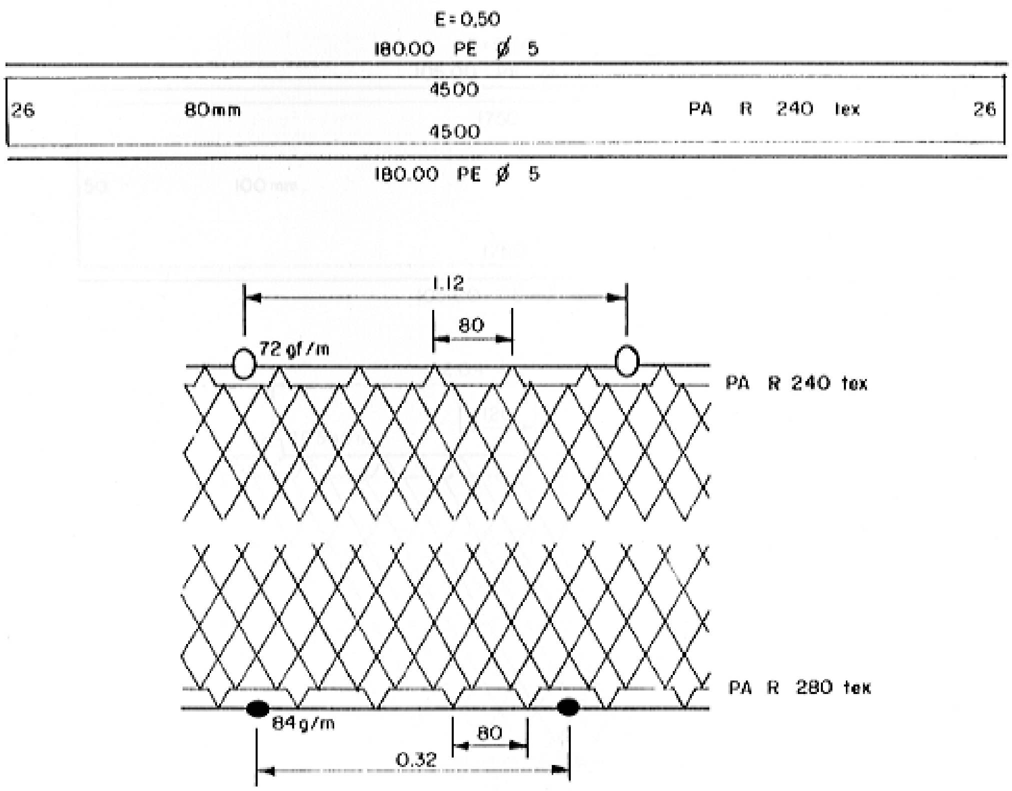


Figure III.6 – Characteristics of the fishing gear used by the gillnet fleet.

The gillnet fishery catches a variety of species, targeting Blue Runner, *Caranx crysos*, Spanish Mackerel, *Scomberomorus brasiliensis*, and Lane Snapper, *Lutjanus synagri*, but the absolute and relative decrease in landings of such species are turning fishermen attention to others less valuable species, such as small coastal sharks, as well as moving the operation of the fleet to areas of fishing whose abundance is relatively lower, increasing operation costs. As well as detected in the present study and those lead by SUDENE (1983), in the State of Pernambuco commercial fishing for small coastal sharks are carried out in predominantly mud bottoms.

In 2002 small coastal sharks represented 1.8% of gillnet captures, with medium commercial value. Four species of small coastal sharks composes the gillnet fishery off Pernambuco: *Rhizoprionodon porosus*, *R. lalandii*, *Carcharhinus aconotus* and *C. porosus* (Mattos, 2002). The Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), is the main caught species, which represents approximately 60% of small coastal sharks captures (fishermen information). It has a wide distribution in the eastern coast of the American continent, ranging from Caribbean to Uruguayan waters. It mainly inhabits continental and insular shelves of tropical and temperate regions (Springer, 1967; Compagno, 1984), being abundant in the entire Brazilian coast.

Just after catch, all fishes are eviscerated, sharks beheaded, washed and conditioned in icebox. Otherwise, the time expended in each fishing operation depends on the time of the year and the volume of capture. During the rainy season, with intense SE winds, fishing usually takes 1 day, boats returning to port every morning, sometimes even late at night. During the summer (dry season), fishing could last up to 5 days, being the most common periods between 2 and 3 days.

For the relative abundance of small coastal sharks, Mattos (1998) estimated the catch per unit of effort (CPUE), in terms of weight and number of individuals caught/1000 m^2 of net/day, as 0,25 of kg/1000 m^2 of net/day or 0,19 of sharks/1000 m^2 of net/day. The estimate had been based on an effort of 2.000 nets, admitting that each boat uses, in average, 10 nets, what gives an area of 1.600 m^2 for boat and a total of 260 fishing days/year.

III.3.2 – THE BIOLOGICAL RESOURCES

The population dynamic study by means of virtual population analysis, through the computational program VIT – Software for Fisheries Analysis, was conducted for two species of coastal reef fishes, the yellowtail snapper, *Lutjanus chrysurus* (Bloch, 1791), and the mutton snapper, *Lutjanus analis* (Cuvier, 1828), because the collected data fit the requirements to establish the growth parameters, and a small coastal shark, the Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), for which species Mattos and Pereira (2002) established the required growth parameters, but raw data was available. For this species, these authors found significant difference between sexes, so the analysis was conducted distinctly for each sex. For the two others species herein studied, sexes were analysed together, because identification was not possible.

III.3.2.1 – SOME MORPHOMETRIC INFORMATIONS AND CATCH DATA ANALYSIS

Although for the collected data population dynamic studies was only possible for the two species of coastal reef fishes before mentioned, regressions of the collected dimensions relating total (TL) with fork lengths (FL), and total and fork length with eviscerated weight (EW), depicted in Table III.5, was established for the main species captured by the hand-line fleet listed in Table III.3, aiming at contributing for future studies of such population when one of these measures would not be possible to collect, and comparison between populations of such species. It can be seen that all estimated regression showed a high correlation value and can properly be further used. Care must be taken with the regression TL and EW and FL and EW for Barracuda and Cobia, whose *b* values were quite different of 3, the expected value in such relation.

A total of 10,152 specimens of yellowtail snapper were caught, but only 529 were measured and weighted which allowed the establishment of regressions lines, the length-weight relationships, and the frequency distribution for the estimation of the von Bertalanffy's growth parameters. Length ranged from 26 cm to 64 cm; 92.8% of the individuals in the analysed sample ranged from 30.1 cm to 45 cm; 51.8% were in the length-class interval from 35.1 cm to 40 cm; 46.3% between 37.6 and 42.5; whilst 32.7% in the class 37.6 cm to 40 cm (Figure III.7). The 10 year historic annual catches data series, from 1993 to 2002 (Figure III.8). With an average catch of 57.1 t, shows the trends in catch and the relative participation of yellowtail snapper in the State total production. From 1993 to 2000, the data series shows a decreasing trend, increasing sharply from 2000 to 2002. The highest catch was in 1996, when 83.4 t of yellowtail snapper were caught, and the lowest in 2000, when only 17 t were caught.

Table III.5 – Regressions for the main caught species of the hand-line fleet settled at Jaboatão dos Guararapes, Pernambuco State, North-eastern Brazil.

Portuguese Name	English Name	Scientific Name	TL X FL	TL X EW	FL X EW
Guaiúba	Yellowtail Snapper (n = 529)	*Lutjanus chrysurus*	$FL=0.9132TL^{0.9806}$ $R^2 = 0.9115$	$EW=0.0183TL^{2.7753}$ $R^2 = 0.8753$	$EW=0.0414FL^{2.6689}$ $R^2 = 0.8541$
Cioba	Mutton Snapper (n = 252)	*Lutjanus analis*	$FL=0.8927TL^{1.0086}$ $R^2 = 0.9785$	$EW=0,0112TL^{3,002}$ R2 = 0,9795	$EW=0.0184FL^{2.9364}$ $R^2 = 0.9666$
Dentão	Dog Snapper (n = 99)	*Lutjanus jocu*	$FL=0.9279TL^{1.0066}$ $R^2 = 0.9962$	$EW=0.0085TL^{3.0942}$ $R^2 = 0.9696$	$EW=0.0109FL^{3.0696}$ $R^2 = 0.9706$
Sirigado	Black Grouper (n = 23)	*Mycteroperca bonaci*	$FL=0.7784TL^{1.0493}$ $R^2 = 0.9986$	$EW=0.02TL^{2.9024}$ $R^2 = 0.9807$	$EW=0.0407FL^{2.7621}$ $R^2 = 0.9793$
Cavala	King Mackerel (n = 150)	*Scomberomorus cavala*	$FL=0.7771TL^{1.0353}$ $R^2 = 0.9599$	$EW=0.0025TL^{3.1589}$ $R^2 = 0.9566$	$EW=0.007FL^{2.988}$ $R^2 = 0.9611$
Dourado	Dolphin Fish (n = 41)	*Coryphaena hippurus*	$FL=0.6772TL^{1.0512}$ $R^2 = 0.9437$	$EW=0.0099TL^{2.82}$ $R^2 = 0.9585$	$EW=0.0373FL^{2.6184}$ $R^2 = 0,9677$
Barracuda	Barracuda (n = 29)	*Sphyraena barracuda*	$FL=0.7843TL^{1.0373}$ $R^2 = 0.9987$	$EW=4.5975TL^{1.5157}$ $R^2 = 0.9036$	$EW=6.617FL^{1.4592}$ $R^2 = 0.9022$
Bejupirá	Cobia (n = 16)	*Rachycentrum canadum*	$FL=0.6236TL^{1.0795}$ $R^2 = 0.9127$	$EW=4E\text{-}07TL^{5.0826}$ $R^2 = 0.8572$	$EW=5E\text{-}06FL^{4.6276}$ $R^2 = 0.9072$

TL – Total Length; FL – Fork Length; EW – Eviscerated Weight.

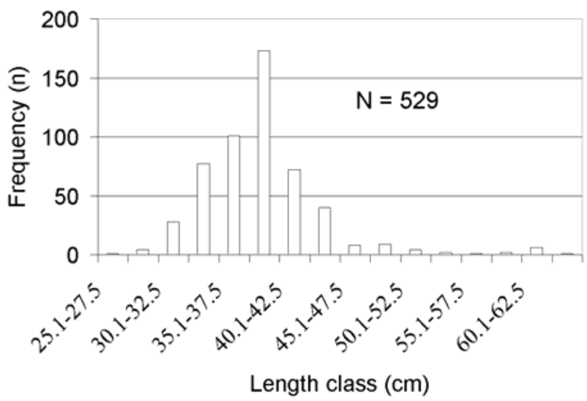


Figure III.7 - Length frequency distribution of the yellowtail snapper, *Lutjanus chrysurus*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

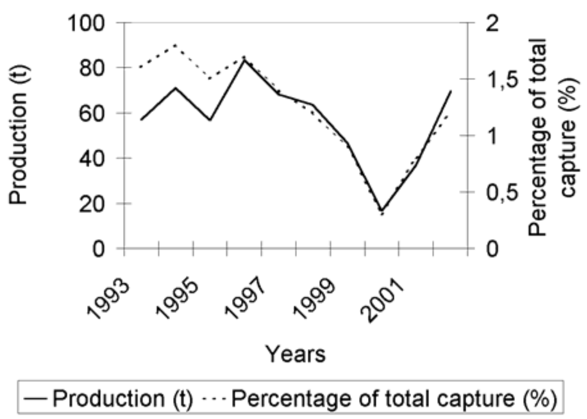


Figure III.8 - Trends of catch and relative participation in Pernambuco State, North-eastern Brazil, total production of yellowtail snapper, *Lutjanus chrysurus*, from 1993 to 2002.

Considering the average species catch for the corresponding data series, the highest production represents an increase of 46.1%, while the lowest production a decrease of 70%. The difference between the highest and lowest catches is as high as 390.6%. There is less available information that can explain in details the variation for yellowtail snapper catches. An analysis of the monthly catches data series for the considered period (Figure III.9) also denotes, with few exceptions, no seasonal variations, but high variability during the year.

As for the mutton snapper, *Lutjanus analis*, a total of 3,749 specimens were caught, but only 252 were measured and weighted which allowed the establishment of regressions lines, length-weight relationships, and the frequency distribution for the definition of growth parameters. Length ranged from 32 cm to 90 cm; 58.3% of the individuals in the analysed sample ranged from 40.1 cm to 55 cm; 43.6% were in the length-class interval from 40.1 cm to 50 cm; 37.7% from 45.1 cm to 55 cm; whereas 23% from 45.1 cm to 50 cm (Figure III.10). The historic annual catches data series, from 1993 to 2002 (Figure III.11), with an average in catches of 139.14 t, shows the trends in catch and the relative participation of mutton snapper in the State total production. It seems that mutton snapper catches are relatively stable, because very small variations can be observed. The highest catch was in 1994, when 169.13 t of mutton snapper were caught, and the lowest in 2001, when 110.7 t were caught. Considering the average species catch for the corresponding data series, the highest production represents an increase of 21.6%, while the lowest production a decrease of 20.4%. The difference between the highest and lowest catches is of 52.8%.

Although, for mutton snapper, trends in catches is not as accentuated as for yellowtail snapper, it seems that, for the available data, mutton snapper presents a seasonal higher catch during summer (from December to February in the Southern Hemisphere), not evidence in all years analysed, but showing a tendency of higher productivity.

A total of 273 specimens of the Caribbean sharpnose shark were analysed, 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. The Kolmogorov-Smirnov test presented significant differences ($p < 0.001$) between the total length frequency distributions for males and females (Figure III.13). Through ANCOVA it was observed that a significant difference occurred between the length-weight relationship of males and females ($F = 4.0966$; $P < 0.05$). A very good fit was obtained both for males ($R^2 = 0.9427$) and females ($R^2 = 0.9545$), and a slightly allometry can be observed, with b for males less than 3 ($b = 2.8993$) and for females higher ($b = 3.1666$) (Mattos et al., 2001). Females

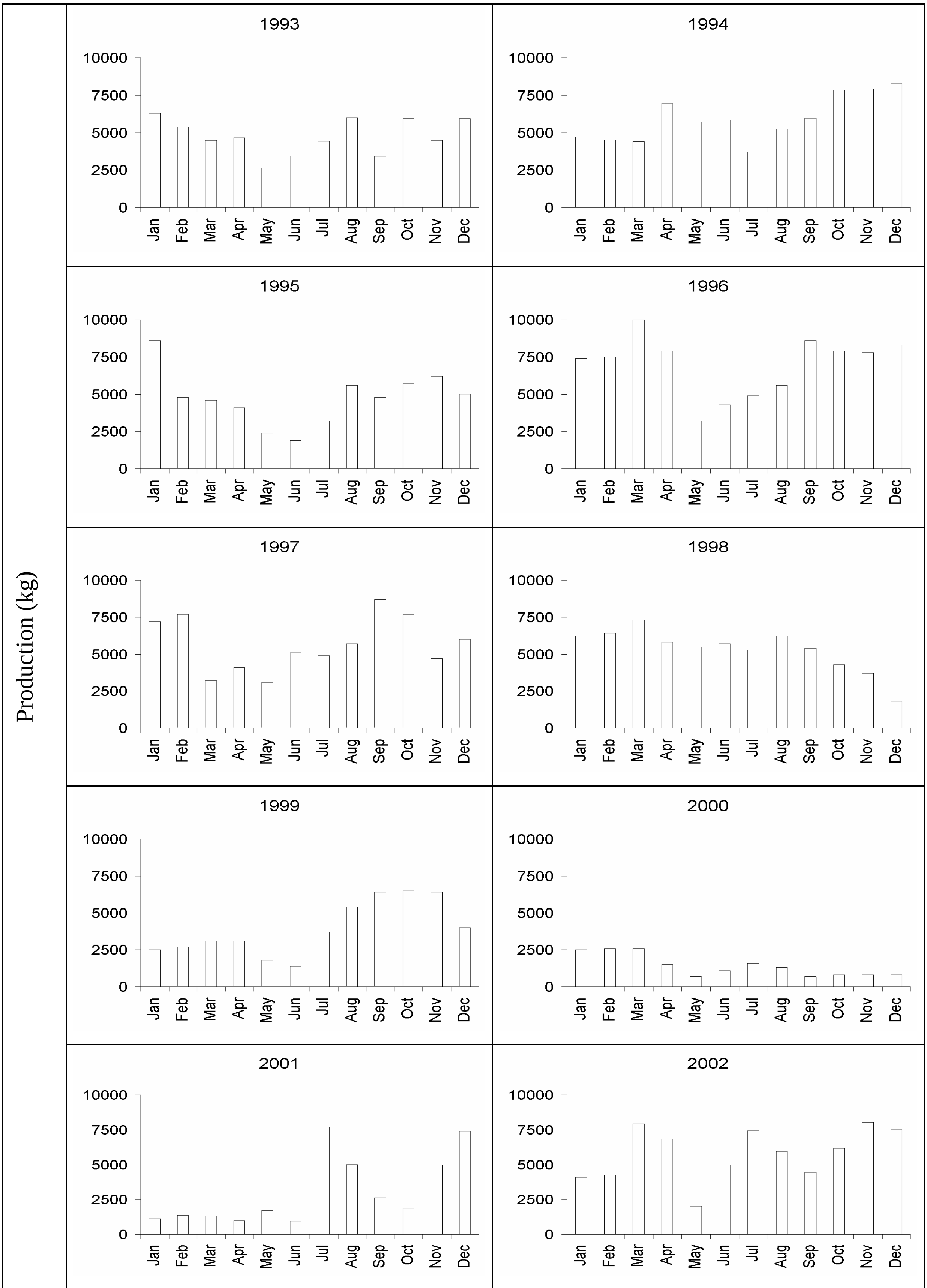


Figure III.9 – Monthly catches data series for the yellowtail snapper, *Lutjanus chrysurus*, from 1993 to 2002, in Pernambuco State, North-eastern Brazil.

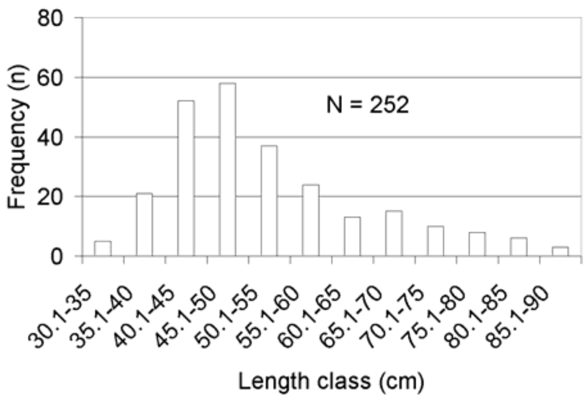


Figure III.10 - Length frequency distribution of the mutton snapper, *Lutjanus analis*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

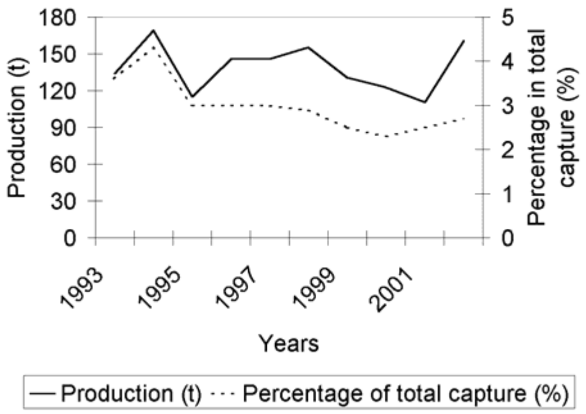


Figure III.11 - Trends of catch and relative proportion in Pernambuco State, North-eastern Brazil, production of mutton snapper, *Lutjanus analis*, from 1993 to 2002.

distributed most frequently from 65.1 cm to 70 cm (25.2%), whereas males from 60.1 cm to 65 cm (26.4%). Otherwise, both sexes were more frequent for the length class from 60.1 cm to 70 cm (49.7% for females and 48.1% for males).

The 10 year historic annual catches data series (Figure III.14), from 1993 to 2002, with an average catch of 17.6 t, shows that small coastal sharks captures slightly increased during this period, as for total capture and relative participation in the total State fishery production. The highest catch was in 2002, with 28.8 t, and the lowest in 1995, when only 4.5 t of small coastal sharks capture was registered. Considering the average catch for the period analysed, the highest catch presented an increase of 63.9%, whilst the lowest a decrease of 74.4%. The difference between the highest and lowest catches was as high as 540%.

As for the annual data series of small coastal sharks, the monthly catches data series for the same period are shown in Figure III.15. It can be seen that no seasonal variation in landings occurs, and this lack of seasonally was already suggested by Mattos (1998) and Mattos *et al.* (2001a). During data collection it was possible to observed that *R. porosus* is more abundant in the north region of the fishing area (Figure I.1), but no spatial distribution

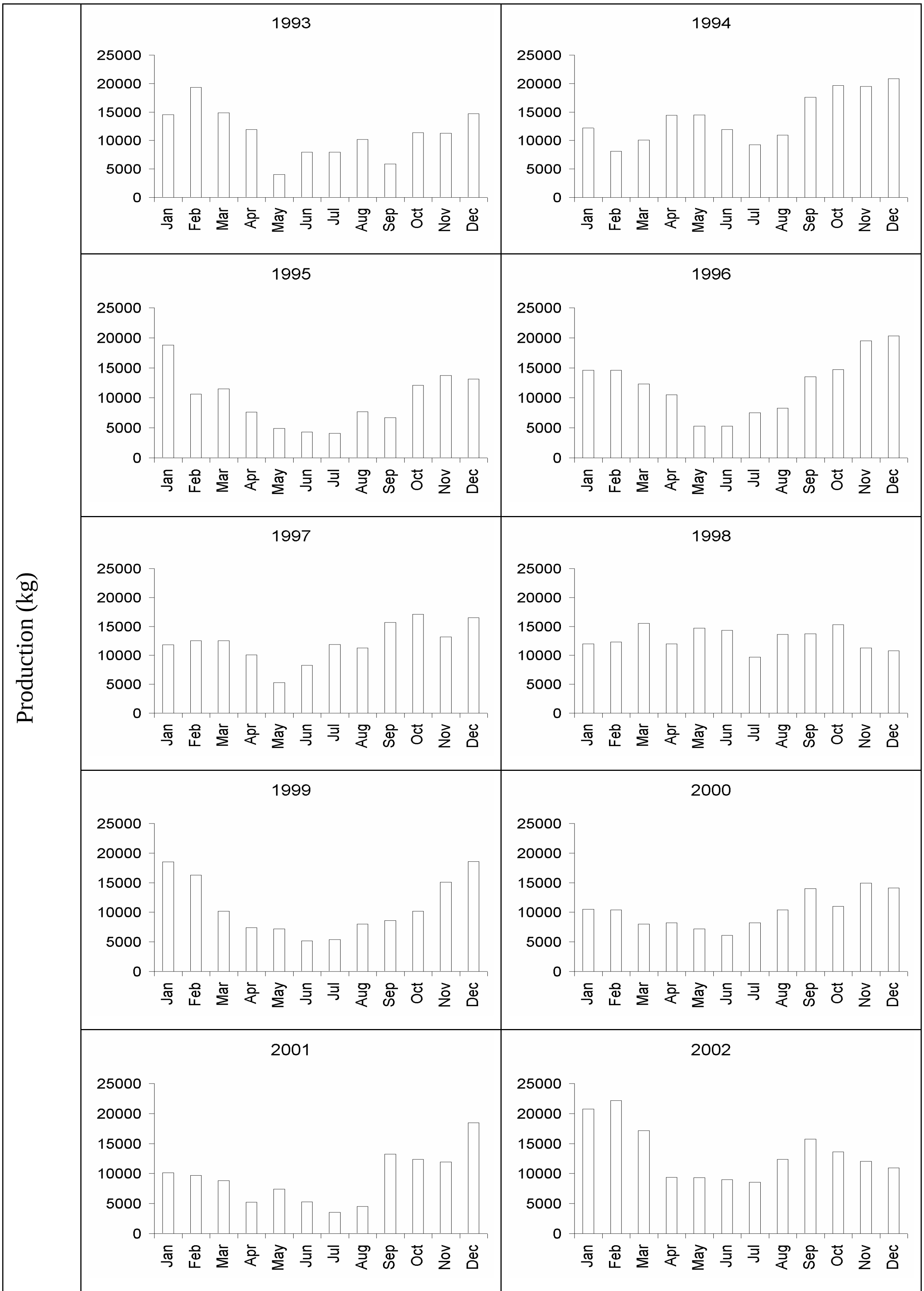


Figure III.12 – Monthly catches data series for the mutton snapper, *Lutjanus analis*, from 1993 to 2002, in Pernambuco State, North-eastern Brazil.

can be drawn, due to the small sample size and because three (*R. porosus*, *R. lalandii* and *C. porosus*) out of the four small coastal shark species caught off this region are locally identified – called *rabo-seco* or *rabo-fino* – by the fishermen as the same species, as already mentioned in item II.4.3.

Trustworthy fishery data information does not allow for the conduction of any statistical analysis for the three species herein studied. As also the total State fishery captures increased by 59.9% along this analysed period, from 3,679.8 t, in 1993, to 5,884.5 t, in 2002, it seems more reasonable to think that fishery statistic data collection are being more accurate, specially with the information of less valuable fishing stocks. A reasonable explanation is the one proposed by Mattos (1998) for whom the decrease in catch of the most valuable species lead the fishermen to commercialise less valuable and non-target species, such as small coastal shark and once distributed among community neighbourhood, to increase profit and confront the daily increase of fishing expenses. This suggests that the relatively decrease in catches for the snappers and the slightly increasing trend in small coastal shark species follows such a trend.

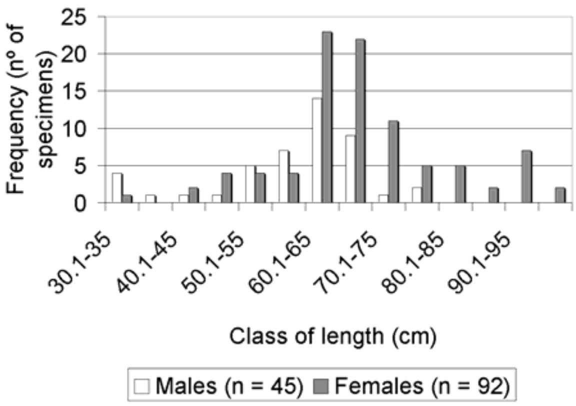


Figure III.13 - Length frequency distribution of males and females Caribbean sharpnose shark, *Rhizoprionodon porosus*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

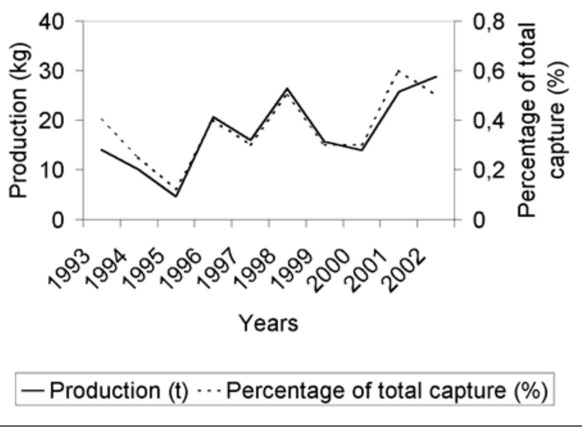


Figure III.14 - Trends of catch and relative proportion in Pernambuco State, North-eastern Brazil, total production of small coastal sharks, from 1993 to 2002.

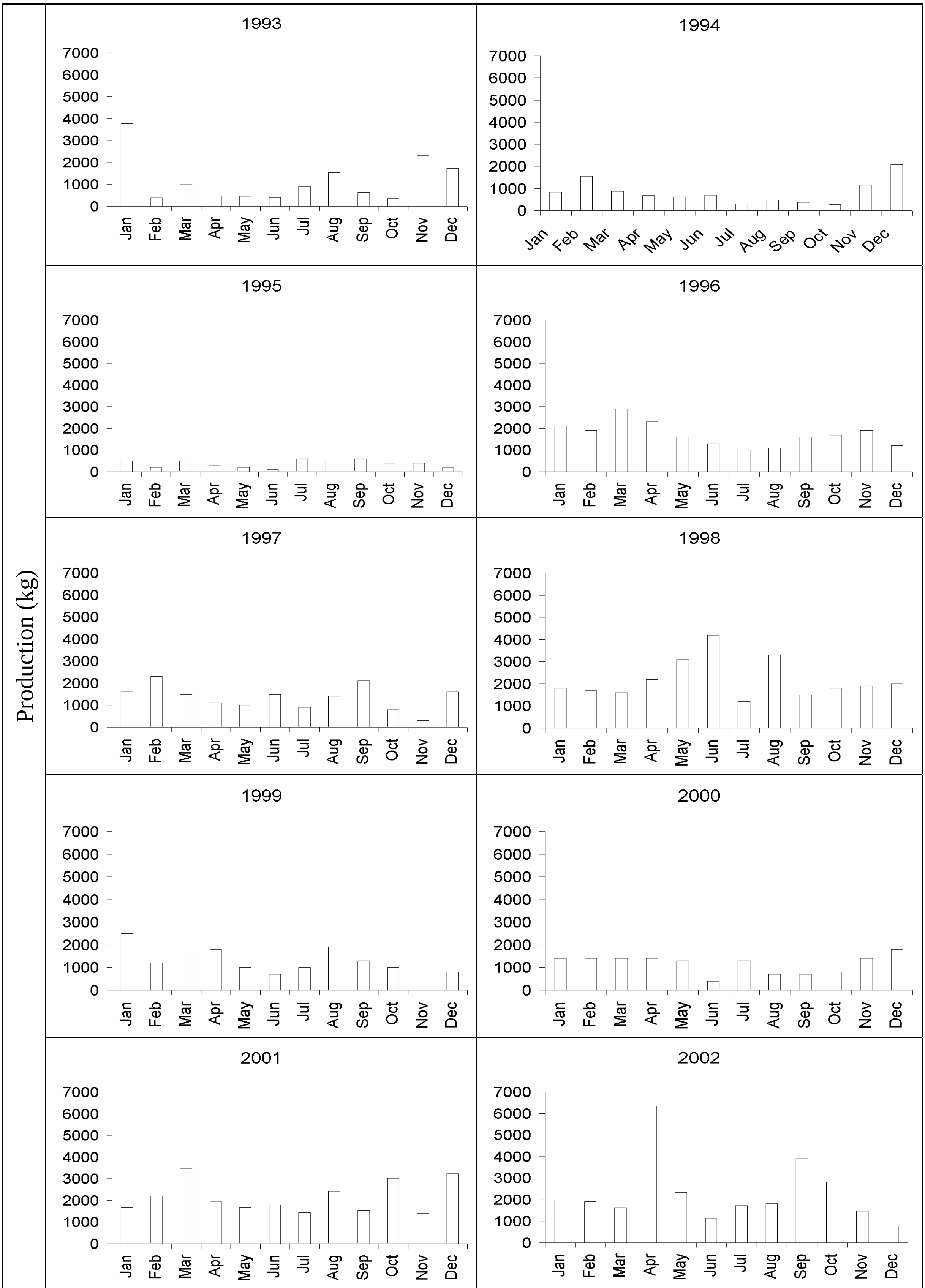


Figure III.15 – Monthly catches data series for small coastal sharks, from 1993 to 2002, in Pernambuco State, North-eastern Brazil.

III.3.2.2 – GROWTH-AT-AGE ANALYSIS

The length-at-age vector computed from the von Bertalanffy's growth parameters and the length-weight relationship were only possible to establish for the yellowtail snapper (Table III.6) and mutton snapper (Table III.7, two coastal reef species. A total of 529 specimens of yellowtail snapper were sampled which permitted the establishment of the length-weight relationships: a = 0.0183, and b = 2.7753; and the growth parameters L_{∞} = 76.67 cm; W_{∞} = 3.104 kg; K = 0.158; and t_0 = -0.728 year. The growth equation in length is as follow:

$$L_t = 76.67\left[1 - \exp - 0.158(t - 0.728)\right]$$

and in weight,

$$W_e = 3.104\left[1 - \exp - 0.158\left(t - 0.728\right)\right]^{2.7753}$$

Table III.6 – Age, length and weight vectors for yellowtail snapper, *Lutjanus chrysurus* (Bloch, 1791), caught off Pernambuco State, North-eastern Brazil, continental shelf.

Age (year)	Total Length - TL (cm)	Eviscerated Weight - EW (kg)
0	0	0
1	11.21	0.015
2	20.77	0.083
3	28.94	0.208
4	35.92	0.378
5	41.87	0.579
6	46.96	0.796
7	51.30	1.018
8	55.01	1.235
9	58.17	1.443
10	60.87	1.637
11	63.18	1.815
12	65.15	1.976
13	66.84	2.121
14	68.27	2.250
15	69.50	2.364

The length-weight parameters for the Mutton Snapper, are: a = 0.0112; and b = 3.0019, and the von Bertalanffy growth parameters are L_{∞} = 108.20; cm; W_{∞} = 14.34 kg; K = 0.168; and t_0 = -0.892 year. The equation in length is as follow:

$$L_t = 108.20[1 - \exp - 0.168(t - 0.892)]$$

and in weight,

$$W_e = 14.34[1 - \exp - 0.168(t - 0.892)]^{3.0019}$$

Table III.7 – Age, length and weight vectors for mutton snapper, *Lutjanus analis* (Cuvier, 1828), caught off Pernambuco State, North-eastern Brazil, continental shelf.

Age (year)	Total Length - TL (cm)	Eviscerated Weight - EW (kg)
0	0	0
1	16.78	0.053
2	30.96	0.335
3	42.94	0.895
4	53.07	1.690
5	61.62	2.646
6	68.84	3.692
7	74.95	4.764
8	80.11	5.818
9	84.47	6.820
10	88.15	7.752
11	91.26	8.603
12	93.89	9.370
13	96.11	10.050
14	97.98	10.650
15	99.57	11.176

For the Caribbean Sharpnose Shark, the growth parameters were based on previous study conducted by Mattos and Pereira (2002), for separated sexes, as these authors found that significant difference occurred between sexes. For females the growth parameters are: L_{∞} = 106.82 cm; W_{∞} = 4.513 kg; K = 0.3; and t_0 = -1.12 year; and the length-weight relationship: a = 0.0017, and b = 3.1666. For males the growth parameters are: L_{∞} = 87.13 cm; W_{∞} = 2.278 kg; K = 0.42; and t_0 = -1.1 year; and the length-weight relationship are a = 0.0054, and b =

2.8993. Age, length and weight vectors for females and males Caribbean sharpnose shark are depicted in Tables III.8 and III.9, respectively.

Table III.8 – Age, length and weight vectors for females Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), from Mattos and Pereira (2002), caught off Pernambuco State, North-eastern Brazil, continental shelf.

Age (year)	Total Length - TL (cm)	Eviscerated Weight - EW (g)
0	32.50	104.23
1	51.70	453.34
2	65.94	979.51
3	76.50	1,567.90
4	84.34	2,134.89
5	90.15	2,636.24
6	94.45	3,056.28
7	97.65	3,395.84
8	100.02	3,663.74
9	101.78	3,871.52
10	103.08	4,030.72
11	104.05	4,151.65
12	104.76	4,242.92
13	105.29	4,311.50
14	105.69	4,362.84
15	105.98	4,401.19

III.3.2.3 – VIRTUAL POPULATION ANALYSIS (VPA)

After the definition of the ancillary parameters for the chosen species, a virtual population analysis (VPA) was conducted through VIT Program – Software for Fishery Analysis, which allowed the provision of indicators and reference points.

For the yellowtail and mutton snappers, it was estimated that the hand-line fleet operates in 70% off Pernambuco State continental shelf. For the former species the fishing mortality (*F*) was estimated considering a catch per unit of effort (CPUE) of 17.62 kg/100 hooks, a total annual catch of 97.6 t, an effort (*f*) of 28,316 hooks, and a coefficient of catchability (q) of 1.26 x 10^{-5}; while for the latter a CPUE of 22.48 kg/100 hooks, a total annual catch of 160.9 t, f of 28,316 hooks, and q of 0.97 x 10^{-5}. Thus, F was calculated to be 0.358 and 0.277, respectively. For yellowtail snapper, the total mortality (Z) was estimated as 0.470, whilst for the mutton snapper as 0.429; this gave an estimation of the natural mortality (M) equal to 0.112 and 0.152, for the yellowtail snapper and mutton snapper, respectively.

Table III.9 – Age, length and weight vectors for males Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), from Mattos and Pereira (2002), caught off Pernambuco State, North-eastern Brazil, continental shelf.

Age (year)	Total Length - TL (cm)	Eviscerated Weight - EW (g)
0	32,50	130,56
1	51.35	491.88
2	63.70	918.67
3	71.79	1,299.07
4	77.08	1,596.80
5	80.55	1,814.10
6	82.82	1,966.39
7	84.31	2,070.52
8	85.28	2,140.64
9	85.92	2,187.39
10	86.34	2,218.37
11	86.61	2,238.81
12	86.79	2,252.25
13	86.91	2,261.09
14	86.98	2,266.89
15	87.04	2,270.70

As, from the collected data, it was not possible to estimate the maturation rate for the two snapper species, the information provided by Froese and Pauly (2003), through the average length-at-maturity for both species was used. According to the information provided by these authors, *Lutjanus chrysurus* first mature between 25 cm and 30 cm. Taking into account the length frequency distribution, it was considered that age-at-maturity, age at which 50% of the individuals are mature, for yellowtail snapper was estimated for the length-class 27.6 cm and 30 cm, while all those above 30 cm were supposedly mature. Through a standard

VPA, and after converting the size-structure data set to an age-structure data set, 11 year-classes was created by the VIT Program, and it estimated that 73.8% of the individuals belonging to the age 2 year-class were mature, whilst all those on the 3+ year-class[39] were mature. The 4 years age class presented the higher mortality rate; VIT estimated a Z = 1.296 (mean rate of 0.54) and an F = 1.184 (mean rate of 0.428). Global fishing mortality was found to be 0.306; while the terminal F was found to be 0.067.

For *Lutjanus analis* these same authors inform that first maturation occur between 40 cm and 50 cm. It was considered, thus, following the same procedure as for *Lutjanus chrysurus*, that age-at-maturity for mutton snapper occur in the length-class 40-45cm, while all those above 45 cm were supposedly mature. Through a standard VPA, and after converting the size-structure data set to an age-structure data set, 9 year-classes was created and VIT Program estimated that 7% of the analysed population reach maturation during the first year of life, 83.6% of the individuals belonging to the age 2 year-class were mature, whilst all those in the 3+ year-class were mature. The 2 years age class presented the higher mortality rate. VIT estimated the higher value for Z = 0.654 (mean rate of 0.465) and for F = 0.502 (mean rate of 0.313). Global fishing mortality was found to be 0.3; while the terminal F was found to be 0.2.

For the Caribbean sharpnose shark, fishing effort (f) and CPUE were established by Mattos (1998). For the estimation of F through the formula $F = qf$, the necessary catch per unit of effort (CPUE) data was 0,6 kg/1,000 m^2 and 0.9 kg/1,000 m^2, and the average weight of 840.52 g and 1,145.47 g, for males and females, respectively. Utilising these data was possible to estimate $q = 0.785 \times 10^{-6}$ for females and $q = 0.714 \times 10^{-6}$ for males, considering f = 320.000 m^2 of net/day for both sexes.

The von Bertalanffy growth parameters and the length-weight relationship were estimated by Mattos and Pereira (2002), as above mentioned, which allowed the estimation of the fishing and natural 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 $Z = F + M$, 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

[39] In the present analysis "age *any* +" refers to the period at which the fish becomes "age *any*" until it dies. The assumption is that of beginning "age *any* +" at the start of a calendar year, even though this usually means that the fish would have lived for less than a full year during "age –*any* +" (Ricker, 1969).

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.

From Mattos *et al.* (2001a), 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, all specimens 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 percentage 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 yellowtail snapper are shown in Table III.10, while for the mutton snapper in Table III.11, and for the Caribbean sharpnose shark in Table III.12.

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 and factor 2 represents a doubling of the 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. It was shown also the effort factor that corresponds to the maximum *Y/R*, where maximum sustainable yield (*MSY*) can be obtained, and where the curve has a slope equal to 10% of that of the curve at the origin – F(0.1).

The performed yield-per-recruit analyses for the above mentioned species are displayed, respectively, in Tables III.13, III.14 and III.15. It is appropriate to comment that the presented results might be somewhat biased because the VPA analysis is very sensitive to variations in the applied values of fishing mortality (*M*), because it was assumed to be constant although it is likely to be higher in the younger fish.

Table III.10 – Summarised information of the virtual population analysis (VPA) for the yellowtail snapper, *Lutjanus chrysurus*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

VPA Parameters	Results
Catch Data	
Catch mean age (year)	3.654
Catch mean length (cm)	37.799
Mean Fishing Mortality, *F*	0.428
Global Fishing Mortality, *F*	0.306
Total catch / year (g)	24438337.9
Catch / Biomass Balance, *D* (%)	81.64
Catch/Biomass, *B* (%)	49.8
Population Status	
Current Stock Mean Age (year)	2.578
Current Stock Critical Age (year)	3
Virgin Stock Critical Age (year)	9
Current Stock Mean Length (cm)	30.218
Current Stock Critical Length (cm)	34.128
Virgin Stock Critical Length (cm)	60.184
Number of recruits, *R*	72478.07
Mean Biomass, *Bmean* (g)	49070292.4
Spawning Stock Biomass (*SSB*) (g)	38049218.4
Biomass Balance (*D*) (g)	29934210.6
Natural death / *D* (%)	18.36
Maximum Biomass, *Bmax* / Mean Biomass, *Bmean*	33.59
Turnover, *D/Bmean* (%)	61
Recruitment	
Biomass/Recruit (B/R)	677.036
Stock Spawning Biomass/Recruit (SSB/R)	524.976
Yield/Recruit (Y/R)	337.183

Through VPA it was possible to verify that although the yellowtail snapper stock is composed of 2.6-year old and relatively small (30.2 cm) individuals, on the assumption of the asymptotic length (76.67 cm), the effort is being applied mainly on older (3.6-year olds) and bigger (37.8 cm) than the critical age (3-year olds) and length (34.1 cm) of the population, which means that older individuals and the spawning stock is more heavily fished. For the sake of clarity, critical age means the average age of the fish in a year-class at which the instantaneous rate of total mortality equals the instantaneous rate of growth in weight for the year class as a whole. At this age, the biomass of the age-class is maximum.

Table III.11 – Summarised information of the virtual population analysis (VPA) for mutton snapper, *Lutjanus analis*, caught off Pernambuco State, North-eastern Brazil, coast.

VPA Parameters	Results
Catch Data	
Catch mean age (year)	3.169
Catch mean length (cm)	51.708
Mean Fishing Mortality, *F*	0.313
Global Fishing Mortality, *F*	0.3
Total catch / year (g)	47047366.2
Catch / Biomass Balance, *D* (%)	68.89
Catch/Biomass, *B* (%)	33.66
Population Status	
Current Stock Mean Age (year)	2.879
Current Stock Critical Age (year)	3
Virgin Stock Critical Age (year)	8
Current Stock Mean Length (cm)	48.54
Current Stock Critical Length (cm)	51.913
Virgin Stock Critical Length (cm)	83.9
Number of recruits, *R*	38541.86
Mean Biomass, *Bmean* (g)	139779837
Spawning Stock Biomass (*SSB*) (g)	119641040
Biomass Balance (*D*) (g)	68293901.5
Natural death / *D* (%)	31.11
Maximum Biomass, *Bmax* / Mean Biomass, *Bmean*	17.13
Turnover, *D/Bmean* (%)	48.86
Recruitment	
Biomass/Recruit (B/R)	3626.702
Stock Spawning Biomass/Recruit (SSB/R)	3104.184
Yield/Recruit (Y/R)	1220.682

Otherwise, the present results suggest that the yellowtail snapper stock off Pernambuco State continental shelf is under high fishing pressure. Such argument is under the considerations on the virgin stock critical age (9-year olds) and length (60.2 cm), the low number of recruits (78,478), the balance between biomass and catch (49.8%), and the fishing mortality rates (0.428 – mean; and 0.306 – global), which represents a rate of exploitation or the rate of current catch per unit of production (*D*) of 81.64%, while the natural mortality represents only 18.36% of the biomass balance. Also, the production per unit of biomass, expressed as turnover (D/B_{mean}) and in percentage, shows a rate as high as 61%, which is equivalent to the total mortality rate in terms of biomass.

Table III.12 – Summarised information of the virtual population analysis for females and males Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), caught off Pernambuco State, North-eastern Brazil, continental shelf.

VPA Parameters	Females	Males
Catch Data		
Catch mean age (year)	2.43	1.8
Catch mean length (cm)	67.264	59.492
Mean Fishing Mortality, *F*	0.375	0.357
Global Fishing Mortality, *F*	0.333	0.323
Total catch / year (g)	19484397.8	8553908.43
Catch / Biomass Balance, *D* (%)	82.04	72.65
Catch/Biomass, *B* (%)	48.88	40.11
Population Status		
Current Stock Mean Age (year)	1.682	1.425
Current Stock Critical Age (year)	2	1
Virgin Stock Critical Age (year)	7	0
Current Stock Mean Length (cm)	56.51	53.76
Current Stock Critical Length (cm)	64.926	51.062
Virgin Stock Critical Length (cm)	97.472	32.236
Number of recruits, *R*	21963.66	16807.91
Mean Biomass, *Bmean* (g)	39862723	21326044.1
Spawning Stock Biomass (*SSB*) (g)	24920194.2	8500012.64
Biomass Balance (*D*) (g)	23749709.2	11774141.1
Natural death / *D* (%)	17.96	27.35
Maximum Biomass, *Bmax* / Mean Biomass, *Bmean*	27.24	29.53
Turnover, *D/Bmean* (%)	59.58	55.21
Recruitment		
Biomass/Recruit (B/R)	1814.94	1268.81
Stock Spawning Biomass/Recruit (SSB/R)	1134.61	505.715
Yield/Recruit (Y/R)	887.12	508.922

Further analysis on yield-per-recruit depicted in Table III.13 and Figure III.16 strengthen the raised overexploitation condition, which assumes the low level of recruitment and high fishing effort. The results suggest a sharp decline on biomass and that a recovery would be possible under a decrease of *f* to a factor of 0.57, which means a reduction of 43% of the current *f* applied, that would generate the maximum yield-per-recruit.

The following transition analysis strengthens even more the high fishing pressure condition assumed for the yellowtail snapper stock off Pernambuco. Figure III.17 shows the transition analysis under deterministic condition and Figures III.18 through III.22 under stochastic condition. The conducted analysis examined variations on the fishing mortality vector, given by the fishing effort factor, as explained in item III.2.2. The simulation was conducted considering the modified condition in the first year only. It can be seen that, for the deterministic condition, although any increase in fishing effort would decrease the current level of the stock biomass by 41% (Factor = 2), 29.8% (Factor = 1.5), and 19% (Factor = 1.25) of the present one, the results show that in approximately 5 years the stock starts stabilisation and would reach new biological equilibrium from the 9th year onward. Even with increasing fishing effort recruitment showed very small variations. On the other hand, any decrease in *F* (Factor's 0.75 and 0.57 – maximum) would favour the recovery of the total and spawning stock biomasses by an increase of 36.4% and 84.7%, respectively, but recruitment would stabilise at present population status in the fifth year, with a terminal increase of 4.6% and 6.3%, respectively.

Table III.13 – Results of the yield-per-recruit analysis for the yellowtail snapper, *Lutjanus chrysurus*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

Slope at origin	2287.8749		
Virgin biomass (g)	385210002		
Factor	Y/R	B/R	SSB/R
0	0	5314.849	5158.63
0.37	346.302	1926.158	1771.526
0.57	362.501	1282.619	1128.779
1.01	337.183	677.036	524.976
2	287.174	393.987	245.695

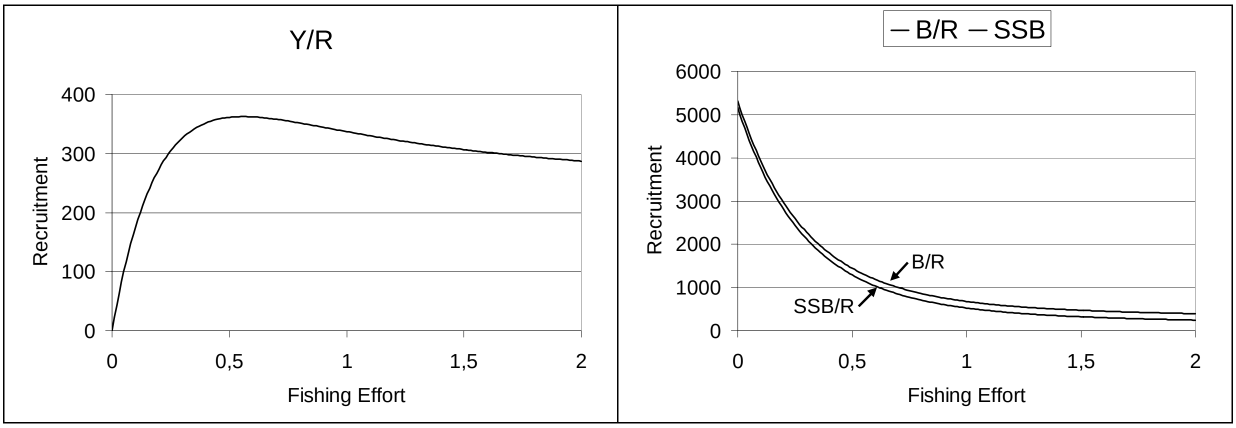


Figure III.16 – Yield-per-recruit (Y/R), biomass-per-recruit (B/R) and spawning stock biomass-per-recruit (SSB/R) curves, for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

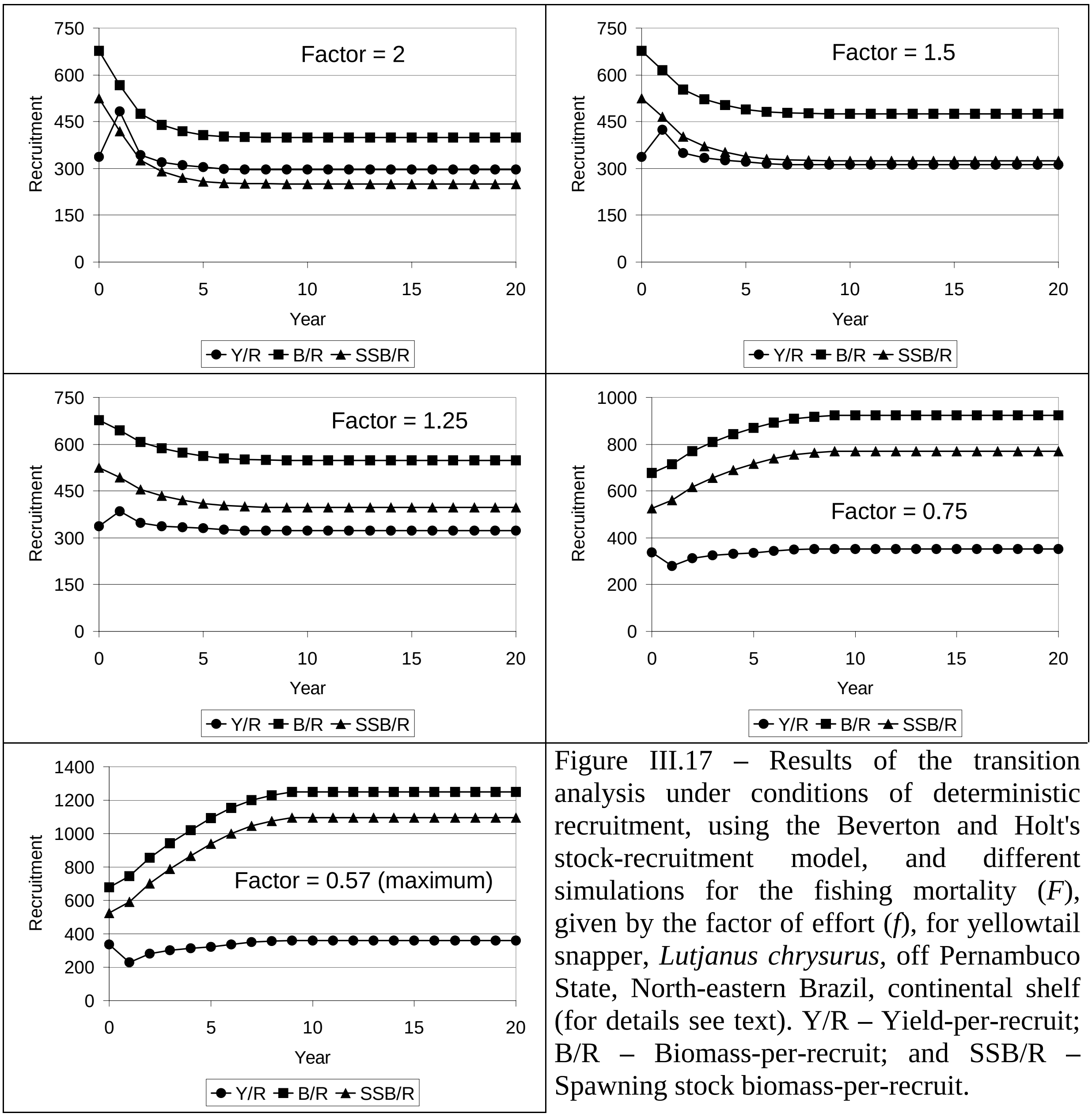
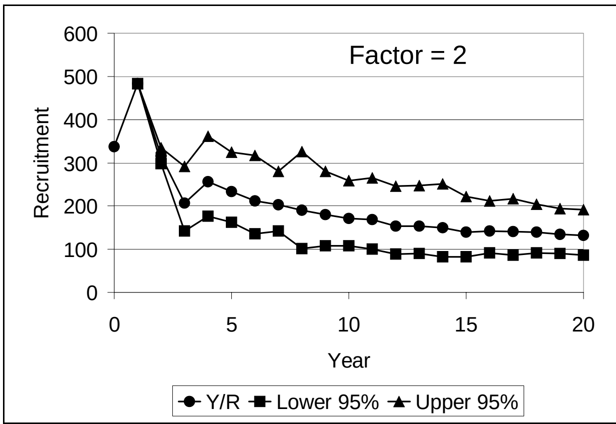
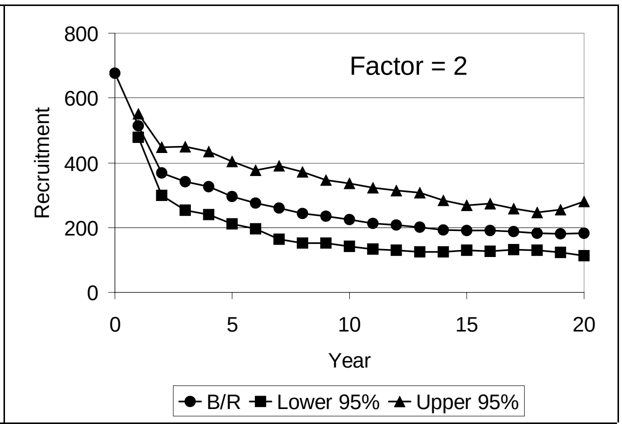


Figure III.17 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (*F*), given by the factor of effort (*f*), for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco 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.

The transition analyses under stochastic condition, however, show high variability for the different factors considered. Anyway, even the 95% upper and lower confidence limit do not suggest that the yellowtail snapper stock could be driven to extinction even under a doubling fishing effort simulation, although the spawning stock biomass can reach a very risk level close to that of the yield-per-recruit. The curves show that, in the long-run (20 years), the difference presented by the confidence limit approximate, once more denoting that the stock should further reach a new biological equilibrium. Considering the effort decreasing factor simulation, in the long-run the curves outdistance apart, although denoting that a recovery would ever occur. Such results probably indicate that yellowtail snapper may have a high reproduction rate, not analysed in the present study, and presents a recruitment-independent on the size of the adult population.





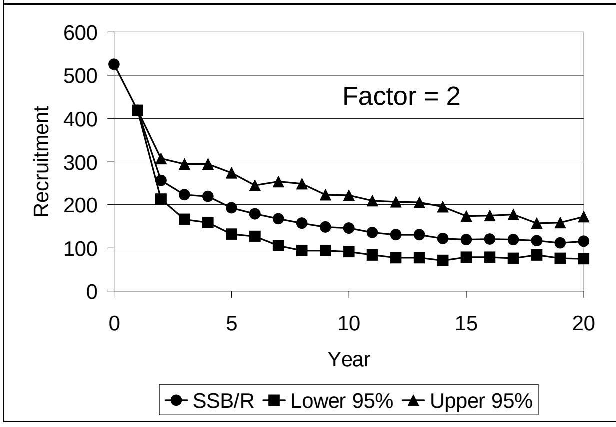
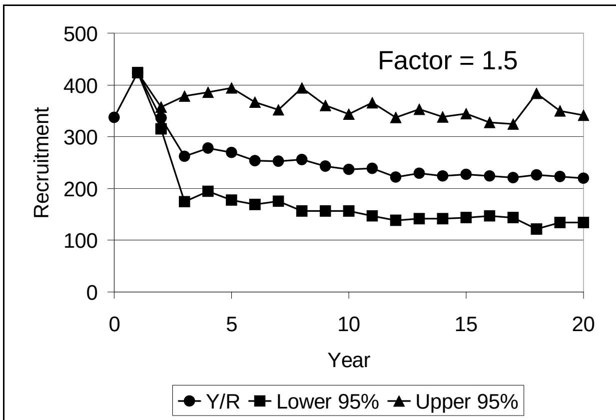
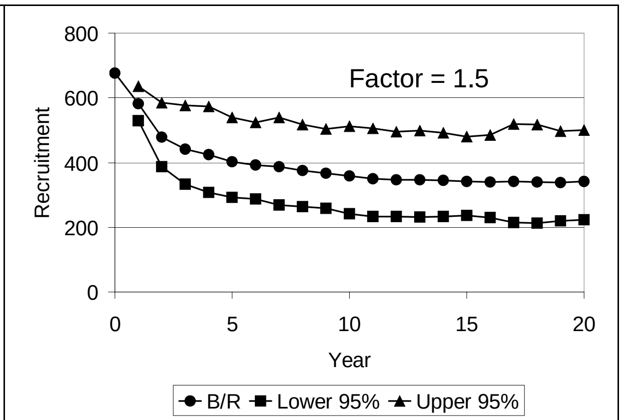


Figure III.18 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 2.0, for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco State, North-eastern 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.





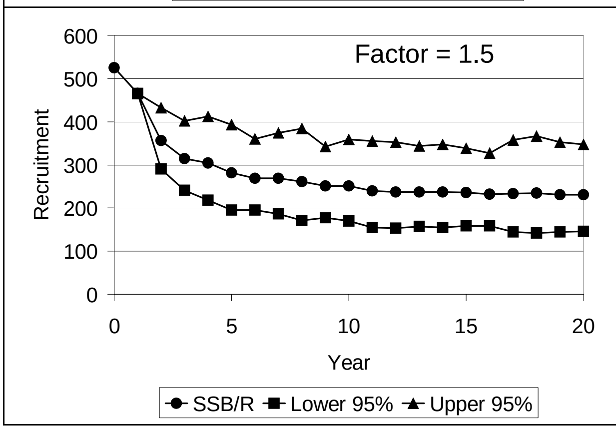
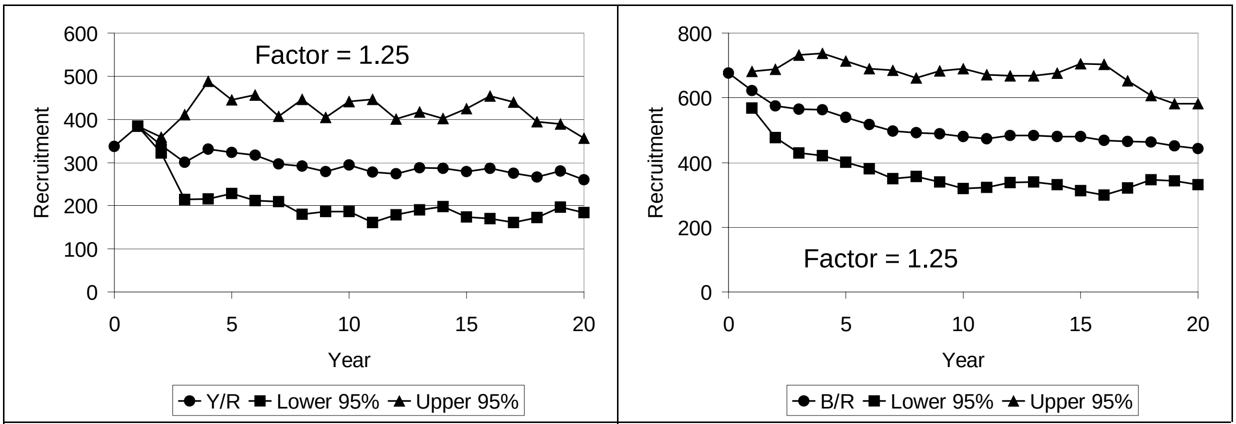


Figure III.19 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.5, for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco State, North-eastern 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.



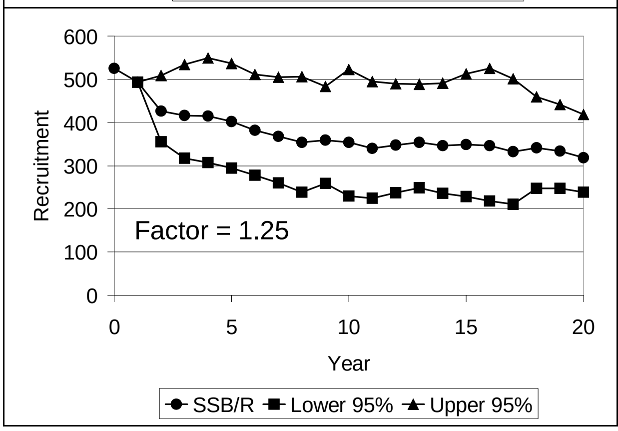
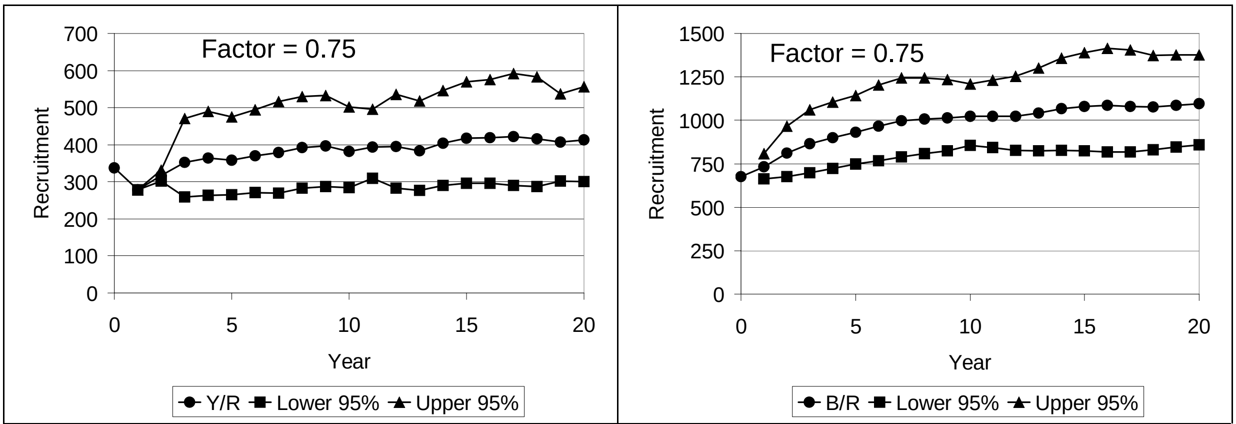


Figure III.20 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.25, for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco State, North-eastern 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.



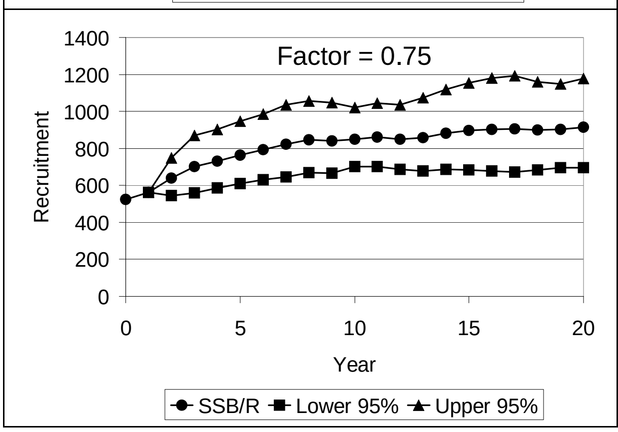
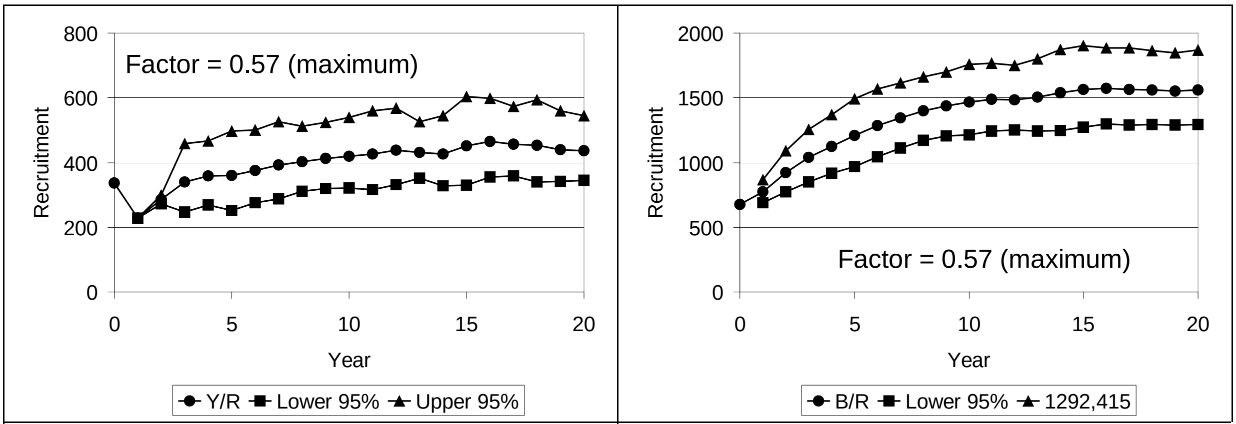


Figure III.21 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.75, for yellowtail snapper, *Lutjanus chrysurus*, off Pernambuco State, North-eastern 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.



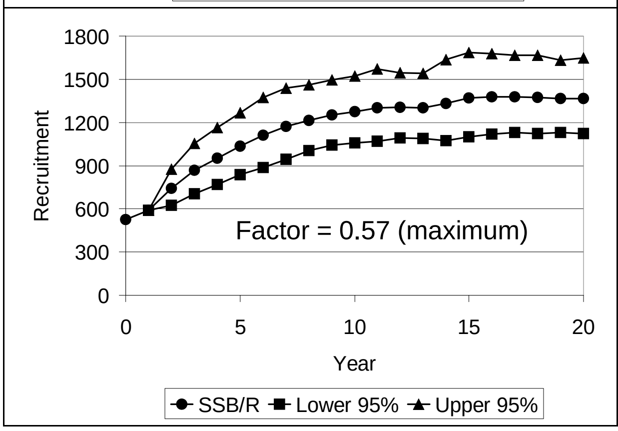


Figure III.22 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.57 (maximum), for yellowtail snapper, *Lutjanus chrysurus,* off Pernambuco State, 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.

Following the same procedure of analysis for the yellowtail snapper, the mutton snapper stock is composed of 2.9-year old individuals and medium size (48.5 cm) individuals, on the assumption of the asymptotic length (108.2 cm). The effort is being applied mainly on older (3.2-year olds) than the critical age (3-year olds) individuals, whilst at approximately same length (51.7 cm) as for the critical one (51.9 cm), which means that the spawning stock population status is not as heavily fished as the yellowtail snapper spawning stock. For mutton snapper it was not possible to state that the stock off Pernambuco State continental shelf is under high fishing pressure, although the contrary cannot be assumed as well.

Otherwise, the virgin stock critical age (8-year olds), higher if compared with the catch mean age, and the low number of recruit (38,542) are worrisome and the effort mainly act in the spawning stock biomass. The balance between biomass and catch (33.7%), and the fishing mortality (*F*) rates (0.313 – mean; and 0.3 – global), shows that the rate of exploitation (*F/Z*), or the rate of current catch per unit of production (*D*) is 68.89%, while the natural mortality represents 31.11% of the biomass balance. Also, the production per unit of biomass, expressed as turnover (D/B_{mean}) and in percentage, shows a rate of 48.9%, which is equivalent to the total mortality rate in terms of biomass. Such results denote that the mutton snapper stock is not heavily fished as the previously analysed species.

Table III.13 – Results of the yield-per-recruit analysis for the mutton snapper, *Lutjanus analis*, caught off Pernambuco State, North-eastern Brazil, continental shelf.

	Females		
Slope at origin			4889.9067
Virgin biomass			602964715
Factor	Y/R	B/R	SSB/R
0	0	15644.411	15041.281
0.58	1185.883	6216.591	5663.17
0.84	1234.265	4451.66	3917.09
1.01	1220.682	3626.702	3104.184
2	998.56	1495.692	1033.745

Further analyses on yield-per-recruit depicted in Table III.14 and Figure III.23 show the low level of recruitment of such stock and that fishing effort is beyond maximum sustainable yield (*MSY*). The results also suggest a sharply decline on biomass and that a recovery would be possible under a decrease of fishing effort (*f*) to a factor of 0.84, which means a reduction of 16% of the current *f* applied, that would generate the maximum yield-per-recruit.

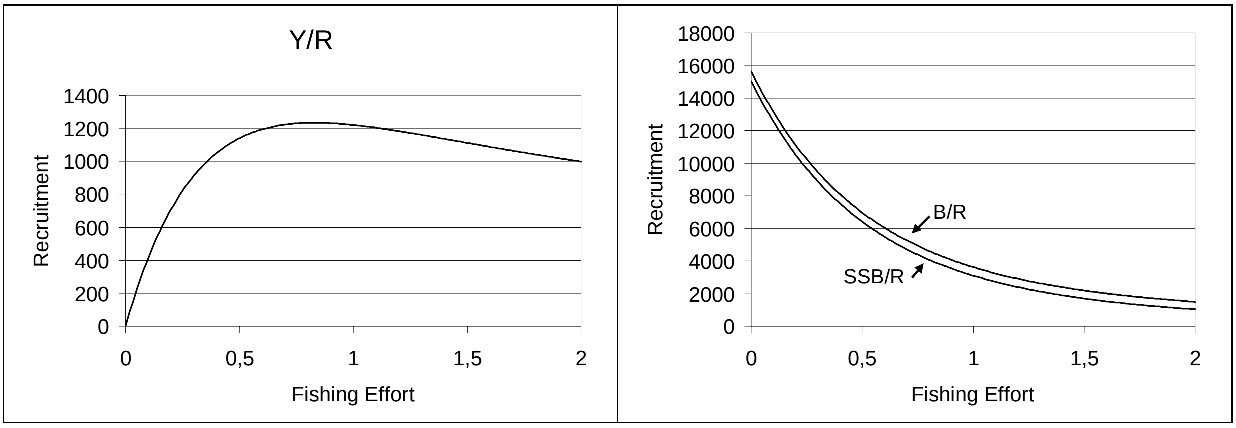


Figure III.23 – Yield-per-recruit (Y/R), Biomass-per-recruit (B/R) and Spawning stock biomass-per-recruit (SSB/R) curves, for mutton snapper, *Lutjanus analis*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

The following transition analysis shows how such high fishing pressure condition assumed for the mutton snapper stock off Pernambuco must be a risk that could lead to overexploitation. Figure III.24 shows the transition analysis under deterministic condition, while Figures III.25 through III.29 under stochastic condition. The analysis followed the same procedure described for yellowtail snapper, as explained in item III.2.2. It can be seen that, under the deterministic condition any increase in fishing effort would decrease even more the current level of the stock biomass, maybe leading to an overexploitation situation. Doubling *f* (Factor = 2) means that biomass would fall 58.1% of the present population status, a 50% (Factor = 1.5) increase in effort would represent a decrease of 39.2% in current biomass level, while a 25% increase (Factor = 1.25) must decrease the current biomass by approximately 23.4%.

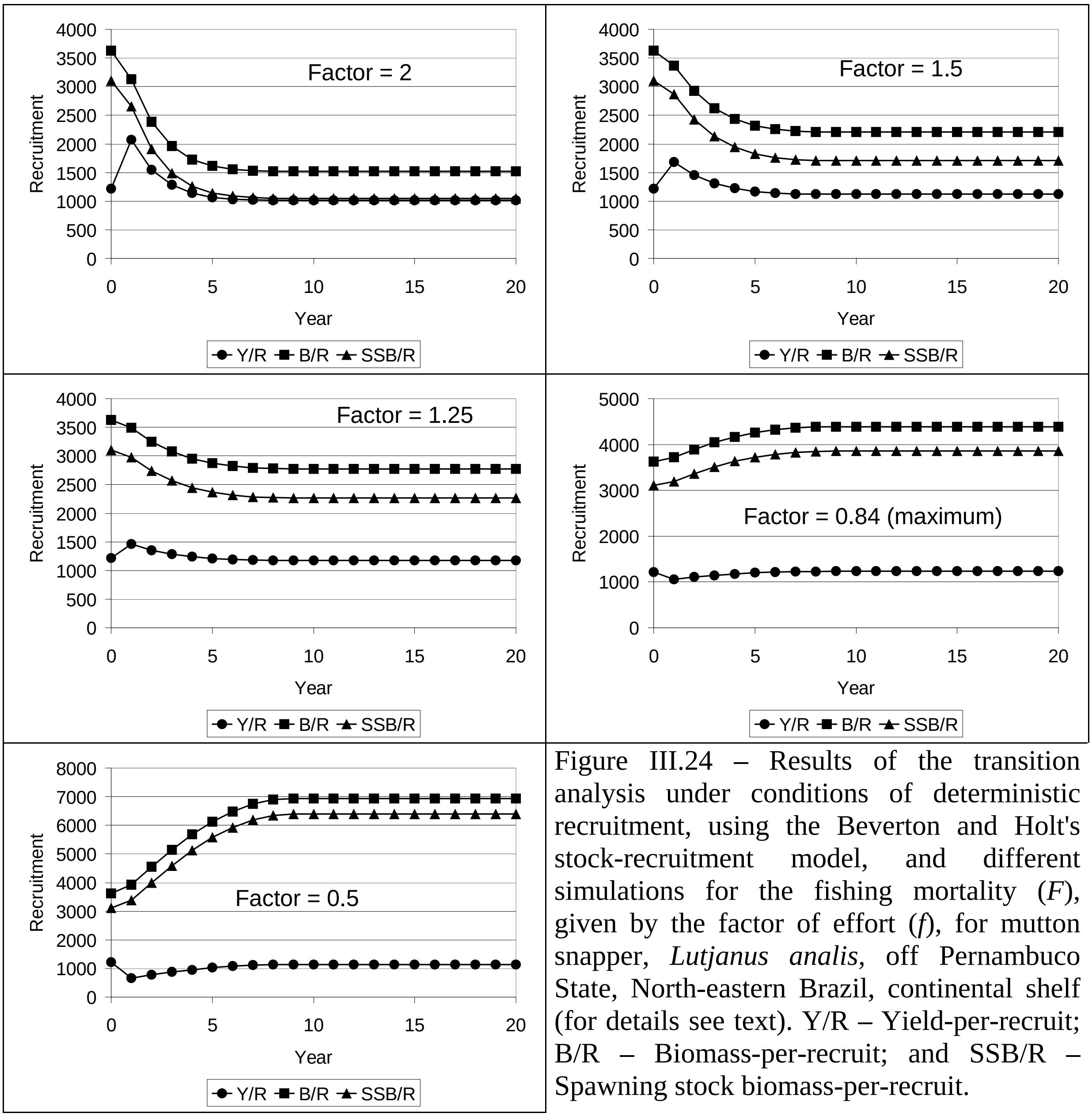


Figure III.24 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (*F*), given by the factor of effort (*f*), for mutton snapper, *Lutjanus analis*, off Pernambuco 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.

The results show that in approximately 5 years the stock should initiate stabilisation, reaching a new biological equilibrium in the 9th year, however. On the other hand, any decrease in *F* (Factor's 0.84 – maximum; and 0.5) would favour a sharp recovery of the total and spawning stock biomasses, increasing in the long-run by 21% and 91.4%, respectively, although the yield-per-recruit would practically stabilise at present population status after the 5th year, attaining a terminal increase by only 0.9% if the maximum factor would be applied, and decreasing by 7.1% if the 0.5 factor would be applied.

The transition analysis under stochastic condition, however, shows high variability for the different factors considered. In such a case the 95% upper and lower confidence limit do suggest that the mutton snapper stock could be driven to extinction especially simulating doubling the fishing effort, and the recruitment, the overall biomass and spawning stock biomass can reach a very risk level at doubling and 50% *f* increase (Figures III.25 and III.26), and even a 25% increase represents a great reduction on the present recruitment level, as shown in the previous analysis.

The curves show that, in the long-run (20 years), the difference presented by the confidence limit do not present great variability, denoting that although the stock should further stabilise, a new biological equilibrium could only be reached for factors 1.5 and 1.25. Considering the effort decreasing factor simulation, in the long-run the curves seems to approximate, denoting that a recovery would ever occur. Such results shall indicate that mutton snapper do not have a recruitment rate that can support any increase in fishing effort, but, as for yellowtail snapper, the species seems to present a recruitment-independent on the size of the adult population.

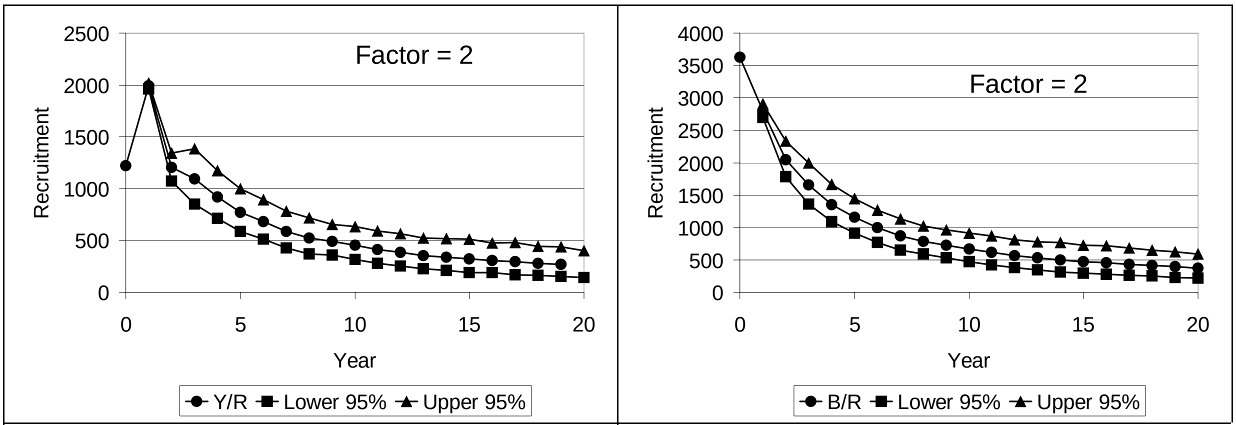
Following the same procedure of analysis before conducted, the Caribbean sharpnose shark stocks are composed of very young individuals (female = 1.7-year olds; males = 1.4-year olds) and relatively medium size (females = 56.5 cm; males = 53.8 cm) individuals, on the assumption of the asymptotic length (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 length (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 status 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.15, for both sexes, and Figures III.30 (females) and III.31 (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 shows how such high fishing pressure condition assumed for the Caribbean sharpnose shark stock off Pernambuco must drive both female and male to overexploitation. Figures III.32 (females) and III.33 (males) show the transition analysis under deterministic condition, while Figures III.34 through III.38, for females, and Figures III.39 through III.43, for males, under stochastic condition. The analysis followed the same procedure described for yellowtail snapper, as explained in item III.2.2. It can be seen that, under the deterministic condition any increase in fishing effort would sharply decrease the current level of both females and males stock biomasses, leading to an overexploitation situation. Doubling *f* (Factor = 2) means that both stocks practically disappears (reduction on the biomass level of 95.7% for females and 92.4% for males), a 50% (Factor = 1.5) increase would represent a decrease in biomass of 71% and 62.5%[40], respectively, while a 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, denoting the susceptibility of this species to high fishing pressure.

[40] For males the factor applied was 1.53 that represented the maximum factor at which the stock should reach maximum *Y/R*.



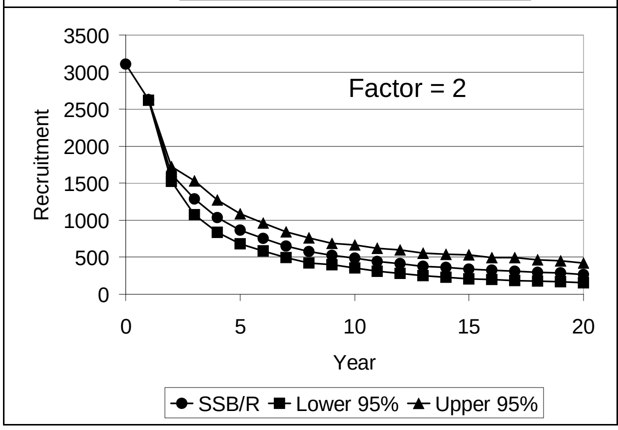
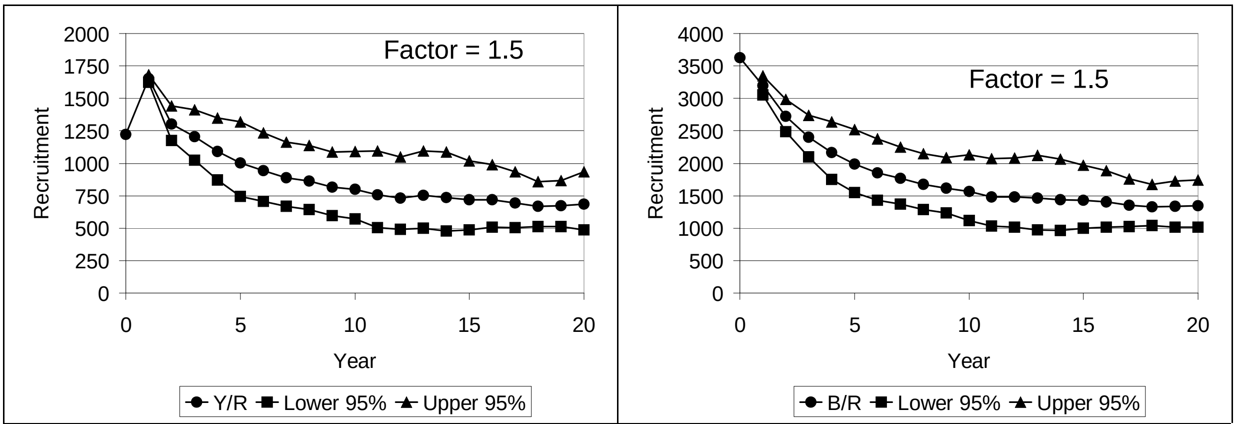


Figure III.25 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 2.0, for mutton snapper, *Lutjanus analis,* off Pernambuco State, North-eastern 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.



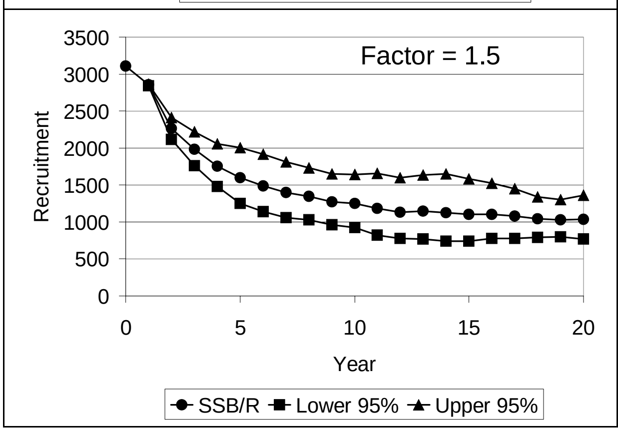
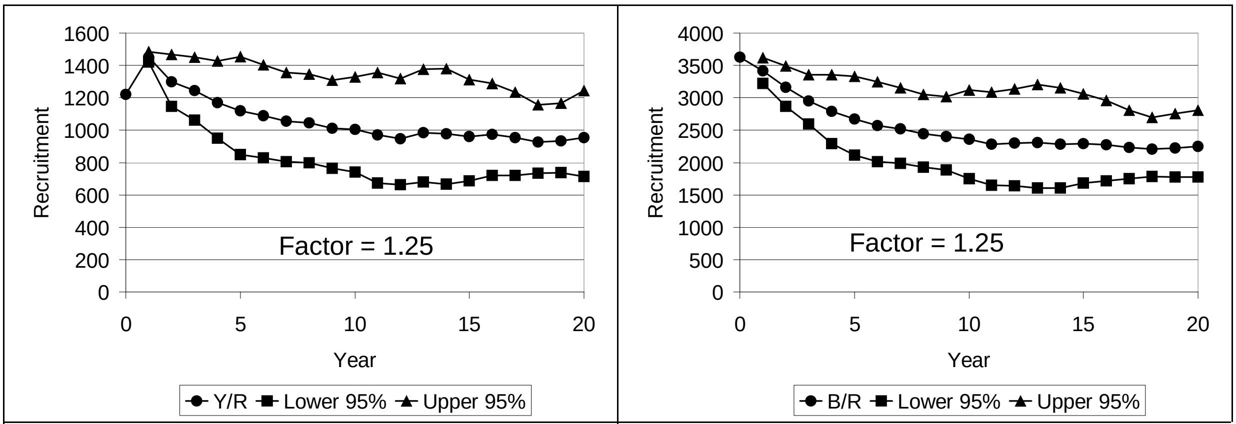


Figure III.26 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.5, for mutton snapper, *Lutjanus analis,* off Pernambuco State, North-eastern 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.



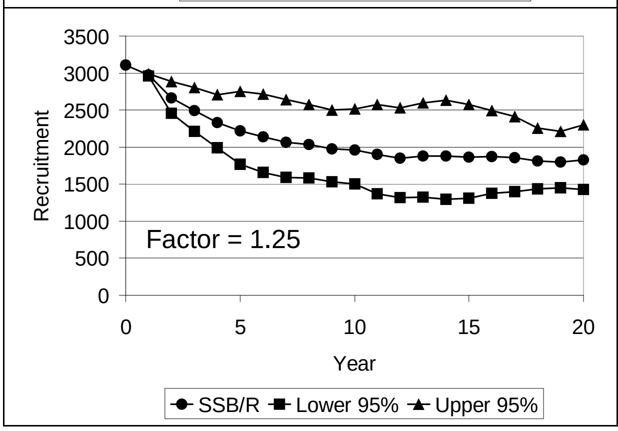
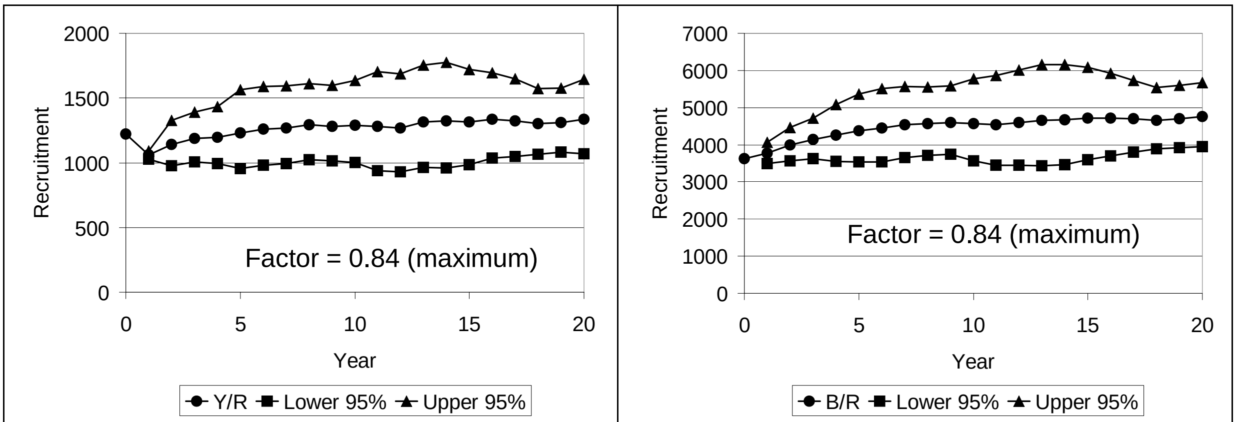


Figure III.27 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.25, for mutton snapper, *Lutjanus analis,* off Pernambuco State, North-eastern 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.



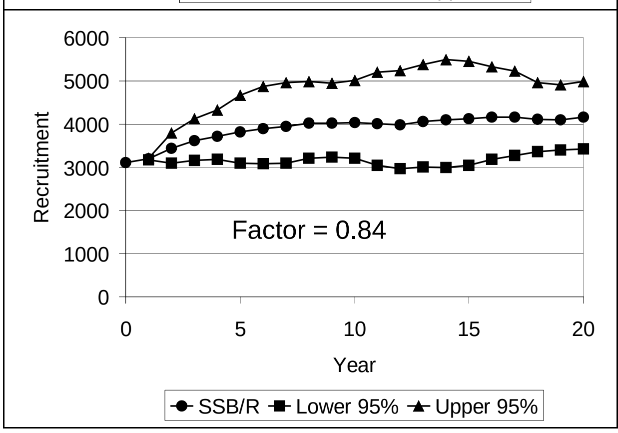
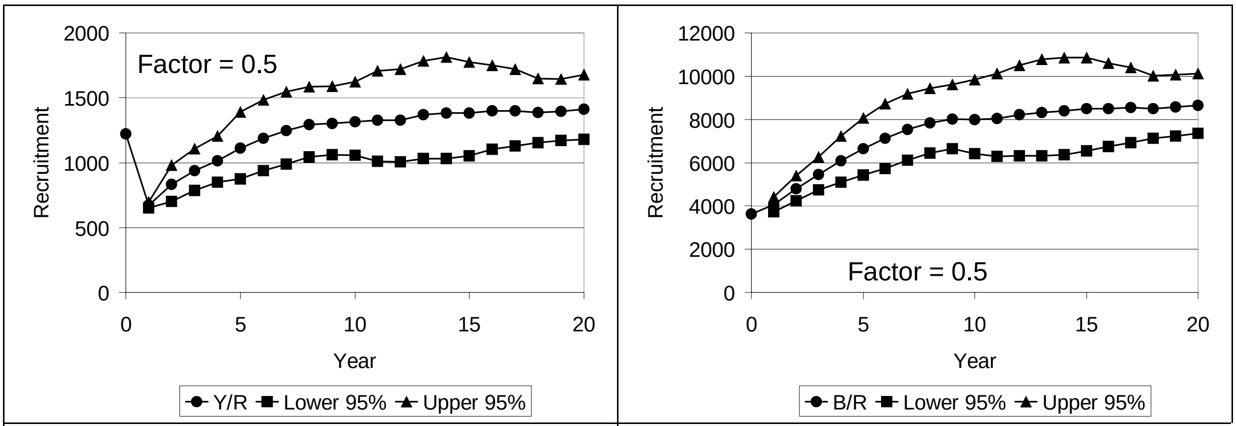


Figure III.28 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.84 (maximum), for mutton snapper, *Lutjanus analis,* off Pernambuco State, North-eastern 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.



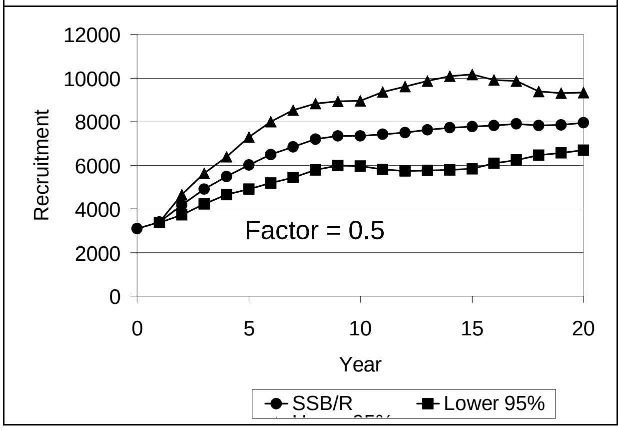


Figure III.29 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.5, for mutton snapper, *Lutjanus analis*, off Pernambuco State, North-eastern 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.

Table III.15 – Results of the yield-per-recruit analysis for females and males Caribbean sharpnose shark, *Rhizoprionodon porosus* (Poey, 1861), caught off Pernambuco State, North-eastern Brazil, continental shelf.

	Females			Males		
Slope at origin			6191.243			1235.5952
Virgin biomass			346353648			55201122.6
Factor	Y/R	B/R	SSB/R	Y/R	B/R	SSB/R
0	0	15769.398	14874.374	0	3284.235	2118.061
0.37	941.575	5659.226	4858.591	-	-	-
0.55	981.489	3872.19	3108.3	-	-	-
1.01	887.12	1814.94	1134.61	508.922	1268.81	505.715
1.02	-	-	-	511.196	1249.545	491.932
1.53	-	-	-	534.133	891.546	250.379
2	690.204	817.267	264.725	524.186	692.968	135.036

Although the *Y/R* analysis for males indicates that a maximum *Y/R* could be reached at a factor of 1.53 (maximum), under non-stable equilibrium the stock presents high vulnerability. On the other hand, a decrease in *f* (Factor's 0.75 and 0.5 – 0.55 maximum for females) would favour recovery of the total and spawning stock biomasses (71.4% and

170.7%, respectively for females; and 40% and 91.1%, respectively for males). The yield-per-recruit for females, should increase by 27.4% and 43.2%, and for male would practically stabilise at present population status in the fifth year.

The transition analysis under stochastic condition, however, shows even higher variability for the different factors considered and strengthen the stock vulnerability to fishing effort. In such a case the 95% upper and lower confidence limit do suggest that the Caribbean sharpnose shark stock could be driven to extinction especially simulating doubling the fishing effort. The recruitment, the overall biomass and spawning stock biomass can reach a very risk level at 50% *F* increase (Figures III.37, for females, and III.42, for males).

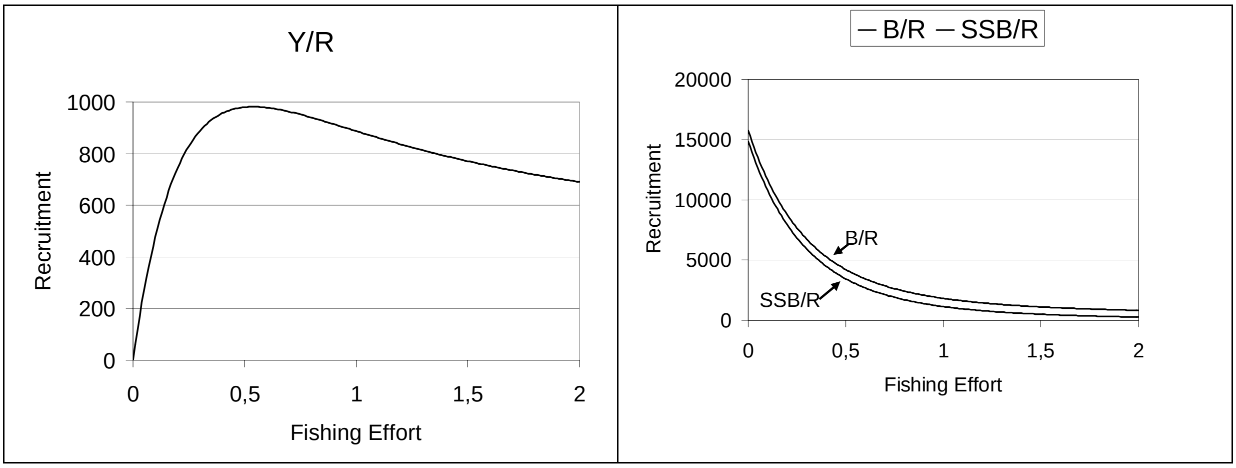


Figure III.30 – Yield-per-recruit (Y/R), Biomass-per-recruit (B/R) and Spawning stock biomass-per-recruit (SSB/R) curves, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

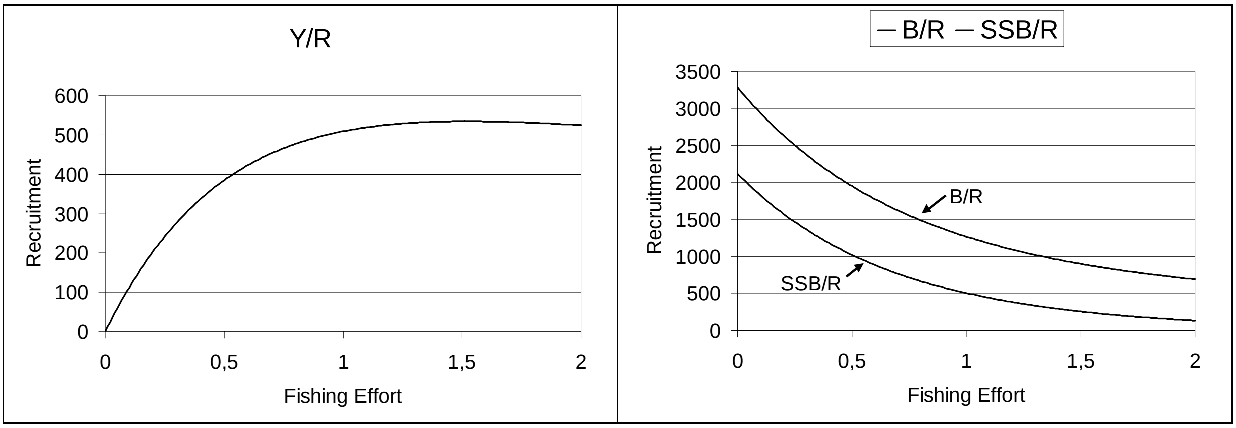
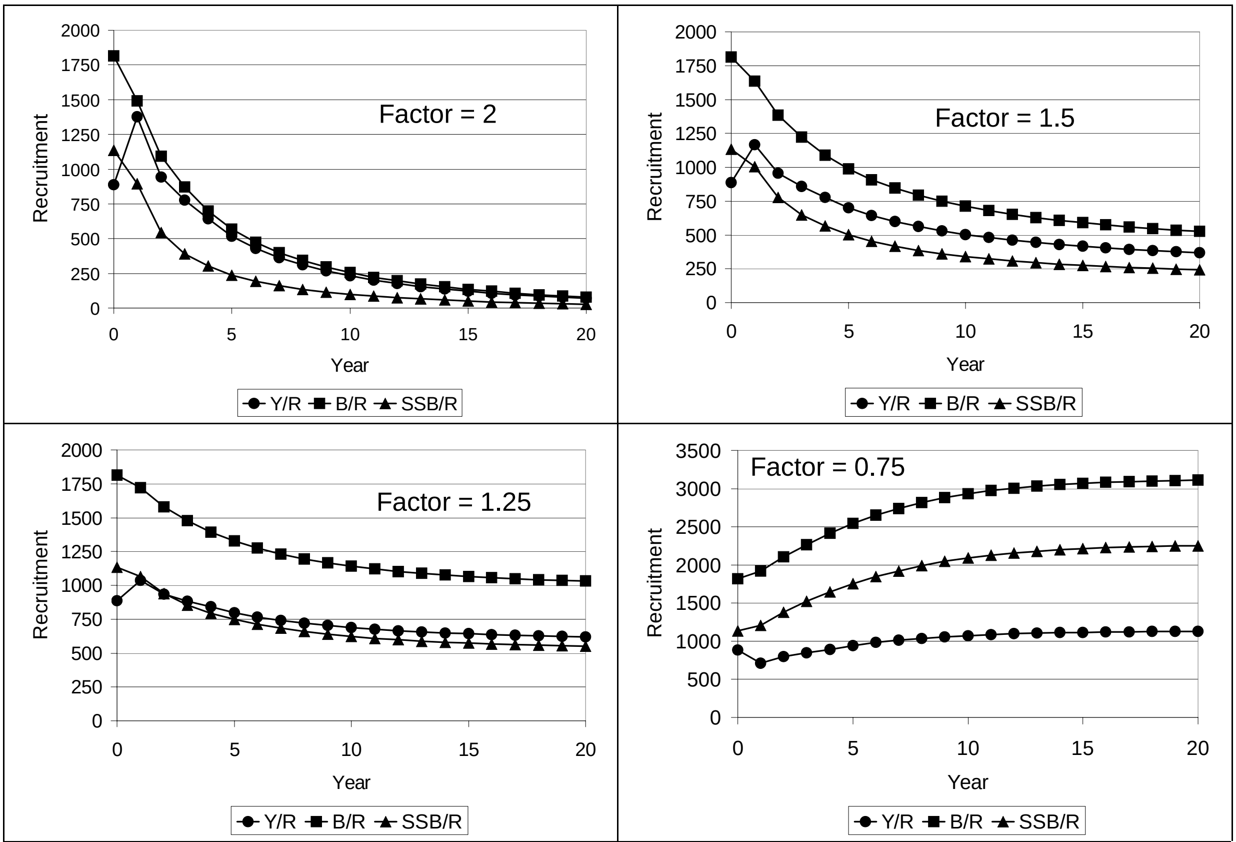


Figure III.31 – Yield-per-recruit (Y/R), Biomass-per-recruit (B/R) and Spawning stock biomass-per-recruit (SSB/R) curves, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco State, North-eastern Brazil, continental shelf (for details see text).

At a level of 25% increase in *f*, the female stock continues to decline, while the male stock seems to support such increase, because the biomass level seems to reach a biological equilibrium after the 8th year. This can be understood because the *Y/R* analysis estimated that the male stock should support higher fishing effort. 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 does not present great variability, denoting that although the stock should further stabilise, a new biological equilibrium could only be reached for factor 1.25.



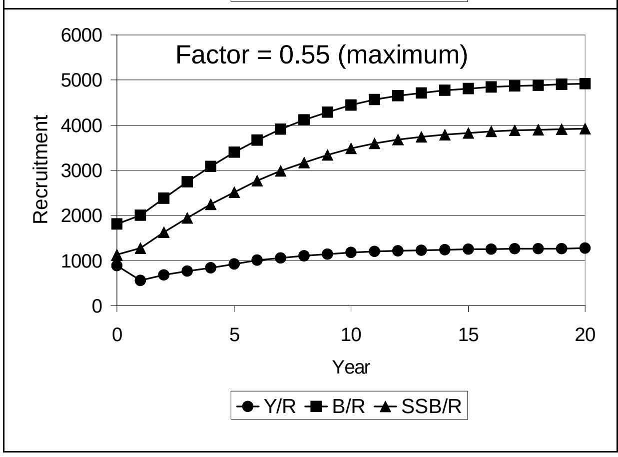
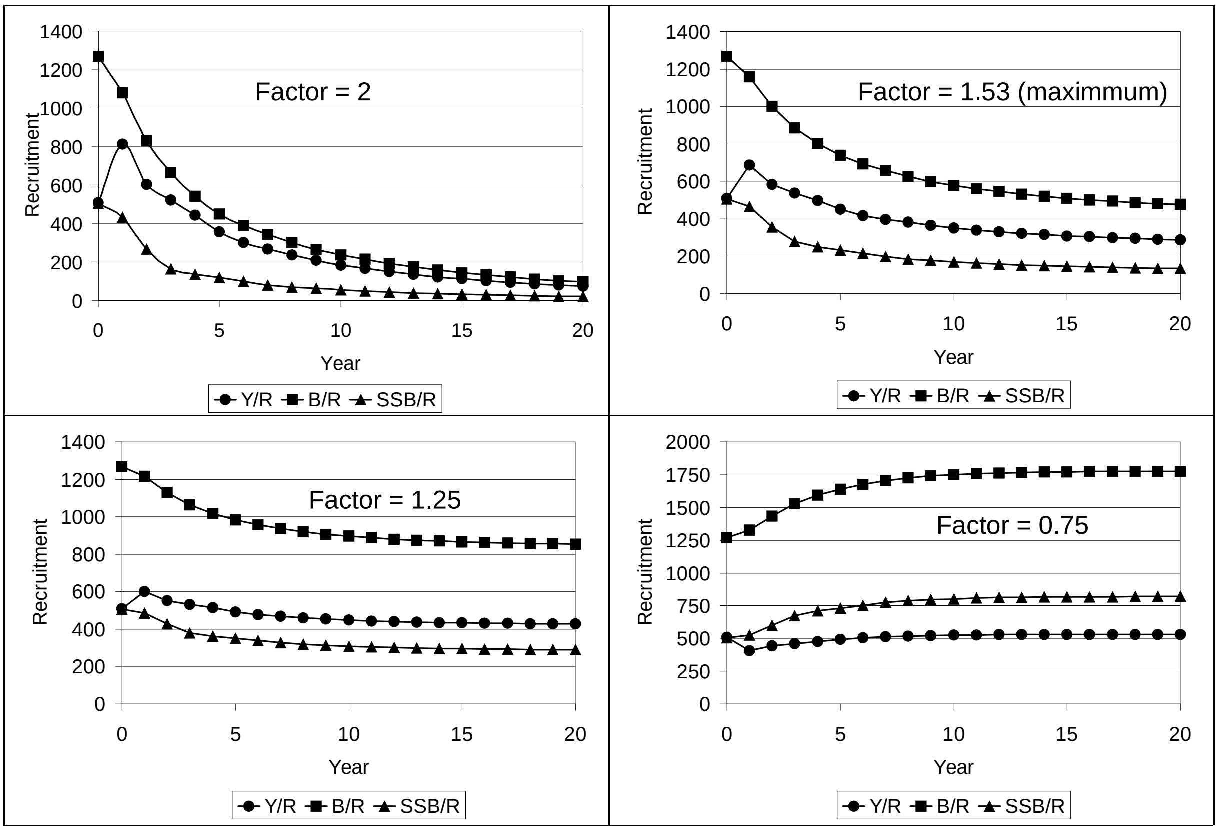


Figure III.32 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (*F*), given by the factor of effort (*f*), for females of Caribbean sharpnose shark, *Rhizoprionodon 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.

Considering the effort decreasing factor simulation, in the long-run the curves seem to approximate for females and to separate apart for males, denoting that the high susceptibility to fishing pressure of such stocks lead to increasing uncertainty in the long-run. Such results indicate that Caribbean sharpnose shark have a low reproductive rate, already stressed by Mattos *et al.* (2001a) and a common feature among elasmobranchs, and cannot support any increase in fishing effort, and that, as different from the previous species, *Rhizoprionodon porosus* seems to present a recruitment-dependent on the size of the adult population.



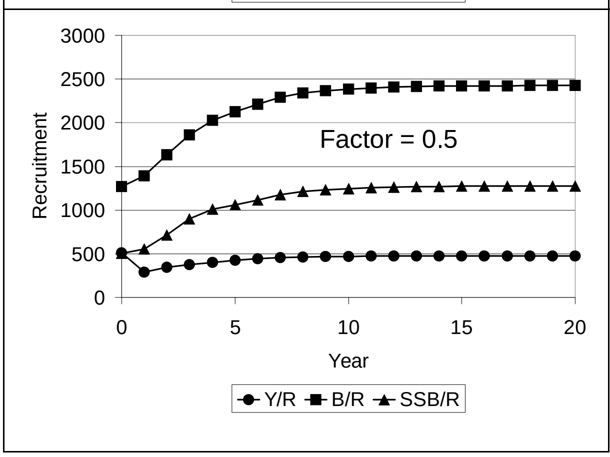


Figure III.33 – Results of the transition analysis under conditions of deterministic recruitment, using the Beverton and Holt's stock-recruitment model, and different simulations for the fishing mortality (*F*), given by the factor of effort (*f*), for males of Caribbean sharpnose shark, *Rhizoprionodon 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.

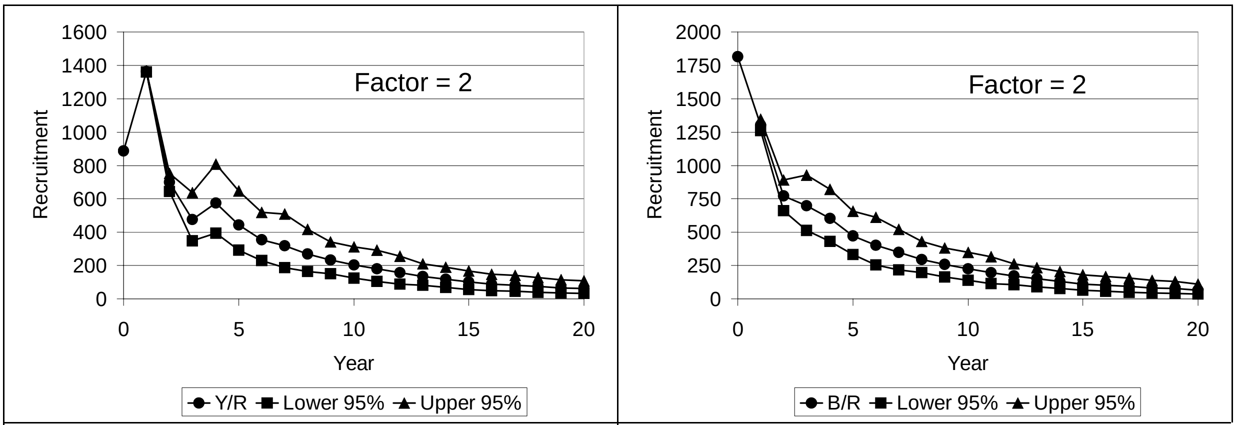
For the four stocks under analysis (yellowtail and mutton snappers and female and male Caribbean sharpnose shark) it seems that the best management procedure concerning fishing effort should be a reduction of 25% of the current level (Factor = 0.75), although further analysis should be conducted to define, with as low as possible level of uncertainty, the best fishing effort level for each stock on the biological point of view.

III.3.2.4 – Sensitivity analysis

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) are shown in Table III.16. The results showed that, for the four stocks considered (yellowtail and mutton snappers, and female and male Caribbean sharpnose shark), the most sensitive parameters was the parameter b of the length-weight relationship. Such parameter represented variation in the result of the yield-per-recruit analysis up to 290%, i.e. female of Caribbean sharpnose shark when a factor of 0.1 was applied. Variation in the yield-per-recruit analysis by a change in such parameter was always higher than 5%, even by a factor of 0.01, denoting its sensitivity. The parameter a of the length-weight relationship implied in the *Y/R* analysis a variation of up to 10% for all groups, although not as high as parameter b.

Notwithstanding the magnitude in which it is considered that VPA analysis is very sensitive to variations in M, in all four 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 Caribbean sharpnose shark, which variation were close to 2% when a factor of 0.1 was applied.

Considering the change in the von Bertalanffy growth parameters, the variations in the *Y/R* analysis implied by them was closely related by all four groups. For yellowtail snapper the parameter $L\infty$ involved a variation from 2.8% (factor 0.01) to 30.3% (factor 0.1); for mutton snapper such variation ranged from 3% to 33.1%; for female Caribbean sharpnose shark from 3.2% to 35.2%; and for male from 2.9% to 31.8%. For the K parameter, such change denoted a variation in the *Y/R* analysis for yellowtail snapper that ranged from 1.8% to 18.9%; for mutton snapper from 1.9% to 19.2%; for female Caribbean sharpnose shark from 1.6% to 15.8%; and for male from 1.4% to 13.9%. The t_0 parameter was the one that implied the lower variation in the Y/R analysis, ranging from 0.3% to 3% for yellowtail snapper, from 0.4% to 3.9% for mutton snapper, and from 0.5% to 5.1% and from 0.5% to 5.3% for female and male Caribbean sharpnose shark, respectively.



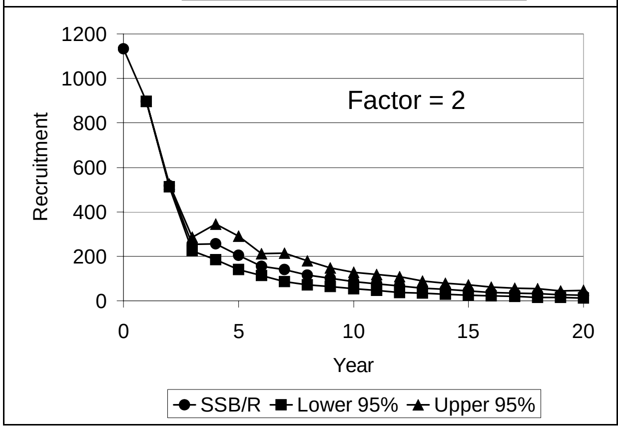
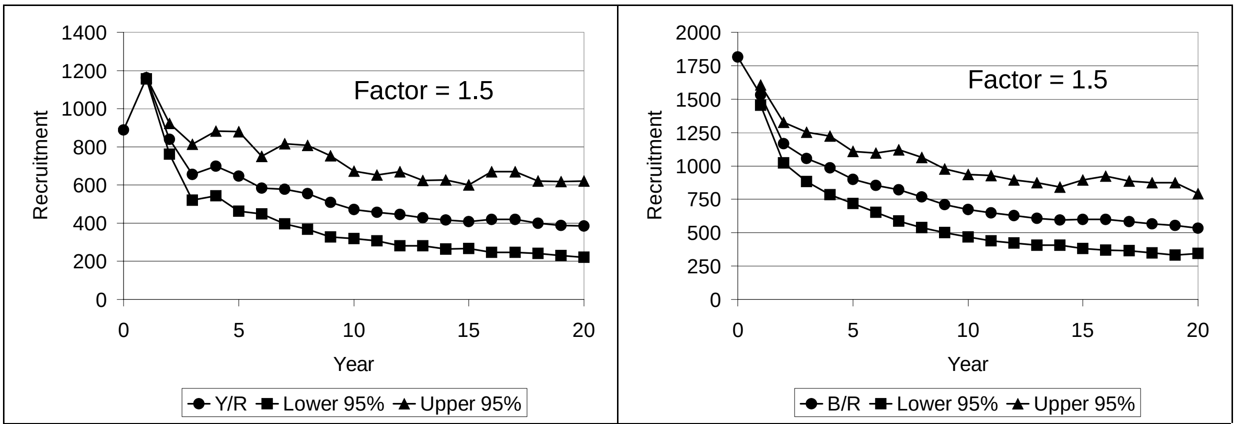


Figure III.34 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 2, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.



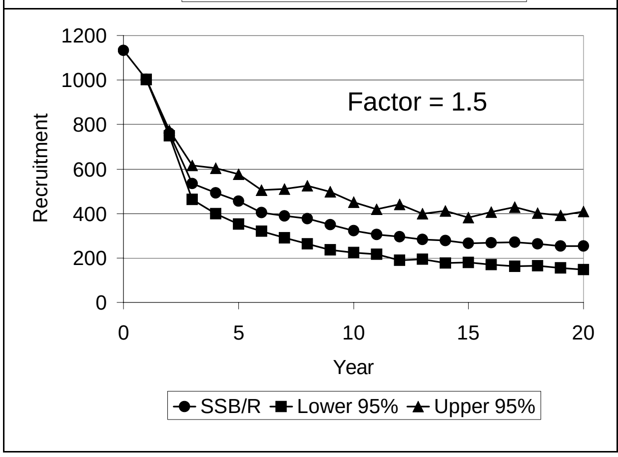
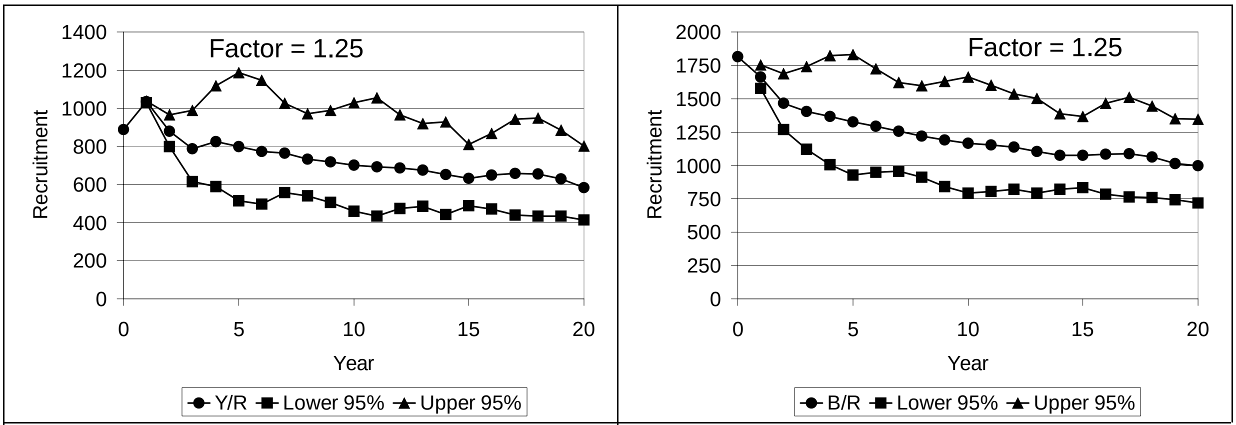


Figure III.35 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.5, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.



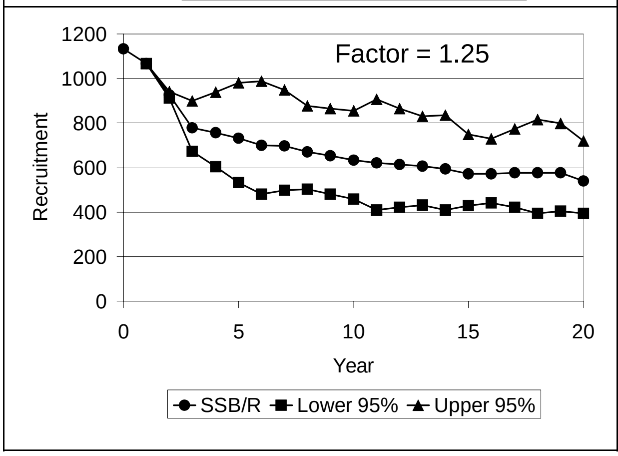
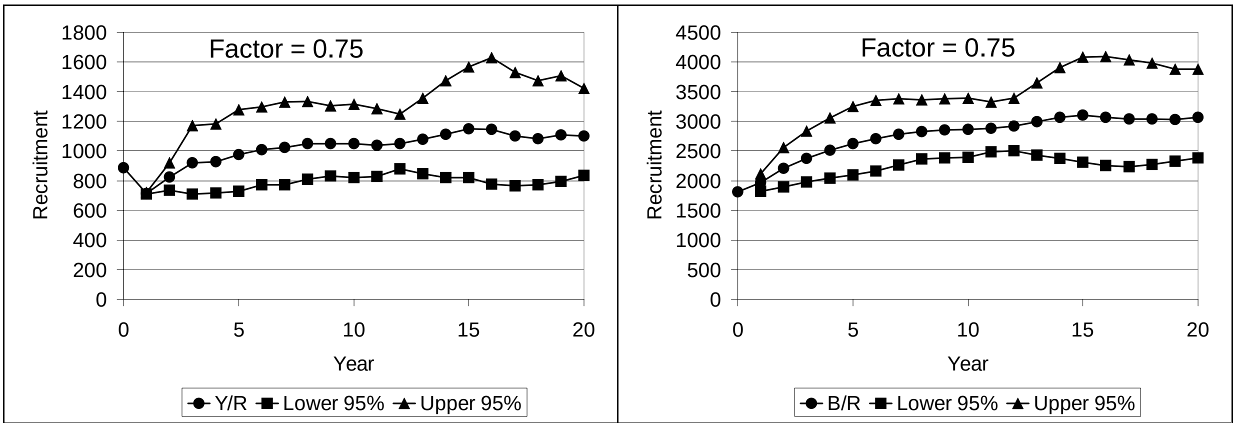


Figure III.36 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.25, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.



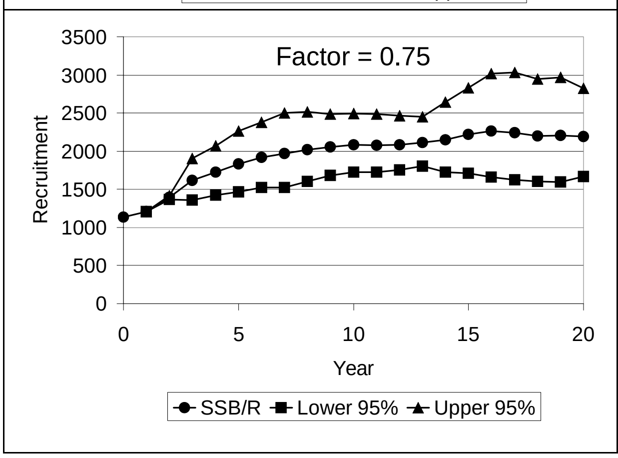
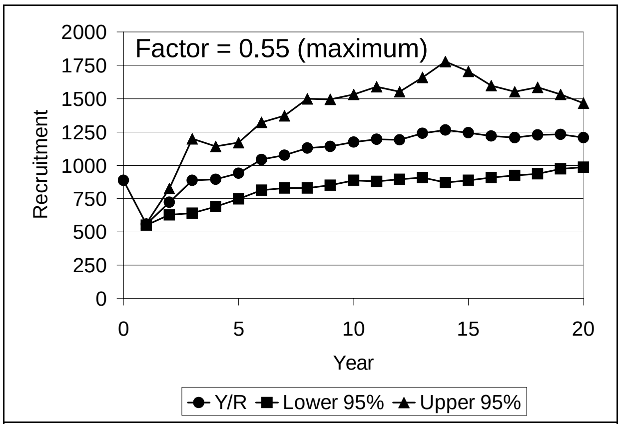
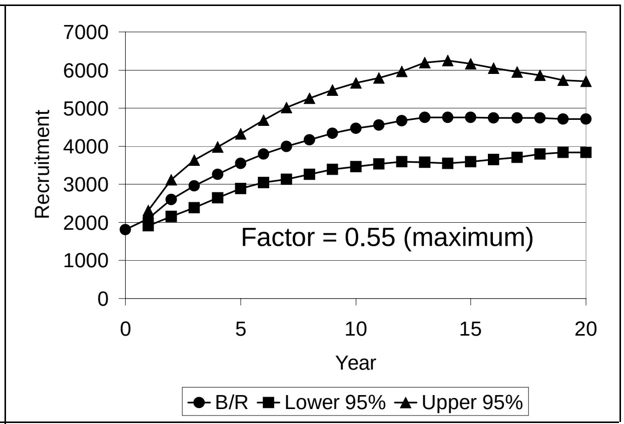


Figure III.37 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.75, for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.





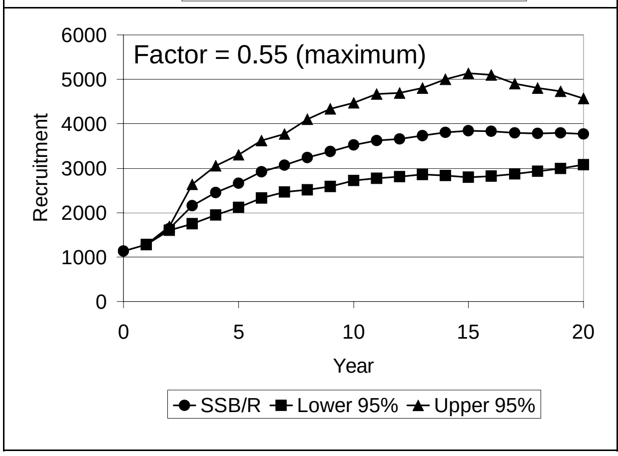
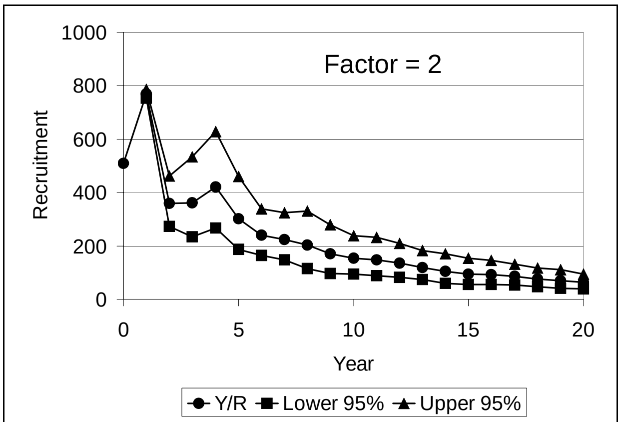
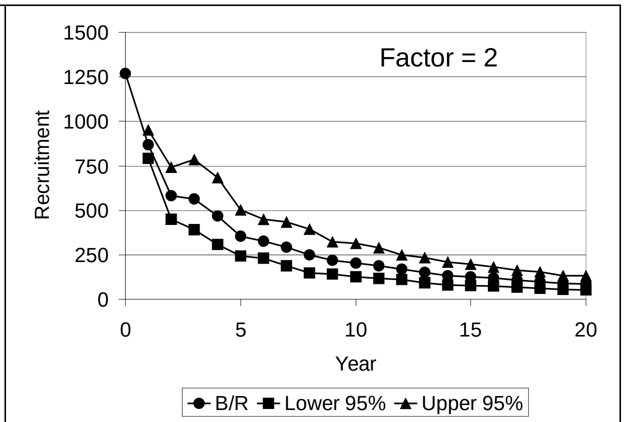


Figure III.38 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.55 (maximum), for females of Caribbean sharpnose shark, *Rhizoprionodon porosus*, 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.





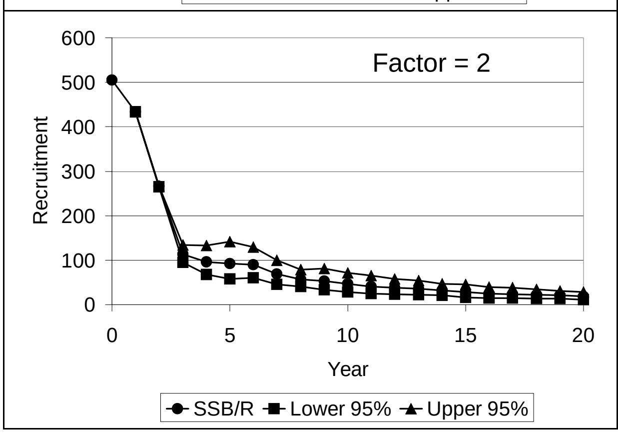
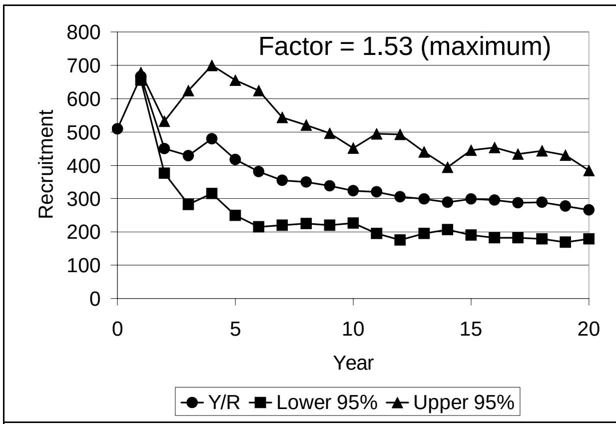
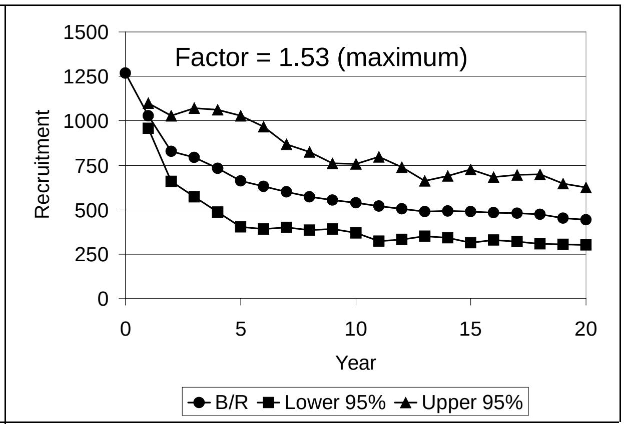


Figure III.39 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 2, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.





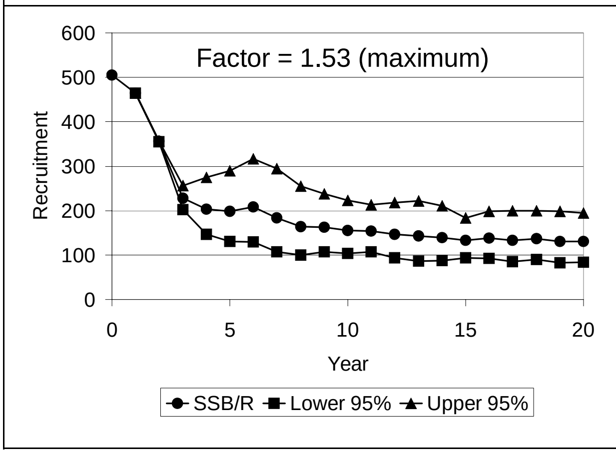
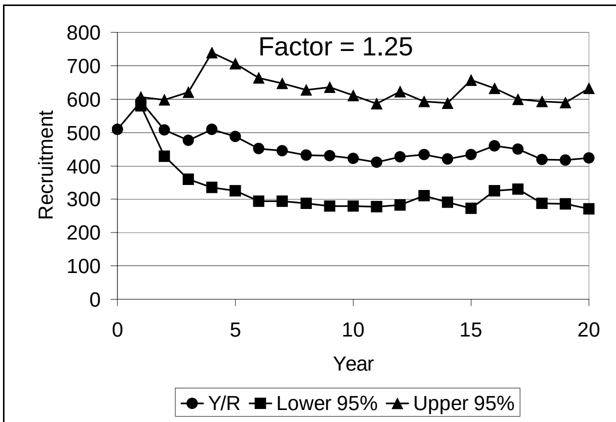
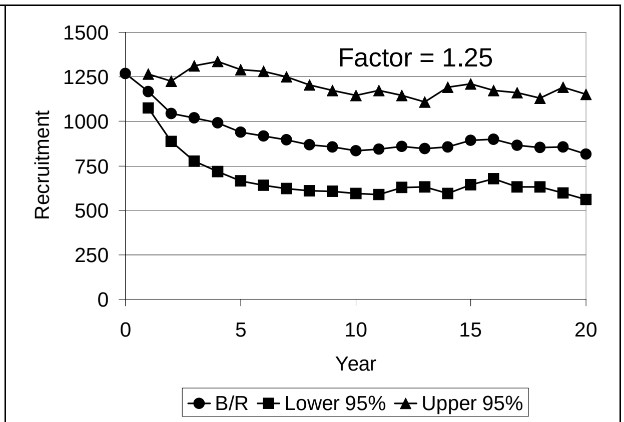


Figure III.40 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.53 (maximum), for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, 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.





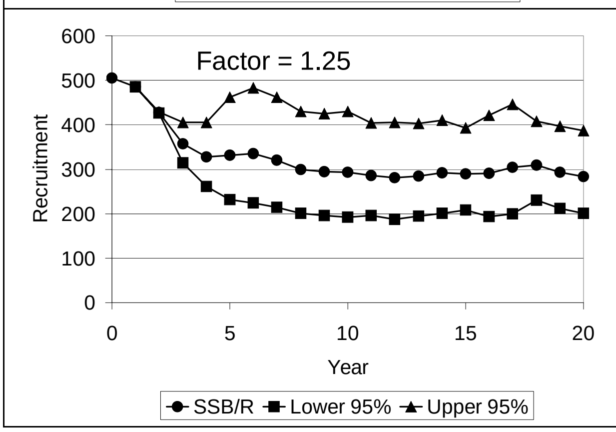
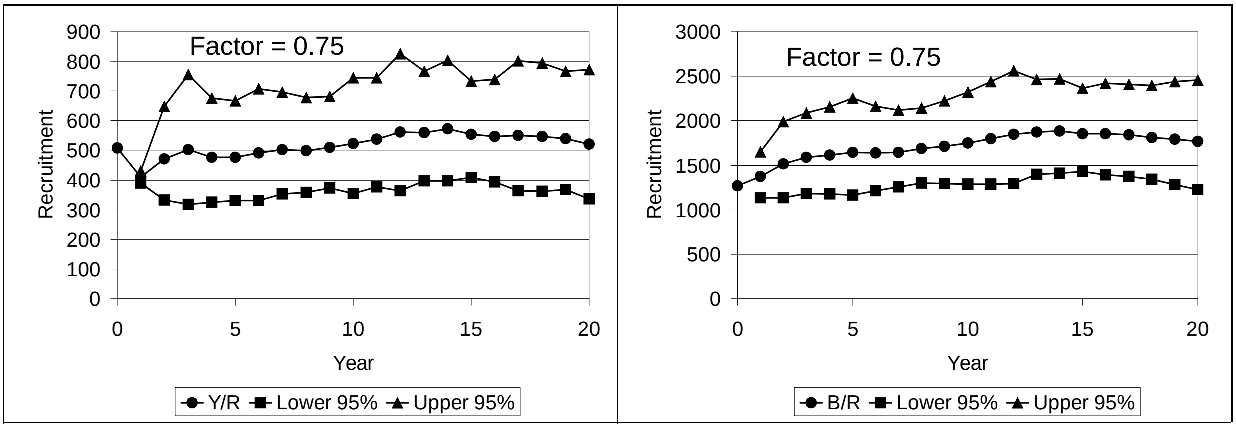


Figure III.41 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 1.25, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.



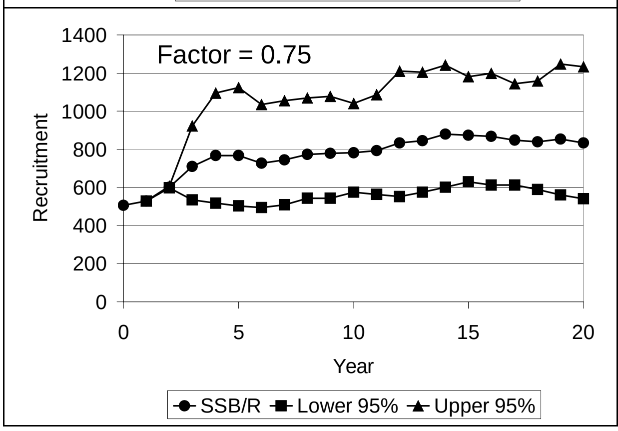
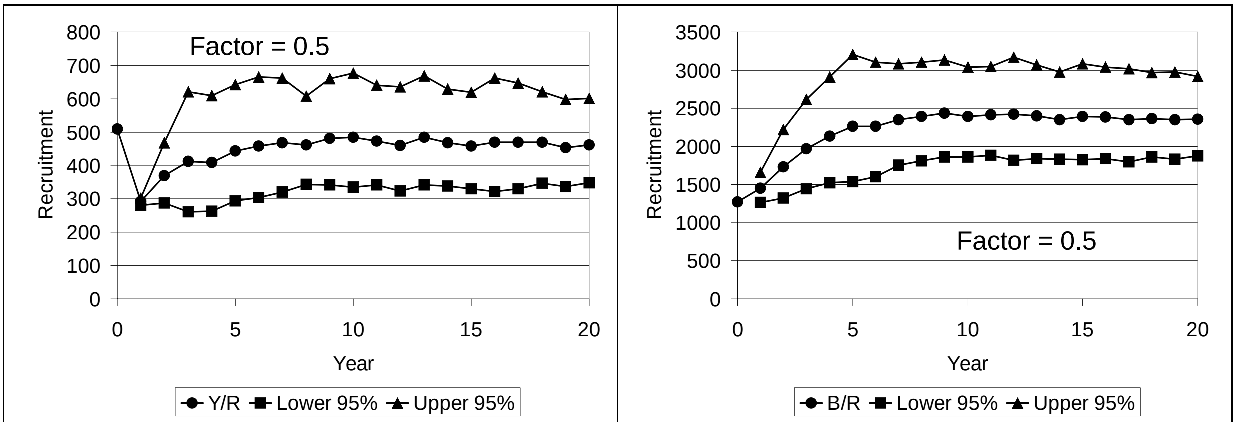


Figure III.42 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.75, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.



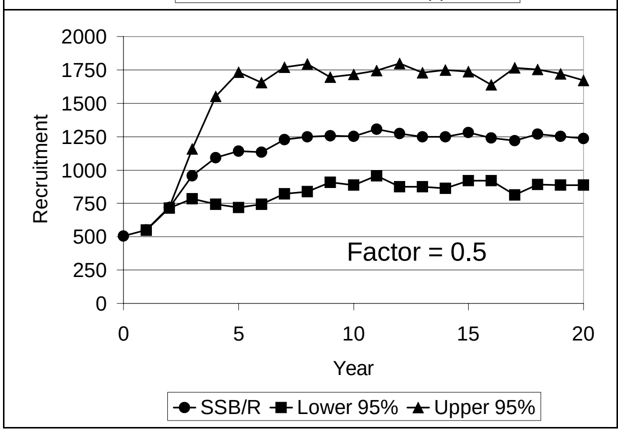


Figure III.43 – Results of the transition analysis under conditions of stochastic recruitment, using the Beverton and Holt's stock-recruitment model, with simulations for increasing fishing mortality (*F*) by a factor of 0.5, for males of Caribbean sharpnose shark, *Rhizoprionodon porosus*, off Pernambuco 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.

Table III.16 - 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), showing the extreme values: *parameter* (1+factor)* and *parameter* (1-factor)*

	Variation Factor 0.01 (1%)				Variation Factor 0.5 (5%)				Variation Factor 0.1 (10%)			
Parameter	YTS	MS	FCSS	MCSS	YTS	MS	FCSS	MCSS	YTS	MS	FCSS	MCSS
L∞ (+)	2.7439	2.9721	3.1326	2.8707	13.2689	14.2707	14.9923	13.8174	25.3544	27.1152	28.3682	26.3224
L∞ (-)	2.7997	3.0327	3.2014	2.9277	14.5026	15.7739	16.7068	15.1949	30.2805	33.1257	35.2308	31.8281
K (+)	1.8447	1.87522	1.5860	1.3715	9.1345	9.2858	7.9233	6.9048	18.0259	18.3209	15.8174	13.9098
K (-)	1.8536	1.8842	1.5849	1.36760	9.3481	9.5037	7.9222	6.7849	18.8741	19.1934	15.8152	13.4304
t_0 *(+)*	0.3025	0.3842	0.5050	0.5285	1.5066	1.9153	2.5182	2.6428	3.0102	3.8126	5.0207	5.287668
t_0 *(-)*	0.3025	0.3850	0.5061	0.5285	1.5155	1.9325	2.5340	2.6428	3.0399	3.8831	5.0816	5.2817
a (+)	0.9995	0.9994	0.9998	1.0002	5.0003	4.9996	5.0004	4.9988	10.0005	10.0001	9.9997	9.9996
a (-)	0.9995	1.0003	0.9998	1.0002	5.0003	5.0004	5.0004	5.0007	10.0005	10.0001	9.9997	9.9996
b (+)	9.7218	11.5624	12.7243	11.3239	40.0231	45.8736	49.3461	45.1583	64.0103	70.6655	74.3225	69.9107
b (-)	10.7717	13.0804	14.5820	12.7721	66.8189	84.9903	97.5730	82.4196	178.4299	242.6483	290.6528	232.9030
M (+)	0.3233	0.1252	0.2953	0.3576	1.6223	2.2806	1.4801	1.7998	3.2623	1.2380	2.9725	3.6213
M (-)	0.3203	0.1252	0.2942	0.3576	1.6015	2.2593	1.4687	1.7763	3.1852	1.2661	2.9251	3.5310
Fterm (+)	0.0089	0.0655	0.0078	0.1807	0.0445	0.3391	0.0405	0.9333	0.0949	0.7143	0.0856	1.9531
Fterm (-)	0.0089	0.0639	0.0078	0.1788	0.0415	0.3088	0.0361	0.8606	0.0771	0.5914	0.0698	1.6544

YTS – Yellowtail Snapper (*Lutjanus chrysurus*); MS - Mutton Snapper (*Lutjanus analis*); FCSS – Female Caribbean sharpnose shark (*Rhizoprionodon porosus*); FCSS - Male Caribbean sharpnose shark (*Rhizoprionodon porosus*)

III.4 - DISCUSSION

Aiming to better understand the answers of a given fishery resource to the fishing effort applied, one must attempt for the conduction of studies on its biological characteristics and the fleet operating conditions, mainly to take into account that many of the species commercially exploited have distinct characteristics and susceptibility to the employed methods of capture.

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) and Maynou (1999)[17], 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.

III.4.1 – THE FLEETS

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

The catch per unit of effort estimated by each fishing gear, considering the weight of the catches per fisherman and per day, showed that gillnet (8.83 kg/day/fisher) presented a productivity 22.5% higher than hand-line (7.21 kg/day/fisher). This seems to occur because gillnet are known to be less selective than hand-line and the catches, although greater, seems not be sustainable. Despite a VPA was not run for any of the gillnet target species, the overexploitation state denoted by female Caribbean sharpnose shark caught as by-catch and the susceptibility of both sexes of this species for any increase in effort, shows that gillnet are non-selective and is operated in an unsustainable manner.

Fishermen constantly face the uncertainty of getting a good production, due to the diverse of variables that make part of the fishing activity. In such a case, the skilfulness of the skipper is highlighted in consequence of his know-how (Silva, 1992), presenting himself as the main productive vector of this activity and as directly responsible for the success of the fishing.

III.4.2 – THE BIOLOGICAL RESOURCES

Samples of fish taken from the wild very rarely include all age groups in proportion to their abundance. For the most part this is because the gear used to capture them is selective by size. Even if it is not, the fish themselves tend to inhabit different parts of their environment at different ages, or within a single environment they may assemble in school containing individuals more or less uniform in length and different from other schools. The result is that the fish toward the lower end of the length range sampled will usually include only the larger individuals of the youngest ages present. There may be the opposite bias at the upper end of the sampling range. If the mean length of incompletely sampled age groups at either end of the range are compared directly with the representatively sampled middle group of ages, the result is that the rate of growth is underestimated (Ricker, 1979).

Allen (1985) mentioned that maximum length for yellowtail snapper is 70 cm and that specimens are commonly caught around 40 cm. This is in accordance with the present length class distribution, in which 46.3% of the individuals ranged between 37.6 cm and 42.5 cm. For mutton snapper this same author informed that maximum length is around 80 cm, whereas the average individual length is 50 cm. Although for this species higher frequency was for individuals that ranged from 40 cm to 50 cm (58.3%), the length amplitude from 45.1 cm to 55 cm was relatively high (37.7%). Caribbean sharpnose shark males most frequently range in the length class that Compagno (1984) and Mattos *et al.* (2001a) defined as the size-at-maturity, from 60 cm to 65 cm. Although Compagno informs that size-at-maturity for females is around 80 cm, which is in accordance with the results found by Ferreira (1988) for the female stock off Rio de Janeiro State in the Southeast Region of Brazil, Mattos and colleagues found that off Pernambuco size-at-maturity is 65 cm, where the sample occur.

Yellowtail snapper presented a high temporal (year to year) and month variability in catches, although no seasonal production pattern could be detected. It seems that during rainy season, from May to August (July and August is the month with most intense winds), rough environmental conditions impede fishing operation and supposedly decrease fishing effort, because these months show slightly smaller fishing production. On the other hand, the mutton snapper did not show a high variability temporal trend, but it does show that catches have a significant decrease during rainy season, with high monthly variability, with some years (1995, 1996 and 1999) clearly showing a normally downward catch distribution. Such high temporal and month variability may be explained by misreporting of data gathering or biological events, such as stock-recruitment relationship.

III.4.3 – GROWTH-AT-AGE ANALYSIS

The biomass of an unexploited fish stock will tend to increase at various rates depending upon its size and will grow towards some maximum weight which, once reached, will be maintained. This population size will be termed the natural equilibrium size. Considering the environmental influence on stock size, three components must be considered of utmost importance in the growth rate of a fish stock: (1) *recruitment,* the biomass weight of fish entering the catchable population during the time period; (2) *individual growth,* the biomass weight of the growth of individual fish within the population during the time period; and (3) *natural mortality,* the biomass weight of fish lost from the population due to natural death and predation during the time period (Anderson, 1977).

A characteristic of the growth of many fishes in nature is a marked seasonal variability, being usually faster in summer and slower in winter, especially outside tropical regions. However, the seasonal cycle of growth is not always, perhaps never, wholly under temperature control. In temperate and northern latitudes the distribution of lengths within a single brood (year-class) of fish is usually unimodal, apart from random variation, and frequently it is reasonably close to a normal or Gaussian distribution. Exceptions occur when spawning takes place at intervals over a considerable period of time and widespread occurrence of greater mortality rates among the larger members of a brood (Ricker, 1979). On the other hand, this is not the case in tropical regions, where, in general, many modes can be found for a single brood.

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 which requires proving the accuracy of an age estimate by comparison with a determinate method, and this procedure must be completed for all age classes available (Cailliet, 1990). Kimura and Lyons (1991) stated that most everyone familiar with the ageing of fish knows this process is fraught with difficulties because, at the very least, there must be random variability about some true age. Yet, it must be emphasised that in age determination studies the term “precision” is used to describe “agreement”, or variability between readings of the same specimen by the same or different age-reader. The term “accuracy” is reserved to describe a comparison of ages generated by readers with the “true” age for specimens of known age.

It is not the intention of the present study to discuss the problems that arise when age and growth estimation of fish are being conducted because, as stated by Gulland (1969), Ricker (1969), and Mulligan and Leaman (1992), a closer analysis of the length-at-age distribution conducted for deepwater rockfish Pacific Ocean perch revealed a systematic bias in the mean residual for each age, and that ageing errors tend to underestimate the age of older fishes. The assumption is that it can be true for the present analysis. 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.

Ricker (1979) pointed out that the existence of asymptotic growth to an indefinitely great age can be neither proved nor disproved; nor need all kinds of fish be the same in this respect. Also, the question is not one of any great importance. Whether asymptote really exist or not, asymptotic formula are a convenient way of modelling many observed growth series, and may be expect them to be used into the indefinite future. Probably, as it was already mentioned in the literature, growth pattern alone are more visible in mature and older individuals, when occurs for one definitive size, an accented growth more of one or another group.

For instance, Cailliet (1990) stressed that for elasmobranchs, and it sounds reasonable for teleosts fishes, 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.

Knight[41] (*apud* Ricker, 1979) has argued that, for fishes, asymptotic growth is a mathematical fiction rather than a real phenomenon. Krüger[42] (*apud* Ricker, 1979), on the other hand, maintain that it is real, even while pointing out that estimates of the position of the asymptote are subject to wide variation depending on the curve fitted. Ricker (1979) believes that Knight is right in this sense, that no matter to what age a fish size is observed to have an asymptotic trend, we can never be sure that it would continue in that fashion if the fish were to survive longer.

Thus, although concerned that further age and growth studies must be conducted, it seems that, from the results obtained, the method of size-frequency distribution well fitted the analysed stocks samples. For yellowtail snapper Froese and Pauly (2003) report, from the work of various authors on this species derived from the Southeast zone of Cuba, for the von Bertalanffy's growth parameters an amplitude on the estimation of $L\infty$ from 40 cm to 69.3 cm (fork length used), for K from 0.1 to 0.332, and for t_0 from –1.79 to –0.27; whereas for the parameters of the length-weight relationship values for a from 0.0117 to 0.0853, and for b from 2.47 to 3.032. It thus sounds reasonable to believe that the attained results were quite adequate for the species in question ($L\infty = 76.67$ cm in total length, $K = 0.158$, $t_0 = -0.728$; $a =$

[41] Knight, W. (1968) Asymptotic growth: an example of nonsense disguised as mathematics. *J. Fish. Res. Board Can.* **25**:1303-1307.
[42] Krüger, F. (1969) Das asymptotische Wachstum der Fische-ein Nonsens? *Helgol. Wiss. Meeresunters.* **19**, 205-215.

0.0183, and b = 2.7753). The analysis conducted by Valle and colleagues[43] for this species in Southeast Cuba found values of $L\infty$ = 69.3 cm in fork length, K = 0.1, t_0 = -1.79, and b = 2.83, which approximate the estimated value for the present study.

For mutton snapper Froese and Pauly also referencing various authors report a variation on the above cited parameters equal to: $L\infty$ = 78 – 118 cm fork length; K = 0.1 – 0.246; t_0 = -1.42 – -0.58; a = 0.0042 – 0.0354; and b = 2.53 – 3.175. Once again the estimated parameters obtained for mutton snapper in the present study sounds quite reasonable and accurate ($L\infty$ = 108.2 cm total length; K = 0.168; t_0 = -0.892; a = 0.0112; and b = 3.0019). The most closely related estimation for the asymptotic length comes from the work of Claro and García-Arteaga[44] for the Northern coast of Venezuela, who found the following results: $L\infty$ = 103 cm in total length; K = 0.17; t_0 = -0.62; a = 0.0104; and b = 3.07; showing high level of accuracy with the presented results.

As discussed by Mattos and Pereira (2002), the parameters of K, t_0 and $L\infty$ (0,42; -1,10 and 87,13 for the males; e 0,30, -1,12 and 106,82 for the females, respectively) are accurately close to values previously estimated for other species in the 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 of the same ones. In any way, such results corroborate from those reported by Compagno (1984), according to whom the maximum values for males reach at least 85 cm, while that for females 108 cm. Parson (1985), analysing a sample of the population of *R. terraenovae* from the Gulf of Mexico, grouping males and females, found that the growth parameters were: K = 0,45; t_0 = -2,01; and $L\infty$ = 92,5 cm.

III.4.4 – VIRTUAL POPULATION ANALYSIS (VPA)

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).

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[43] Valle, S. V.; García-Arteaga, J. P.; Claro, R. (1997) Growth parameters of marine fishes in Cuban waters. *Naga ICLARM Q*. **20**(1):34-37.

[44] Claro, R.; García-Arteaga, J. P. (1994) Crecimiento. In: R. Claro (ed.) *Ecología de los peces marinos de Cuba*. Instituto de Oceanologia Academia de Ciencias de Cuba and Centro de Investigaciones de Quintana Roo (CIQRO), México, p.321-402.

There are too little informations in the consulted literature on the rates of fishing (*F*) and natural (*M*) mortalities for snappers. Allen (1985) informed that the von Bertalanffy growth coefficient (*K*) and exponential rate of mortality (*M*) were estimated as 0.16 and 0.20, respectively, for the Cuban population of yellowtail snapper. The rate of *M* for this species was estimated as 0.112, whereas for mutton snapper 0.152. No information was found on the estimation of *F* for the latter species. It is well known that *M* is quite hard to estimate, and many factors – biological and/or ecological – may be involved on the natural mortality of any species of fish. Otherwise, *F* is directly dependent on the fishing effort (*f*) applied and its estimation, although straightforward, deserves attention but is particularly specific of a particular fishery, and comments can only be done to make possible the comprehension of the exploitation pattern and fishing pressure in which a fishing stock is submitted. Nevertheless, as these parameters are needed to run the VIT Program, their estimation were carefully conducted and validated by the program. It can be seen that yellowtail snapper is under heavier fishing pressure, with an *F* of 0.358, whereas for mutton snapper *F* was estimated as 0.277. The exploitation ratios, given by the relation between fishing and total mortalities (*F/Z*) thus, are 0.76 for the former and 0.53 for the latter.

Before going further on, however, it should be interesting to point out the argument raised by Ricker (1969) where differential mortality exists, the calculated average length of a particular year-class in an earlier year of the fish life represents the former *size of the fish that survive to the sampling age*, but it differ from the average length of the year-class as it actually exited in previous times. Lacking better information, biologists frequently postulate an average population mortality rate that does not change with age, in making numerical population models. However, when there is positive differential mortality by size, such an assumption implies that the mortality rate of the fish *of any particular initial size* must gradually increase (italics by the author).

The evaluation of natural *vs.* fishery related mortalities 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 limitation and the available data did not allow estimation by size or age.

The presented results on the trends of catches for these two species, the population status and the yield-per-recruit (*Y/R*) analysis, which express the need of reduction in the current level of *f*, probably denote that the yellowtail snapper stock off Pernambuco continental shelf is more heavily fished than the mutton snapper one. Otherwise, the relative small variations presented by the level of recruits in changing effort factor conditions, either for increasing or decreasing factors should indicate that recruitment for the yellowtail snapper population off Pernambuco is stock density-independent. After the above cited rates of mortalities and the exploitation ratio, the decreasing trend in catches for yellowtail snapper should be the stock response for such a high fishing effort level, with can be clearly evidenced by the estimated exploitation ratio. The diminishing effect of effort means that destruction of the population is virtually impossible; the fishery can sustain a great amount of effort, but the yield will be very low, indeed. 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.

Another assumption that must be taken into account is the hypothesis raised by Lloret and Lleonart (2002) that reproduction and recruitment of some species living in temperate and subtropical characteristics of the Mediterranean Sea might not follow a clear seasonal cycle. This occurs because fish populations living in warmer waters breed continuously and has long (or continuous) recruitment season, which seems to be the case of the herein-analysed tropical stocks of fishes. Such pattern is of utmost importance to consider because it could therefore constitute a significant shortcoming for their assessment, due to difficult to define population parameters (e.g. year-class strength, growth and maturity) and modelling (e.g. establishment of stock-recruitment relationship and yield-per-recruit analysis).

The preceding analysis seems to indicate that yellowtail snapper, one of the smaller lutjanid species, is more frequent in shallower regions off Pernambuco shelf, thus more vulnerable to the fishing effort applied, due to the accessibility of hand-liners to inshore fishing grounds, and the utilised fishing gear. Mutton snapper, on the other hand, a larger species, may inhabit deeper regions of the platform and the continental slope, whereas younger may be more frequently found in shallower regions off Pernambuco continental shelf. Although hook-and-line seems to be quite selective, it is known that the size of the hook may apply great variability on the size of fish caught and may change selectivity effects. However, as indicated by Ricker (1969), and it sounds plausible for the present study, recruitment of a year-class to a fishery means its increase in vulnerability to the fishing gear in use, as a result of increase in individual size, changed distribution, or changed behaviour.

However, others assumptions concerning catch and effort data for snappers may indicate that, as both these species may be considered target for hand-liners, the type and size of the hook used should, in average, act on older but smaller fishes of yellowtail snapper and younger of mutton snapper, as shown by the VPA population status results. Some questions immediately arise. Are these stocks submitted to size selective mortality? There is no sufficient data to ascertain on this argument, but the catch-at-size data may indicate that the larger fish of a year-class of yellowtail snapper population should have disappeared more rapidly than the smaller ones, and vice-versa for the mutton snapper population, as denoted by the mean length and age of these populations (Tables III.10 and III.11, respectively). Due to the non-selective aspect that characterise the gillnet fishery and lack of additional detailed information on gear characteristics, it seems premature to infer if the Caribbean sharpnose shark stocks are submitted to the same condition as for snappers.

This pattern can be explained by Lee’s phenomenon, cited in item I.4 and 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.

Ascertain on the determination of the biological and physical processes affecting the recruitment of snappers, aiming at constructing the spatially structured models of their population dynamics, is essential for the understanding of catch-effort data variability and it still poorly known for many species in Brazilian waters. In this sense, following Maynou *et al.* (2003), the determination of the location of nursery areas and the environmental processes that determine the habitat preference of these species recruits is important for assessing the differential survival of recruits in different recruitment areas.

Although not analysed in the present study, reproduction rate must be very high to support recruitment at practically minimum variation levels because, as stressed by Cushing (1975) a reduction in stock yields may result a greater increase in recruitment in more fecund species, which can support a high rate of exploitation without endangering recruitment. Others factors such as migration from less fished fishing grounds and recruitment based on colonisation of eggs and larvae from others stocks, very common among reef fishes, may happen.

Although it is not in the scope of the present analysis to discuss the spawner-recruit relationship, it must be pointed out that it 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, and carrying out some sort of nonlinear regression or nonparametric smoothing to the stock-recruit data.

For the Caribbean sharpnose shark the exploitation ratios were estimated to be 0.7 for females and 0.6 for males. Although not a target species it seems that the female stock of this species is under heavy fishing pressure, as demonstrated by the VPA results on the population status and the *Y/R* analysis, and that the male stock is under-exploited. Otherwise, even the male stock would not support increase in the current fishing effort level, presenting rapidly population collapse. 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.* (2001a), the under-exploitation condition of males should be related to the species migration pattern. Parturition ground must be coastal and estuarine regions off Pernambuco where adult females give birth to neonates. As individuals become older, they migrate to deeper waters of the platform and the continental slope, where adults should mate and find their prey. Females, thus, become more vulnerable to the fishing gear during their migration to and from parturition grounds and deeper waters, while males should spent their whole adult life in such deeper regions.

The obtained results for *R. porosus* of Pernambuco State coast make possible the attainment of the von Bertalanffy’s growth curves in total length and eviscerated weight, through the method of length frequency distribution for females and males separately, and the ascertains that exists significant difference in the growth pattern between the sexes. The artisanal gillnet fleet fish mainly in coastal regions and catches a greater amount of youth 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 shelf (Mattos and Pereira, 2002).

As already mentioned, the official statistics do not identify small coastal sharks by species, that is why a historic data series for *R. porosus* is not available, and as, for long, lack of trustful reliable data was a barrier to the local fishery management, it is not possible to infer on the exploitation condition of such stock, the results showed that the population presents a density-dependent stock-recruit relationship.

Fluctuations of fishing yield from year to year has been reported for many fisheries and although for the coastal fishery of Pernambuco there always have been considered that any fluctuation on catches was related to misreporting of catch/effort data, these could be related to fluctuations of the year-classes of the species populations followed, which are themselves determined at a very early stage. The above cited authors mentioned that Hjort[45] studying cod, herring and haddock proposed two main mechanisms for such fluctuations which are directly related to larval biomass: (1) food availability; and (2) larval dispersion. This and further studies consider that larval biomass is density-dependent in the seasonal availability of food, as well as environmental conditions, and Cardinale and Arrhenius (2000) showed that mortality of eggs and fish larvae was dependent on the age and size of the spawners. Older individuals producing offspring with higher rates of survival, so that recruitment is not only proportional to the spawning stock biomass but also the age-classes structure of the spawning stock. Poor recruitment has certainly been a factor in slowing the recovery of cod in Atlantic Canada (Myers *et al.*, 1997).

Fromentin and Restrepo thus stressed that there is no simple and unifying mechanism to explain variations in recruitment and year-class. The processes differ between species and depend on the local environments. Variations in recruitment and year-class strength appear thus to be related to three main classes of factors: 1) *human activity*, mainly through over-exploitation of the spawning stock, but also through pollution of the spawning and nursery areas; 2) *biological processes*, such as predation, cannibalism and competition and 3) *environmental events*.

[45] Hjort, J. (1914) Fluctuations in the great fisheries of northern Europe: viewed in the light of biological research. *Rapp. P. Reun. Cons. Int. Explor. Mer.*, **20**:1-228.

At small stock sizes, the net effect of recruitment and individual growth is greater than natural mortality and natural increase is positive and increases with stock size. At some intermediate level the rate of growth begins to fall off as the stock continues to grow, because mortality become relatively more powerful. Eventually a point will be reached where recruitment and individual growth are just balanced by natural mortality and stock growth will cease (Anderson, 1977).

Thus, notwithstanding the misreporting of fishery data by the official Brazilian agency, fluctuations on catches of the herein studied species may have others factors that must be taken in consideration. Also, such analysis can help in the assumption raised of density-independent stock-recruit relationship among snappers' species, which resulted from the VPA analysis. Although there is no available information on food availability for fish larvae off Pernambuco continental shelf, the other factors previously described, i.e. biological processes and environmental conditions, may influence and play an important role in the success of a year-class recruitment. As far as current scientific information states and based in the consulted bibliography, among snappers predation and cannibalism has not been reported and competition although must occur, there is no information for the stocks under analysis. Also, available data show the relative stability of the environmental conditions off Pernambuco State continental shelf, mainly sea temperature which fluctuates from 25ºC to 29ºC (item II.2), a characteristic of tropical and equatorial regions. It is well known that reef areas are generally stable and protected areas from predation and cannibalism, and although they could not prevent eggs and larvae to be carried far away out by wind and current, so that they could not return and reach their nursery grounds, they could prevent from other environmental events, i.e. storms.

This can explain the high temporal (year to year) and seasonal variations in catches for the three analysed species, more accentuated for yellowtail snapper and Caribbean sharpnose shark, rather than only deny administration for misreporting. Although complaint on the fact that data gathering and fishing statistics collection must be handled carefully and improved, the present analysis demonstrates that other aspects should be involved on catch variations and that the local statistics could be better than most local scientist believe.

The results derived from the deterministic and stochastic simulations should not have been well justified when the standard of accuracy of the data, the complexity of the biotic system with which the biological processes occur and the analysis are dealing, and the order of magnitude of the expected discrepancies, are all taken into account. Partial data allowed a systematic visualisation of the activity and, thus, the parameters of collection of information can be modified, what allow the accompaniment of the situation, in real time basis, of the exploitation of a specific marine population, and the study of the interaction of different fishing gear. In these “probabilistic” models account is taken of the fact that, in reality, population parameters do not have constant numerical values but fluctuate to a greater or lesser extend under the influence of chance events, because population changes as a stochastic process.

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. The influence on the *Y/R* analysis of the mortality vectors did not occur, probably denoting that such parameters well fitted the studied stocks.

III.4.5 – FINAL COMMENTS

Local environmental conditions and climatic changes play an important role in the tactics of fishing. Thus, it has to be considered, together with these diverse aspects, the individual capacity of each fisherman and his knowledge on the fishing ground. It is important to consider, however, the reproductive strategy of the analysed species for the effective management of the fishing activity. The ovulation period, as an example, not only varies among species but also with the prevailing local temperature and food availability.

With the accented decline of the indices of capture presented by the species of higher commercial value, decurrently of the generalised degradation of coastal ecosystems and the extreme applied fishing effort, many before undesirable accompanying fauna, by the commercial point of view, turned to desirable ones, although not being target species. Such fact strengthens the necessity to conduct studies to subsidise regulation and management measures that aim at the adequate administration of the resource. Concerning, thus, the raised stock-recruit relationship that may occur for the analysed stocks, it must be pointed out Cushing’s (1975) argument that if recruitment were assumed to be independent of parent stock, decision related to conservation measures could be made more quickly. Such a procedure can be dangerous, however, because any decline in recruitment is attributed to natural causes rather than to fishing.

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 that the authorities of the national fishing sector urgently define a "fishery policy", aiming fishery regulations and the generation and diffusion of new technologies that allow the exploitation of new fishing grounds. 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.

Otherwise, regulation and management measures should propitiate a diversification in the offers of fishing products, within the sustainability view and the rules of co-management of the involved communities, respecting the socio-economic and cultural characteristics of the such communities (Mattos *et al.*, 2002). Co-management, practised currently in Europe, is based on a continuous model of the natural resources, where the responsible agencies for the administration pass to be only the co-ordinators of the activities, allowing that the local communities and the State participate effectively of this model, which is a desirable action fishermen organisation and insertion in the management process, strengthen local development.

III.5 – CONCLUSIONS

- 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. Nevertheless, the comparison of the obtained parameters and the sensitivity analysis showed that these could be utilised for the virtual population analysis and the corresponding reconstruction of the population;

- The mortality vectors indicated that the four studied stocks are submitted to high levels of fishing effort, the exception being the male stock of the Caribbean sharpnose shark, denoting that the two snappers' species and the female stock of shark are overexploited;
- The results denoted that snappers should rapidly recover with decreasing fishing effort and that low increase in the current effort level indicates that stabilisation should ever occur, and new biological equilibrium should be reached. This must be related to the stock-recruit density-independent pattern of these stocks, because a decreasing fishing effort although imposing an increase in biomass does not indicates the same pattern in the recruitment level. On the other hand, 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 and that there a density-dependent stock-recruit relationship, because biological equilibrium should never be reached;
- The results obtained suggest that the studied stocks suffer from size-selective mortality, but a more detailed study on gear selectivity should be conducted to ascertain on such a way;
- Given that VPA grossly underestimate the rate of increase in mortality at age 3 and that the VPA's depend upon reliable catch statistics, one general conclusion is that 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 for all four stocks herein studied 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 for each one, and improve control on fishing gear selectivity; and
- Nursery areas, specially for small coastal sharks, off Pernambuco waters 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.

CHAPTER IV – THE ECONOMICS OF THE FISHERY

IV.1 – INTRODUCTION

Fisheries complexities may, and must, be treated beyond the strictly concepts of the biological science, because *human* is an important part of the whole system, either as work force or consumer. It is clear that how fishery can be analysed and evaluated to reach sustainable yields over the long term is part of the fishing biological science, but when the availability of fish to supply any demanding society is inherent during the process of analysis, social and political aspects are automatic incorporated and, since then, fishery is treated as commercial and better managed and assessed through the rules of the economic science. Settled the biological and economic bases of the fishery, it is when the socials and political circumstances must be accommodated to reach the *fisherman optimum*.

With the objective of understanding the economic structure of Pernambuco State hand-line and gillnet fishing operation system, an analysis of the fishermen decision process was conducted. For such a view, it sounds reasonable to mention once more the institutional property characteristic on which fishing resource are allocated, already described on item I.5. Until 1988, when a new Federal Constitution was promulgated, the fisheries resources were considered as of common property, since then they were defined as of State Property[46]. As emphasised in the general introduction, coastal fisheries resources off Pernambuco State were for decades considered of free access, without defined property, facilitating an indiscriminate extraction. Nowadays, the concepts are that those fisheries resources have a defined property, enforced by the administration.

This utmost important shift in fishing management followed international rules for the sustainability of fisheries, due to the significant reduction of certain available natural stocks. A large body of literature reports that only effective institutional controls (provided by the administration or by the fishermen organisations) can results in a reduction of effective fishing time. If this control is not effectively enforced a free access system can prevail and sustainability can not be reached.

[46] In the Art. 20 of the *Magna Constitutional Letter*, the natural resources of the continental shelf and Economic Exclusive Zone (EEZ) off Brazil belong to the State, as well as the territorial sea. Otherwise, the fishery resource property are better defined in the Art. 225, already described in item II.3.3 (The Fishery System).

As a natural resource, fish should be considered as for its biological aspects, but also as an economic powerful tool for those engaged in the productive chain, which is ruled by the market, because fish forms an important part of human diet in many countries, especially in developing coastal States. The operation of markets, as pointed out by Kula (1992), depends on the existence of well-defined and easily transferable property rights, and regulations must take place to avoid a common access basis. Fishing is one of the most vulnerable natural resources to common access, especially in the open sea where it is extremely difficult to establish property rights on the resource base. Even resource nationalisation or the establishment of economic exclusive zones would fail to solve the problem, due to e.g. the extension of the area to be monitored and migratory and transzonality characteristics of many fish stocks.

Concerning the economic point of view and the objectives to pursue for overcoming difficulties faced by the fishery sector in the State of Pernambuco, one of the problems found is the need to improve fish quality and stabilise the offer for wholesalers and retailer; and the need to increase productivity aiming at the improvement of individual income. These objectives were not generated due to public intervention, but in the market context, whose forces seem to have conducted the Pernambuco fishery economy to an equilibrium situation, considering the commercialisation of fish products, where productivity and fish quality are low. In a completely efficient market it should mean that the fishery sector in Pernambuco was at an optimum social level, that unfortunately denotes backwardness in the State economic condition.

Many problems appear during an economic analysis. One of them is that a model do not shows all the possible mutual dependencies and interrelationships that exist between different types of fishing concerning the markets of products and goods. Other may be the difficult to establish and validates the applied economic parameters, due to over- and under-estimations of costs and profits. According to Franquesa and Guillén (2002) some parameters determine the level of each cost within a fishery system: (1) general economic parameters that embrace the diverse fleets (such as cost of fuel); (2) technical and economic parameters characteristic of each fleet (initial vectors of catchability and fishing mortality, gross tonnage, initial capital, etc.); and (3) particularisation of the characteristics of each boat (specific costs, capital and catchability).

Considering that one of the basic assumption is that fishermen always try to maximise the profits obtained from the activity, the decision of the fishermen is based on the outcomes of each individual boat, because in each boat the costs are going to be deducted from revenues obtained by the fishermen from selling the catch. The difference between fishermen earnings and costs may lead to different situation, because from the total incomes the fishermen need to cover different costs, the remaining difference being the outcome. For the purpose of the present economic analysis, the term *fisherman* is herein used to define *boat owner*, that can or cannot be a through fisherman.

Thus, trying to go further in the economic of the fisheries in the State of Pernambuco, this chapter do not aims to describe and deepen analysis in the fisherman optimum economic to continue fishing, because it will be better treated in the next chapter on the bio-economic analysis of the coastal fishing in Pernambuco, during the application of the bio-economic model MEFISTO – Mediterranean Fisheries Simulation Tool, but the objective is to analyse the most significant aspects related to revenues, costs and profits that fishermen may incur involving fishing operations for the hand-line and the gillnet fleets herein considered, which could lead to support fishermen decisions during the fishing process and to define and estimate those economic parameters that will be entered into MEFISTO model.

IV.2 - MATERIAL AND METHODS

Economic and organisational information was collected directly in the fishing communities of Piedade (Fishing Association Z-27), at Jaboatão dos Guararapes City, and Brasília Teimosa (Fishing Association Z-1), at Recife City, both cities located at Pernambuco State littoral, considering the focus of the present research, being tabulated in a matrix of data to facilitate the analyses of the intra- and inter-specific relationships.

For the analysis of costs, the methodology adopted by Franquesa and Guillén (2002) was applied, in accordance with the leading discussion for the development of the Bio-economic Modelling for Mediterranean Fisheries (BEMMFISH)[5] Project. Nevertheless, this methodology was based on previous studies conducted by Lleonart *et al* (1999a) and was adopted by Franquesa and Guillén to produce the Annual Economic Report of the European Union Fisheries[47], applied to the specific conditions of the Mediterranean. For the purpose of

[47] GEM-UB (Director), ICM-CSIC, IFREMER, IEO-Palma, OIKOS and LEI-DLO (2000) *Quantitative analysis of the relations which condition the North Occidental Mediterranenan Fishing System* (DG XIV – MED/93/022). Final Report.

the present economic analysis it must be convenient to express that such methodology is defined as the fisherman box, one of the three boxes that compose the bio-economic model MEFISTO, the basic method that support and compose the present bio-economic study and that will be applied in detail in the Chapter V. The functioning of the fisherman's box is illustrated in Figure IV.1, which shows the relationships between the different variables of this part of the model.

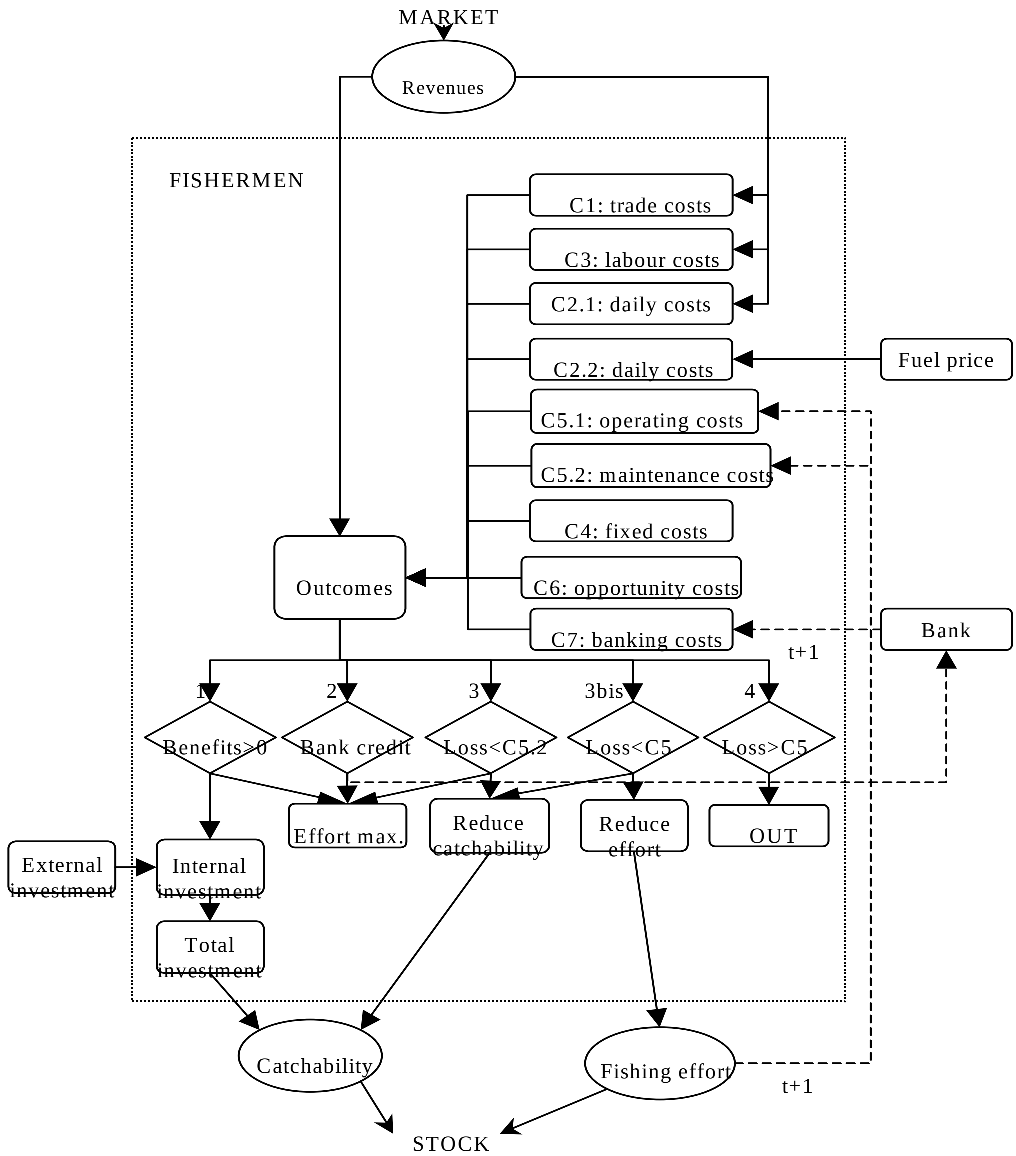


Figure IV.1 - The MEFISTO fisherman's box.

Thus, the framework of the fisherman box was adopted and was applied only as a function of total revenues to help the understanding of the economic structure of Pernambuco State hand-line and gillnet fleets fishing operation processes. This means that the equations developed to be utilised inside the box to help run the model was not applied at all, because it only makes sense and will be better illustrated during the application of MEFISTO in the next chapter, that is, the utmost objective is the definition of the economic parameters that will be entered into MEFISTO model to proceed with the suggested bio-economic analysis of this particular fisheries. Furthermore, the emphasis will be on the variable and fixed costs of fishing operations, and others costs that fishermen may incur, and will be only mentioned and analysed if some relation is found with total revenue.

The expenses that the fishermen should meet shall be divided into 7 groups (summarised in Table IV.1):

Table IV.1 - Possible costs that fishermen may incur.

Term	***Type of Cost***	***Costs Denomination***	***Code***	***Explanation***
Short-term cost	Variable cost	Trade Cost	C1	Function of catch
		Daily Cost	C2	Function of effort
		Labour Cost	C3	
	Fixed cost	Compulsory Cost	C4	Constant
		Maintenance Cost	C5	Function of profit (1)
				Constant (2)
Long-term cost		Opportunity Cost	C6	Price of money
		Financial cost	C7	Interest rates

Obs: (1) A part of the maintenance costs is function of benefits. These costs are devoted to improvement of the boat (increases capital) and are avoidable.
(2) A part of the maintenance costs are held constant and represent a minimum unavoidable maintenance of the boat.

In the MEFISTO Model *i* must be considered for each boat, and can be expressed through each equation. Explanation of each cost that fisherman can incur is followed.

- *C1 Trade cost*. All costs that are possible to express as a percentage of the Total Revenues (*RT*) (value add taxes - VAT, fishermen's association taxes, labour taxes, local taxes, sale process, etc.). These are percentages of the total of the benefits, or total revenues, and can be expressed through the equation:

$$C1_i = c1_g \cdot RT_i$$

  In the MEFISTO Model such relation $c1_g$ is considered to be the same for each group of boats (fleet). For this item, the payment for the national institute of social security (INSS) was also considered.

- *C2 Daily costs*. These are the costs caused by the fishing activity (fuel, net mending, daily food expenses, bait, ice, etc.), excluding labour cost. They are a function of the daily cost of fishing by effort (the time of fishing: days x hours) and include a part of maintenance costs, such as net mending, which are proportional to effort:

$$C2_i = c2_i \cdot E_i$$

- *C3 Labour costs*. These are composed of the share ("part") corresponding to the crew and owner as a function of *RT* reduced by *C1* and *C2*:

$$C3_i = c3_g\,(RT\text{-}C1\text{-}C2)$$

  It is also possible to obtain the average wage as:

$$AW_g = C3_g \,/ \textit{crew number}$$

  Owner's share is a percentage of the revenues that include commercial costs, daily costs and fuel costs, that pertain to the owner, to pay for the costs incurred in the fishing operation (annual fixed costs, etc.), and profit, if there is some. Note that it's complementary to the crew share, and it is distributed among the crew as salary.

- *C4 Compulsory costs*. Or fixed cost, it is a yearly costs incurred by the fisherman for keeping his business legal (harbour costs, license, insurance, etc.), and they are constant. They are not dependent upon effort (number of days at sea).
- *C5 Maintenance costs*. Or variable (flexible) cost, these are the costs required to maintain the boat at its maximum performance level. They are included in the reinstatement of the used capital, repairs, etc. They are considered as an exogenous variable and is divided in two parts: the first part is the operating costs that are indispensable to meet to remain in the activity; and the second part is the other maintenance cost, which is avoidable but reduces the catchability (painting, maintenance of electronic devices, maintenance of engine, etc.).
- *C6 Opportunity cost*. This is the cost of using the capital invested, i.e. the income that the boat owner could obtain from the capital invested in the activity if the capital were instead deposited, or invested elsewhere for a fixed term, at risk zero. It is a function of the capital invested by the rate of the "Public Debt". It indicates the revenues lost (or "opportunities" lost) to the fisherman by investing in the fishing activity. As stressed by Anderson (1977), the important concept of opportunity cost thus indicates that cost is not stated best in terms of money but

rather in terms of things that must be foregone. The money cost of an item is essentially a measure of the value of the things foregone.

The opportunity cost can be seen also as the cost of having foregone a best alternative for investment, i.e. the price paid for not investing in a different economic activity or the income lost from missed opportunities. An approach of this parameters, expressed in percentage, is given by the rate of public debt in a specific moment and country, and can be expressed through the follow equation:

$$C6_i = c6_c \cdot I_i$$

- *C7 Financial cost*. This figure represents the cost to the boat owner to take loan, expressed as the yearly payment claimed by the financing institution or rules defined by the borrower, as official or not, when the boat has a credit debt. In case of negative profits, debts arise and any further investment necessitates loans. *C7* depends on the applied interest rates (*c7*) and an individual debt incurred. This percentage is the average rate of the loan in a specific moment and country, and can be expressed through the equation:

  $$C7_i = c7 \cdot D_i$$

  D_i has an upper limit (maximum debt accepted by the borrower) depending on the total capital invested, as the borrower is not willing to lend more than $d_m \cdot K_i$, where d_m is a maximal percentage of lend allowed by the borrower, and K_i the total boat investment.

IV.3 – RESULTS

Annual average variable and fixed costs for the hand-line and gillnet fleets are summarised in Table IV.2. Prices are shown in Brazilian Reais (R$).

For the hand-line fleet, detailed fishing operating costs were obtained by following a whole year operation of the boat *Estrela da Manhã*, with additional information gathered from others 17 boats, through interview with owners and crewmembers. For the gillnet fleet, fishing operating information were obtained through interview with the followed 10 boat’s owners and crewmember. Some additional information was supported by the data collected from the hand-line boats, because accessibility to such information was facilitated. For both fleets average value were used.

Table IV.2 – Summary of the annual average variable and fixed costs for one boat of the hand-line and gillnet fleets in Pernambuco State – Brazil, during 2002.

COSTS	HAND-LINE BOAT			GILLNET BOAT		
Variable	***Value (R$)***	***(%)***	***% Total***	***Value (R$)***	***(%)***	***% Total***
Food	1,471.50	26.19	*24.20*	885.00	18.27	*16.68*
Fuel	1,462.50	26.04	*24.06*	1,860.00	38.39	*35.05*
Ice	1,256.00	22.36	*20.66*	230.00	4.75	*4.33*
Cooking Gas	452.00	8.05	*7.44*	49.00	1.01	*0.92*
Bait	283.00	5.04	*4.66*	-	-	-
Net Mending	-	-	-	1,125.00	23.23	*21.20*
Spare parts	230.00	4.10	*3.78*	230.00	4.75	*4.33*
Lubricant oil	19.50	0.35	*0.32*	23.40	0.48	*0.44*
Services	442.00	7.87	*7.27*	442.00	9.12	*8.33*
Total Variable	*5,616.50*	*100.00*	*92.39*	*4,844.40*	*100.00*	*91.28*
Fixed	***Value (R$)***	***(%)***	***% Total***	***Value (R$)***	***(%)***	***% Total***
Maintenance	391.44	84.57	*6.43*	391.44	84.57	*7.37*
Boat license	26.00	5.62	0.43	26.00	5.62	0.49
Boat insurance	45.41	9.81	0.75	45.41	9.81	0.86
Total Fixed	*462.85*	*100.00*	*7.61*	*462.85*	*100.00*	*8.72*
TOTAL COSTS	**6,079.35**	**-**	**100.00**	**5,307.25**	**-**	**100.00**

Obs: Values in Brazilian currency (Real - R$). Brazilian minimum salary (= R$ 240.00). Change rates as in December/2002: 1.00 € = R$ 3.50

It can be seen costs items for the hand-line fleet, considering the total costs, are food (24.20%), diesel (24.06%) and ice (20.66%), together representing 68.92%. If only variable costs are analysed, these three variable items are again the most representative, with 26.19%, 26.04% and 22.36%, respectively, representing together almost 75%. For the gillnet fleet, higher costs items considering the total costs are diesel (35.05%), net mending (21.20%) and food (16.68%), representing together almost 73%, while considering variable costs only these items are also the most representative, with 38.39%, 23.23% and 18.27%, respectively, together representing close to 80%. Analysing the fixed costs for both fleets, the most representative item is the maintenance cost, representing 84.57%, which represents only 6.43% of the total costs in the hand-line fleet, and 7.37% in the gillnet fleet.

It may be observed that boats of the gillnet fleet has total costs 14.55% smaller than the boats of the hand-line fleet, and 15.94% if we consider only variable costs, because fixed costs are equal for both fleets. Higher differences are found between the following items: cooking gas (822.5% smaller for the gillnet fleet); ice (446.1% smaller for gill-netters); food (66.3% smaller for gill-netters); and diesel (48.1% smaller for hand-liners). These high variations in the variable costs between the analysed fleets suggest different fishing operation strategies, aiming reducing costs and increasing profitability. Gill-netters, targeting less valuable coastal species, seems to have developed a fishing operation strategy to reduce costs – however not at all understood in this sense by owners and fishermen – specially during the rainy season (winter) when boats return daily to port, some fish up to 6 days/week, from Monday through Saturday, leading to an economy in food, cooking gas and ice for fish conservation on board, although with higher cost in diesel.

Otherwise, if we analyse the total revenue and profit for each fleet, the results show that gill-netters operating fishing strategy seems gone effectively. The annual average total revenue for one boat in the hand-line fleet was R$ 18,420.00, considering an average annual total production of 3.8 t/boat, and an average fish price of R$ 4.85/kg; while in the gillnet fleet was R$ 12,425.00, considering an average total production of 4.0 t/boat, and an average fish price of R$ 3.10/kg. This means that the owner annual gross profit, considering the share system explained below, was approximately R$ 3,130.00 for the hand-liner boat, which represents 51.5% of the total costs, while a gill-netter owner gross profit was approximately R$ 2,770.00, representing 52.2% of the total costs. This means that gross profit for hand-liners is 11.5% higher than that for gill-netters, whereas total revenue and a total cost were 32.5% and 12.7% higher, respectively. These results show that a hand-line boat owner earned approximately R$ 260,00/month, and a gillnet boat owner approximately R$ 230,00/month, which represent approximately 75.00€ and 66.00€, respectively, that even in Brazil, and in the Northeast Region, is a very low income.

The economic parameters concerning costs that fishermen may incur are presented in Table IV.3, followed by a descriptive analysis. Values are presented in Brazilian currency (Real – (R$).

- *Trade cost (c1)*. The only commercial cost registered for the hand-line fleet was landing cost (*c1.1*), which is common, either for the owner or for the crew, and is taken before commercialisation. As explained in Chapter III, there is a labour force called *luteiros* that works during landing. This labour force retains 10% of the production value for landing, and correspond, approximately, to R$ 1,842.00. For the gillnet fleet, it was not observed such a cost. Other costs are beyond operating fishing costs, and besides a function of total revenue are taking from owner's profits.

Table IV.3 – Economic parameters defined for the hand-line and gillnet fleets of Pernambuco State, North-eastern Brazil. Values are shown in absolute or in percentage, according to collected information, and explanation on how parameters values were calculated or collected is presented in the followed text. All the presented values means the "*c*'s" in the presented equations for each defined cost. Values in Brazilian currency (Real - R$). Brazilian minimum salary (= R$ 240.00). Change rates as in December/2002: 1.00 € = R$ 3.50.

Fishermen Expenses	Parameter	Hand-line Fleet	Gillnet Fleet
Trade Cost (C1)	Trade cost (landing) (c1.1)	10%	Zero
	Social Security (c1.2)	0.1%	0.1%
	Fisherman Association (c1.3)	0.05%	0.05%
Daily Cost (C2)	Fuel price (2002 average) (c2.1)	R$ 0.95/l	R$ 0.95/l
	Fishing days (c2.2)	190	230
	Daily fishing hours (c2.3)	10h	10h
	Daily ice expense (c2.4)	R$ 6.60	R$ 1.00
	Fishing gear repair (e.g. net mending) (c2.5)	Zero	R$ 1,125.00
	Operating fishing cost/day (c2.6)	R$ 29.56	R$ 21.06
	Others daily costs (c2.7)	R$ 15.25	R$ 11.97
Labour Cost (C3)	Owners share (c3)	25%	37.5%
Compulsory Cost (C4)	Total Fixed Cost (c4)	15.43%	15.43%
	Boat License	5.62%	5.62%
	Boat Insurance	9.81%	9.81%
Maintenance Cost (C5)	Maintenance Cost (c5)	84.57%	84.57%
Opportunity Cost (C6)	Opportunity cost (c6)	5.9%	5.9%
Financial Cost (C7)	Maximum Credit (c7.1)	30%	30%
	Interest (financial cost) (c7.2)	Zero	Zero

Local municipal taxes are not established for the fishing activity. Registration to professional organisation is not compulsory and many fishermen don't have the interest to register at fishermen's associations, especially because cultural characteristics of *freedom* to fish whenever they want do not stimulate organisation. Nevertheless, to stimulate participation, a monthly fixed tax of only R$ 2.00, corresponding to less than 1.0% of the minimum salary and approximately 0.05% (*c1.2*) of total costs, are charged. Boat owners, even not being true fishermen, have to pay as well and participate more actively.

Today the fishermen are considered special workers for the National Institute of Social Security (Instituto Nacional de Seguridade Social – INSS), and their contributions should be calculated at a rate of 2.1% over their production. As individual control does not occur, tax is calculated over the regional minimum salary, at a same rate (2.1%), that represents, approximately, 0.1% (*c1.3*) of total costs.

It must emphasised that there still exist many informal relationships and trade inside the activity actually unknown from outsiders, and some commercial cost may be hidden beyond personal negotiations.

- *Daily costs (c2)*. In the present analysis daily costs will be presented as a matter of costs aiming at the comprehension of the fishermen financial health. As previously mentioned, the equations herein presented only makes sense to run the bio-economic model MEFISTO.

  Fuel price (*c2.1*) was considered as an average price for 2002, during data collection, being calculated as R$ 0.95/l.

  Fishing days (*c2.2*) were calculated as an average of the fishing operations for the accompanied boats, and according to the collected data. Considering the followed 18 hand-line boats, each fishing cruise lasted in average 4.2 days and 45 cruises were taken during 2002, which means that each boat, in average, fished 190 days. For the gillnet fleet, it was not possible to follow fishing operations accurately, but according to fishermen information a 230 fishing days can be considered for each boat. One of the reasons that can explain a greater number of fishing days for the gillnet fleet against the hand-line fleet is the strategy to reduce costs, as explained before.

  In the hand-line fleet some boats fish the whole day, but generally fishing occurs during the night, due to higher productivity and the decision of some fishermen to not waste bait. Doing so, the average effectively daily fishing hours (*c2.3*) for hand-liners was 10h, considering the time of immersion of the fishing gear. Otherwise, for the gillnet fleet, fishing operations always occur during the night, and nets are set twice, as already detailed in Chapter III (item III.3.1.2). Immersion for each set last for 5h, so daily fishing hours was calculated to be, also, 10h.

Daily ice expense (*c2.4*) was calculated to be R$ 6.60 for the hand-line fleet, according to collected data, and for the gillnet fleet, daily ice expense should be considered close to zero, specially during rainy season, as fishing takes place during the night and boats return to port everyday. During dry season (summer), a small amount of ice is consumed, due to higher temperature and because boats sometimes take more than one day fishing, so a daily ice expenses can be calculated as a base of R$ 1.00 per day, according to fishermen information. Such economy in daily ice expense, significantly smaller than the daily ice expense of hand-liners, seems to be compensated by a greater expense in fuel, higher for gill-netters, due to the different fishing operating strategy adopted by each fleet.

For the hand-line fleet, the fishing gear belongs to the fisherman and owners have no responsibility for their acquisitions and repair (*c2.5*), so it was considered equal to *zero*. Otherwise, in the gillnet fleet fishing system, the gears belong to owners, and between 10% and 15% of revenues are retained for net mending, previously accorded, so a 12.5% was estimated for this item, which means an absolute value of R$ 1,125.00, as better explained in *c3*.

Operating fishing cost per day (*c2.6*) was calculated dividing the total annual cost by the annual number of fishing days, and can be considered an average total daily cost. Other daily costs (*c2.7*) were calculated after taking off commercial, fuel and ice costs, divided by the number of fishing days. The value entered in the table was an average for the followed boats, but in the model for each boat a respective value was calculated.

- *Labour costs (c3).* For the hand-line fleet, boat maintenance and expenses to go fishing are taken from owner's share, locally called the *boat part,* and the only common expense is the landing cost, explained in *c1*, and the remaining production is divided equally between owner and the crew. Fifth percent, thus, are paid for the crew as salary, in accordance with each fisherman production, and fishing gear is fishermen belongings, as already mentioned in *c2*. Otherwise, as the MEFISTO model was developed according to the north-western Mediterranean Sea fishery system, where common costs also include the expenses to go fishing, and the remaining divided *a posteriori*, the calculated value for owner's share for

Pernambuco fishery system must withdraw from the owner share the main expenses to go fishing, such as food, fuel, ice, cooking gas, bait (for hand-liners), and lubricant oil, whose values are considered common costs in MEFISTO, due to the prevailing north-western Mediterranean fishery system. Thus, taking off 26.8% of owner's revenue, whose calculation was based on the relative participation of these items, the owner share for hand-liners was estimated to be 25% (*c3*). For the gillnet fleet, boat maintenance and expenses to go fishing are owner's share responsibility, as aforementioned. From the remaining 50%, between 10% and 15% is retained for net mending, adjusted in advance between owners and fishermen, and the remaining 35%-40% is divided among crewmembers, with a greater part to the fishing master (boats with 3 fishermen, the master takes 40%; and boats with 2 fishermen, the master takes 60%). So, for the gillnet fishery, owners share was considered to be 37.5% (25%, as share + 12.5%, as net mending). In spite of, in the gillnet fishery, the fishing gear is the boat owner property, repairs are taken from the crew "part", as described, which ends, in both types of fisheries, to be fisherman *responsibility*, with the difference that in the hand-line fishery it is taken from each fisherman wage, while in the gillnet fishery from the crew wage/production.

- *Compulsory costs (c4)*. Boats are not charged by the fishermen associations, but governmental licenses are compulsory to boats greater than 8.00 m long and targeting fishes, nowadays corresponding to R$ 26.00 per boat, which correspond to 5.62% of total costs. Smaller boats are exempt, and for others groups of commercial species, such as crustaceans (especially lobsters), there are different license values applied by the government. A fixed yearly insurance tax is also compulsory (R$ 45.41), which correspond to 9.81%. Considering these costs and those related with the expenses for the boat maintenance (*c5*), the compulsory cost, or the fixed costs, represents 15.43% (*c4*).
- *Maintenance costs (c5)*. In the present case, this practically do not exist, each owner trying to make small repairs when extremely necessary, consequently reducing his boat catchability, and very low expenses were observed to maintain fishing boats in operation, because it is always avoided by owners and fishermen, as mentioned in c4. Compared to the fixed costs, maintenance costs represents,

approximately, 85% (*c5*). However, if compared with the total expenses to fish, for the hand-line fleet it represents 6.43%, and for the gillnet fleet, 7.37%.

- *Opportunity cost (c6)*. Money cost in Brazil is measured through the *Selic* rate, whose origin comes from the interest taxes effectively observed in the internal market system. In 2002 the accumulated *Selic* rate was as high as 19.2%, but the real rate, taking off the inflation calculated by the IPCA – Índice Nacional de Preços ao Consumidor Amplo (National Ample Index of Prices to the Consumer), or the public debt rate, was 5.9%, the lower level since 1990[48].
- *Financial cost (c7)*. The most important fishermen dependency is the *financial cost* that is dominated by small groups of wholesalers, because bank loans are not available. They borrow money to go fishing and their production is borrowers guarantee. Considering that an amount of the catches is for self-consumption, and there is no salary, notions of production costs are extremely vague. For the fishermen the production costs are all those goods that require money outlay, but there is no computation of the work force.

  In the case of Brazil as a whole, bank loans practically do not exist for the artisanal fishery, rare exception being governmental banks punctual programs that, in most of the cases, have a high political interest, especially for local politicians. Financial costs for the hand-line and gillnet fleets are raised by boat owners seeking better markets for their fishing products or with few small investors, that pay the expenses to fish, with the guarantee to receive the boat production as an informal and personal compromise, and fish price is maintained the same as those applied locally.

  Wholesalers, once the artisanal fishing operating supporters and, therefore, production intermediates and prices stipulators, practically disappeared from the local fishery system, due to local production decline. The maintenance of their business are supplied through external market (other states and fishing nations).

  Credits, as from boat owners or small investors, is not calculated according to boat value, but as the sum of expenses to go fishing, and correspond, in average for a whole year, to approximately 30% (c7.1) of boat value, according to collected information. Generally those small investors operates with 2 boats, and if revenues do not cover the costs of the initial expenses, owners and those small investors

[48] Boletim do Banco Central do Brasil. Relatório Anual de 2002. http://www.bcb.gov.br

cannot finance more than 4 fishing operations. Direct money interests (c7.2) do not exist and boat owners' and investors' gains are taken from the fish production commercialisation. Thus, although from the economic point of view an interest *zero* for a loan is unthinkable, such interest is maybe hidden internal and personal compromise that was not possible to clarify during data gathering and because the provided information, either from borrowers or from creditor, is that interest do not exist. So, for the purpose of the present study, it was considered *zero*.

Some other strategic process may be hidden beyond the economic structure of such fleets that was not revealed by the collected data. A known strategy, that may explain why they continue in the activity, is that some boat owners are also middlemen and/or retailers and have an extra income through the fishing production commercialisation. Owners, when middlemen, sale their production for retailers or wholesalers, at a prices ca. 10% higher than the price paid for the fishermen/crewmembers, or the price applied in the first commercialisation process. Owners, when retailers, sale the fish production at ca. 50% higher than the first commercialisation price. If it is the case, this strategy breakdown the intermediate process of commercialisation that raise prices up for consumers, because owners, commercialising their own production, are able to go for prices approximately 10% less than those applied by larger retailers, and wholesalers. However, this part of the economic structure will not be considered in the present analysis, because the objective, as already mentioned, is the analysis of the economic and financial system related to the fishing operation. The applied prices are listed in Table IV.4, and the reference price will be entered in MEFISTO Model to analyse the bioeconomic condition of the hand-line and gillnet fisheries.

One of the main assumptions, after the presented results, is the conception of costs and profits among local fishermen. In most of the cases single computations of adding up and deducting the invested capital with the production value are done. This is to say that it was not observed among local fishermen awareness on the net economic yield, but only in the difference between the relation amongst the yield and the fishing effort, the catches per unit of effort, and the catches per unit of cost or, which is the same, what the net unit yields are.

From the values presented in Table IV.2, the boat owner's profit was taken from the gross revenue that he or she had right, or gross profit, because trade and landing costs were not included. This seems to occur because not long ago the organisation system was even worse than is nowadays presented, because fishermen associations were totally and directly administrated by the government. Also, when fish was abundant, the less valuable fishes were distributed as a gift to the poorest people that, in some extend, helped in the landing of the fish production. This process evaluated to a stipulated wage for landing, which is not computed as production value by the boat owner, because is taken before commercialisation.

Table IV.4 – Reference prices of the defined main species as for bioeconomic analysis. Reference price was obtained through the official statistic control (CEPENE/IBAMA), while middleman and the retailer price through directed interview. Values in Brazilian currency (Reais - R$). Change rates as in December/2002: 1.00 € = R$ 3.50

Type of Species	**Species name**	*Reference price (R$)*	*Middleman price (R$)*	*Retailer fish shop price (R$)*
Main	Yellowtail snapper	4.36	5.00	7.50
	Mutton snapper	4.93	5.50	7.50
	King mackerel	5.68	6.00	7.50
	Spanish mackerel	3.69	4.50	7.00
Accessory	Dog Snapper	4.76	5.50	7.50
	Dolphinfish	4.27	5.00	7.00
	Blue runner	3.90	4.50	6.50
	Lane snapper	3.01	3.50	6.50
	Others (Hand-linners)	3.50	3.85	5.50
	Others (Gilnetters)	2.50	2.75	4.00

Here the analysis should lead to verify which are the best choice for the fishermen: if continue in the fishing activity, considering the available information of costs and revenues for the fishing operations; or to pass on his business and invest the amount got in a financial institution. The simulation considered average prices, as was the methodology adopted in the present analysis, and because the detailed analysis for each followed boat will be conducted in the next chapter. As the assumption for such an economic analysis is that the physical unit chosen must be closely related, boats, fishing devices and equipment for hand-liners and gill-netters are practically the same, and the values were considered equal for both fleets. The approximated values are as follow:

- ✓ Average value of boats – R$ 7,000.00
- ✓ Fishing devices – R$ 1,000.00

- ✓ Equipments – R$ 500.00
- ✓ Fishing operations annual costs for hand-liners – R$ 6,100.00
- ✓ Fishing operations annual costs for gillnetters – R$ 5,300.00
- ✓ TOTAL HAND-LINERS – R$ 14,600.00
- ✓ TOTAL GILLNETTERS – R$ 13,800.00

With this amount of money in hand, a deposit – investment – without risk in a financial institution after one year will be: for a hand-liner owner R$ 2,803.00 (19.2% - approximately 800.00€), or the equivalent to R$ 233.00/month (approximately 66.75€/month); and for a gill-netter owner R$ 2,650.00 (19.2% - approximately 757.00€), or the equivalent to R$ 221.00/month (approximately 63.00€). Taking off the Brazilian inflation, the net result would be: for hand-liners R$ 861.00 (5.9% - approximately 246.00€), or the equivalent to R$ R$ 71.75/month (approximately 20.50€); and for gill-netters R$ 814.00 (5.9% - approximately 233.00€), or the equivalent to R$ 67.80/month (approximately 19.40€). Such interest value, considering the profitability of 19.2%, means a result 10.4% smaller than the profit got from hand-liners, and 4.3% smaller than the net profit got from gill-netters. Of course that the obtained result is an average value obtained from 18 hand-line and 10 gillnet boats and additional information is needed after conclude which is the best choice for the fishermen, and will be treated in Chapter V – The Bio-economic of the fishery, in detail.

According to Franquesa and Guillén (2002), regarding the fishermen's "financial health" after one time-unit period, there exist 4 possible results. Figure IV.2 shows, in a simple form, the possible economic results from a fishing operation and the decision fishermen may follow.

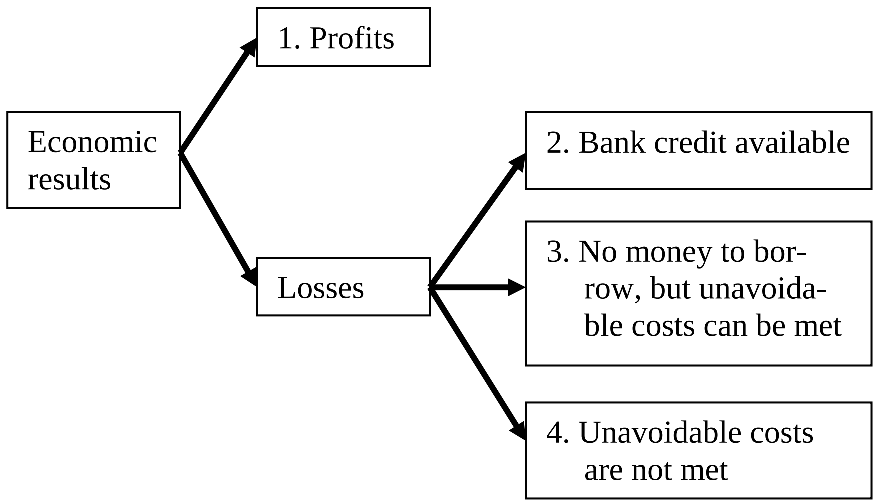


Figure IV.2 – Fishermen possible economic results.

- ***1st** Positive Profits.* The profits are totally re-invested. There exists a technical limitation establishing a restriction concerning catchability that will not be discussed here. The model assumption is that the value of the capital of the fleet increases with the investments. The result of positive profits is, therefore, to increase catchability, in the following period, for the gear that has obtained them, while maintaining fishing effort at its maximum levels.

  The profits explain a part of investment, the internal investment, but the total investment is also affected by subsidies. As in Pernambuco State coastal fishery there are now subsidies, neither from governmental nor from non-governmental bodies, and it seems to be true for almost the entirely Brazilian artisanal fishery sector, the only capital the fishermen has is the internal investment, as from revenues or from small investors. The fisherman can re-invest to improve the catchability of the boat and fishing gear, but as profit is very low the capital is only re-invested to continue in the activity.
- ***2nd** Negative Profits (losses).* Credits are still available, and fisherman shall try to maintain the same level of activity by borrowing money. If credit is obtained, the result is that the catchability and the effort are maintained, but the following year a new added cost will exist: the financial cost (*C7*), which is unavoidable. This result was not revealed by the collected data, because credit is only available through governmental programs and official banks and, since long, is not put into practice. The perception is that small investors sporadically outlay from bank investment going through extra, but risky, money in the fishing activity.
- ***3rd** Negative Profits (losses).* It is not possible to borrow more money, but the unavoidable costs can still be met. If the fisherman cannot cover the costs and can no longer borrow money to maintain maximum catchability and fishing effort, he will have to reduce avoidable costs, such the maintenance costs (*C5*) in the first place. The maintenance costs are necessary to maintain the boat in top operative condition, and reducing it will reduce catchability. If these costs cannot be covered the value in capital of the fleet decreases and the catchability falls. The fisherman will try to fish at the maximum physical boat limit, but if his losses are larger than the maintenance costs he will be forced to reduce other costs, such as the variable daily costs (*C2*), reducing fishing effort.

- ***4th*** *Negative Profits (losses)*. Unavoidable costs, or the fixed costs, cannot be met. If losses become larger than the avoidable costs (*C2+C5*), the fisherman can no longer make it in the face of these unavoidable expenses and he ceases fishing. In this case, not only the catchability decreases but also the effort, and the boat disappears from the fishery. The decrease of fishing mortality will profit the remaining boats. What could be possible to observe, either for the 3rd or for the 4th possible results, is that, at Pernambuco coastal fishery, there is partial and sporadic reduction in fishing effort and dismissal of some boats that can not meet unavoidable costs. Nevertheless, no detailed information is available and it will not be discussed here.

Notwithstanding the results obtained show that profit exist, although at a very low level, the 4 possible results stressed by Franquesa and Guillén (2002) may be observed in Pernambuco State hand-line and gillnet fisheries.

Insofar the control of the fishing activity is very difficult and that there still exist many informal relationships and trade in the fishing operating process actually unknown from outsiders, the economic relationships may be hidden beyond personal negotiations, and payment basis is defined internally in such fishery system. In a general view, it seems that economic relationship are fixed locally by those involved in the activity, and profitability of the small-scale coastal fishery at Pernambuco State is low to meet the necessary investment, or re-investment, to keep the fleet in top operating conditions and to improve the fishery system, but sufficient to continue fishing, and in the basis of the results found indicates low revenues.

IV.4 – DISCUSSION

…The development of commerce and commercial capital brings about everywhere an orientation of production towards exchange values, increases in volume, multiplies and universalises it, develops money into world money. Commerce therefore has everywhere, more or less of a dissolving influence on the existing organisation of production, which, in all its different forms, is primarily oriented towards use value. The extent to which commerce brings about dissolution of the old mode of production depends on the solidity and internal structure of the latter. The outcome of this process of dissolution, or in other words, what a new mode of production will take place of the old, does not depend on commerce but on the character of the old mode o production itself (Diegues, 1983).

Such hypothesis brings about the importance of economics science on the study of an exploited renewable natural resource, whose production and products have an inherent commercial value. Commercialisation of fisheries products have increased in a global perspective and now face a growing world-wide concern, because the increasing demand for fish is pushing up fishing effort. Even localised fisheries have experienced growing demand from the globalisation of markets. In an extremely capitalist context, the market, if no failure occur, works and produces social efficient results and is the main instrument of interaction between agents in a capitalist society. This interaction may help for the definition of strategic policies that shall be effective in the development of a particular economic sector. However, such strategies do not implies, necessarily, a governmental intervention, because commonly agents' co-ordination is sufficient to overcome obstacle for a sustainable development.

The main economic indicators of the relative scarcity of goods and services deriving from coastal and marine systems – prices – suggest that resources are becoming less, not scarcer. That is why there are many reasons for which prices are inadequate, are well understood, observers of resources. Such indicators may include the structure of property rights, the incompleteness of markets, the effects of government policy, the public-good nature of some resources and simple ignorance. In a system in which most resources allocation is decided in a decentralised way by households and firms, resource users base their decisions on market prices net of the effect of tax and subsidy regimes, and pattern of public expenditure (Perrings, 2000).

Local fisheries were always considered a high-risk activity, and although economic studies are missing it seems that profit is the threshold or limiting factor to go fishing. The reality observed in Pernambuco State coastal fishery is that in only one fishing operation fishermen can earn as much as for an average month profit, what stimulate fishermen, boat owners and small investors to continue in the activity. For the fishermen, the maintenance of the activity is essential for their living, because is the only task they really know. Nowadays, tourism is a way of escape from the decline of fishing, but very few are prepared to change their way of life and the job and knowledge herded from their ancestors. According to Anderson (1977), many fishermen are not equipped for other types of work, and, additionally, they are geographically isolated from other sources of employment. The incomes received from fishing are usually not a good measure of their opportunity cost but are often just the amount necessary to keep them working.

Although social and cultural aspects must be considered in the analysis of fishermen behaviour, in a strict economic sense, as it is this chapter objective, a reasonable and simple explanation of the fishermen understanding of the fishing operations costs and revenues is done by Hundloe (2000), for whom the costs of production (harvest) include the cost of labour, fuel and anything else used in the process plus the cost of capital (the means of production), the costs of the manager's/owner's time, and the access to a fishery resource or a fishing ground. The physical capital would be acquired by borrowing or by using the owner's financial capital. The lender or the owner would expect (and require) a return, or the interest. In a real-world practical situation, the lender and borrower (fisher) would come to a contractual arrangement on the rate of interest, and the repayment of the principle. Regardless of the success of the fisher and the profits earned, or losses incurred, the interest would be expected to be repaid, with the principle.

This financial relationship is intrinsic to the local fishery system, and although interest do not exist, the process of borrowing money to go fishing is a common practice between local fishermen, boat owners and small investors. It was not possible to inquire from where comes the small investor's capital, but it seems, however, that the developed share system is a factor that prevented the introduction of direct interest to the borrowed money to go fishing. That is to say that small investors accepted such established conditions, and that if someone attempt to borrow money with interest, fishermen do not accept it.

Diegues (1983) when described the artisanal fishery production system in the Southeast Region of Brazil, gave a good explanation based on previous works of Zoetwey[49], Mordrel[50] and Bidet[51] on the system of *part* or *share* established between fishing enterprises, boat owners and the crew for the payment of the work force on board. The basic principle of the establishment of the share system was to reduce the elevated risk that fishery imposes to capitalism, due to the unpredictability of fishing production and market. To the owner is a form to allot risks with the crew, especially to the small one, to whom a system of payment based on fixed salaries could mean bankruptcy if a series of bad results take place, because the risks to large enterprises are thus compensated and spread over more units of boats. Those

[49] Zoetwey, H. (1956) Fishermen remuneration. *Economies of Fisheries*, Rome, FAO.
[50] Mordrel, L. (1972) *Les institutions de la pêche maritim, historie et évolution: essai d'interpretation sociologique.* Tese de Doctorat, Paris.

authors consider this system a mask used by the capital to better exploit this work force, considered a disadvantage to the crew, due to high-income oscillations, and to uncertainties on naturals productive forces.

The share system as well as the idea of egalitarian partners on the productive process should be an ideological support met by the owner of the production means to mask the capitalist character submitted to the work force, in which the owners, generally, get richer and fishermen poorer, magnified by the bad condition of life on board. This system best respond to the capital imposition in a determinate stage of development of the productive forces, leading to an intensification and prolongation of the hours of working, which demystify the defended theory of common expenses and profits.

According to Diegues (1983), the fact in which *work* is not entered as a production cost, or considered as merchandise that has a selling price, may be considered as one of the indicators of the presence of a production way in which merchandise did not yet invaded all the production sectors. Notwithstanding Diegues arguments for the Brazilian reality, the share system seems to work in other regions. Ulrich *et al.* (2002) pointed out that for the English Channel artisanal fisheries the share system encourages and rewards harvesting efficiency and cost effectiveness, which makes the crew share somewhat different from a standard wage cost.

In this sense, and adopting Diegues argument to Pernambuco State fishery system, it is important to understand the fact that, if each fishing trip must cover, at least, the common costs that are compose by heterogeneous elements, such as wages, expenses to fish and profits, considered as a boat due; if part of it is shared between the owner and the crew; and if in this capitalist production the distribution is based on the triple ideology of common costs, owner share, and crew share, the system allow, even considering a bad production, the reproduction of part of the variable and fixed costs. Apparently the common costs, the association composed by the boat owner and the crew, and the owner share each, assume risks and invest a specific capital, but in reality these are the same capital, owned since the beginning by the owner that converts his money in production means. To the crew income variations determines an average wage that coincides with the average wage of his work force, equivalent on what he put on the productive process. The owner, on the other hand,

[51] Bidet, J. (1974) Sur les raisons d'être de l'idéologie: rapports sociaux dans le secteur de la pêche. *La Pensée,* Paris, **174.**

leaves the process with an additional that permits to increase his capital and the fisherman get out as it got in: owner of his work force.

However, insofar as the fishing productivity is highly dependent on the skillfulness and persistence on the work force and not at all on the technical capital, and insofar as the capitalist can not control *in loco* the working process, the share system must be considered as a relationship form of non-capitalist production, if the economic activity aims to produce merchandise and profit based on other forms of remuneration rather than salary (Diegues, 1983), which could happen through the valorisation and strengthening of fishermen traditional knowledge, because there was no outside intervention, and can be understood as the way fishermen took their decision to continue in the activity.

The fishermen decision process elaborated by Franquesa and Guillén (2002) in accordance to the observed mechanism developed by the North-western Mediterranean fishermen and based on previous work developed by Lleonart *et al.* (1999a) shows that the market feeds this developed mechanism, and the total revenues, if there are positive ones, is converted into fishing effort and catchability. On a simplified quantitative process the input is the profits obtained previously and the output the effort and catchability applied next. At this point, what is of concern is in what extend the mechanism developed by the Pernambuco State coastal fishery boat owners can be analysed through this scheme aiming to understand the economic results of the preceded analysis and the fishermen decision to continue fishing.

If the profits are positive (over the social average) boat owners try to invest more in the activity to obtain more profits, the investment possibly limited by institutional restrictions (that banned to increase the number of boats) and by budget limitations: the resources available are the precedent profits obtained from the activity. If the profits are negatives (over the social average) the boat owners try to leave the activity but try to obtain revenues from the capital invested before, that do not have alternative value.

Attempts to increase the proportion taken by man to increase the intensity of fishing will generally tend to decrease the total production of the exploited stock, and may ultimately imperil the future of the resource. Forman (1970[52] *apud* Diegues, 1983) stressed that *any economic activity thus affected by the law of diminishing returns requires a mechanism for the conservation of the stock, maintaining up to a point both the overall productivity capacity of the community and the maximum efficiency of individual units. To go beyond that point*

[52] Forman, S. (1970) *The raft fishermen: tradition and changes in the Brazilian peasant economy.* Indiana University Press.

could mean over-exploitation to the last detriment of the fishermen themselves…. Free access to sea resources and common knowledge of all fishing spots could encourage over-exploitation through excessive competition, because, as stressed by Dieques (1983), in the artisanal local fishery system the trajectory characteristics of the capitalist production expansion that occurred in others sectors of the social production can be well visualised, and, therefore, it develops exhausting the two sources from where richness comes: the sea and the fishermen. For Anderson (1977), the only reason that individual fisherman can stay in business when forced to use inefficient methods is that the fishery is capable of earning a rent that no one entity in the fishery can keep to himself.

It is not clear what are fishermen understanding on the fishing production possibility. Considering their scholar level (very low indeed), one may be induced to believe that they have no comprehension on such a process, but it is not possible to affirm such hypothesis. Apparently resources are being used to produce only enough effort to return a value equal to the cost of those resource. In the context of the existing fishery it is useful to understand that individual boat are producers of effort rather than of fish, because no one can control the success of a given unit of effort.

However, the importance, at this point, is to conclude that the applied methodology allowed the definitions and estimations of economic parameters that will subsidise and will be entered in the MEFISTO model for the conduction of the bio-economic analysis of Pernambuco State coastal fishery. Also, it must be highlighted the fisherman decision to continue in the activity with so low wage, especially if we consider that higher income would be acquired in a financial institution, with no risk. It is very poorly understood indeed, in the economic assumption with which the maximisation of present value will call for the complete destruction of the fish stock if the value of harvesting the stock until it is depleted is worth more than the value of any sustained catch throughout the future, the fact that fishermen do not increase effort on such a way. Maybe the assumption is that it is not physically possible to do so, because the increase in effort do not only imply the increase in the number of e.g. hook, but of all the harvest intrinsic costs, that is the cost of providing the effort of producing fish.

With the traditional knowledge highly established and with very few other options to choose, even others activities from the primary economic sectors (agriculture, services, etc.), the presented data and results suggests that fishing, if not the best choice for those already engaged in the activity, is an option whose fishermen decision to continue are highly dependent on the social and cultural way of life established and herded. From the individual fisherman’s point of view, his operating decisions are rational and denote an economic equilibrium point. Although fishery resources are State property, in fact the observed context is of a common property or open access use, which leads to sub-optimal results, and an uneconomic amount of effort will be applied to the fish stock. But this relationship will be better discussed in the next chapter.

IV.5 - CONCLUSIONS

The conclusions that can be taken from the economic analysis of the coastal hand-line and gillnet fisheries in the State of Pernambuco are:

- The applied methodology seemed adequate to define and estimate the economic parameters to subsidise a bioeconomic analysis through MEFISTO model;
- Profits obtained from the fisheries are re-invested in the activity. Although considering the very low income taken, the fishermen's decision is to re-invest in the activity, because socially and culturally is the only task they know;
- Fishermen financial entry is basically the revenue that outcomes from the activity, trying to fish as much as possible aiming at increasing profitability;
- The system of share, although seemingly capitalist, was developed inside the economic structure of the fishery system, without outsider's interventions, even governmental, which strengthen relationship between those directly and indirectly involved;
- In both areas of analysis (Candeias, Jaboatão dos Guararapes City, and Brasília Teimosa, Recife City), do not exist extra incomes from other activities, such as subsistence agriculture, services, etc. What was revealed, but not analysed, was that some boat owners are small retailers, which commercialise their own and others fishing production, raising extra profits, and may be an explanation on how they continue in the activity;
- Although not directly revealed and analysed by the collected data, it seems that credit is only available through small investors that sporadically outlay from bank investment going through extra, but risky, income on the fishing activity; and
- Low income is the limiting factor that impede the increase in fishing effort, either not encouraging new entries or limiting re-investment to increase fishing effort, and may suggest that the hand-line and gillnet fleets had established an economic equilibrium point.

CHAPTER V – THE BIOECONOMIC ANALYSIS OF THE FISHERY

V.1 - INTRODUCTION

Quantitative and qualitative informations are important aspects to analyse when the dynamic of a renewable natural resource is to be conducted. However, as for such purpose a great and historic amount of data must be available, and generally a study is conducted at defined points in time. That is why, for practical purposes, static analysis is somewhat commonly used and, consequently, easier to handle, and modelling for fisheries management has been given special attention and many fishery scientific institution and fishing nations administration have prioritised modelling for defining strategies for fisheries development.

Under these concepts, and according to Lleonart *et al.* (2003), a series of techniques based on deterministic and stochastic simulations and computational statistics have recently been developed. The purpose of these tools is to facilitate analysis of the consequences and risks of different management measures applied to particular stocks. These models consist of using a stock simulator (operating model) and a simulator of the assessment process, both provided with different error sources. Using this procedure, the whole process of stock dynamics, fishing activity, fishery assessment and fishery management as an adaptive process can be simulated.

In this Chapter, the intention is to reach a preventive management of the fisheries, through estimations of models on the stock and fisheries dynamics at short, medium and long run. Considering, however, the development of these models based on a specific fishery, the North-western Mediterranean Sea, that although already highlighted common aspects with those found in the State of Pernambuco, there still have some peculiarities and distinct realities that is important to have in mind, aiming at conducting the necessary model adjustment to get the best response for providing scientific and technical advises for administrators and decision-makers. Hence, bioeconomic studies will be conducted having as a start point the use of those models, but the development of a new computational model for the Pernambuco State fisheries peculiarities will not be considered, just because much has to be done and to be known before attempting for the concepts of modelling of this distinct local fisheries.

The main problem in applying models does not depend on the deterministic form of the model chosen, but on the quality of parameters and data, and on the fitting method (the stochastic form of the model). According to Lleonart (1993), a model is composed by: (1) a set of hypothesis expressed in mathematical form, which is the deterministic form of the model and can include sub-models related to the parameters used; (2) a set of data; and (3) a fitting procedure connecting data and equations, which in the stochastic form of the model includes the error type (process or observation) and its distribution.

For example, a basic question that a bioeconomic model should answer is that any fishery has repercussion, positive or negative, in the whole of social and economic benefits, which must lead to the local assessment and management of such a fishery. Considering that the introduction of fishery is considered as a perturbation factor in the dynamic ecosystem, a model must consider the economical interests in exploring this activity constrained by ecological factors in order to avoid the drainage of some of the species harvested (Facó, 1988).

The objective of the present chapter is to proceed with a bioeconomic analysis of the Pernambuco State, North-eastern Brazil, coastal fishery. The objective of modelling such a fishery is to reproduce the bioeconomic conditions in which the fisheries occur, carrying out projections to simulate alternative management strategies, starting from the current situation that better describes a scenario, and forward into the future with the purpose of analysing the behaviour of the fishery under different conditions, particularly different management situations.

The bioeconomic model MEFISTO - *ME*diterranean *FI*sheries *S*imulation *TO*ols, developed for the North-western Mediterranean Sea fisheries (Franquesa and Lleonart, 2001), was used to analyse Pernambuco State hand-line and gillnet coastal fisheries, aiming at simulating diverse management strategies. The cornerstone of MEFISTO, according to Lleonart *et al.* (1999a), Franquesa and Lleonart (2001) and Lleonart *et al.* (2003), is to reproduce the fishing conditions characteristic of the Mediterranean, including several aspects that differentiate it from the models elaborated for the Atlantic fisheries. It was adapted to some particularities of Pernambuco coastal fisheries, such as:

- as above mentioned, the model should necessarily be bioeconomic to accommodate at the same time the dynamic nature of living resources, and the economic relationships that govern local fisheries;
- even considering that a management is based on effort control, lack of control for the enforcement of any management measure leads to an open access system, controlled basically by technical and economic conditions in which the fishery occurs. In other words, effort is controlled because the local fishing activity is not profitable;
- as for the Mediterranean fisheries, the management system is non-adaptive. No regular assessments are done and hence no adaptive management policy is implemented. Technical management measures, e.g. TAC´s, do not exist and the economic administrative tools acquire as much importance (or more) than the technical tools;
- increasing "catchability" (in effect, efficiency) is the mechanism of increasing fishing mortality by fishermen, but new technologies are not easily accepted. As law for coastal area defines that fishing effort must be controlled, fishermen are only allowed to fish with licence, the only control mechanism the government has; and
- It must be multispecific, multigear, and multifleet.

The final users of the model product are three: the scientist, the decision-maker, and the fisherman. For the scientist the present model constitutes a research tool that should lead to an improved understanding of the mechanisms by which the fisheries system operates. It can also be an advisory tool, as the model acts as a test bench for analysing different management options, decision risks, sensibility of the parameters, etc. In addition, it identifies the fundamental parameters. For the administrators and decision-makers, the model offers a way to assess the economic and biological effects of particular management measures (technical, economic or both) in the short and mid terms. This could be very useful in the design of policies for mid-term objectives and for exploring the different ways to attain them. It is also important that the administrators realise the extent to which the fishery depends on the dynamics of a biological resource and not only on economic decisions. The model offers fishermen a new perspective on the behaviour of the system, including its temporal scale. The model should contribute to increased comprehension of the usefulness or uselessness of certain management measures, and establish the difference between short and mid terms regarding earnings and losses (Franquesa and Lleonart, 2001; Lleonart *et al.*, 2003).

As it is true for the Mediterranean Sea, in general the coastal areas off Pernambuco have low productivity and the demographic pressure at the littoral, whereupon does intensify the stock exploitation level, by virtue of the strong demand for fish. Today it is fished more than before, but with a fishing effort disproportionally high. In addition to the above mentioned, there are similar characteristics between the fishing activities conducted in Catalonia and Pernambuco that can justify the application of the bioeconomic model developed for the Mediterranean Sea. These similarities are well defined by the comparison made in the Introduction considering the statement of Martín (1991), Lleonart *et al.* (1999b), and Bas (2002). Also, as aforementioned, the application of this specific bioeconomic model is well justified because the main objective is to reproduce the fishing conditions characteristic of a specific fishery, including several aspects that differentiate it from the models elaborated for a more generalised conditions, such as those developed for the Atlantic fisheries, which permitted to adjust it to some particularities of Pernambuco State hand-line and gillnet fisheries.

V.2 - MATERIAL AND METHODS

The MEFISTO model is, perforce, multispecific and multigear. The main management procedure is effort limitation. The model also incorporates the usual fishermen strategy of increasing efficiency, in order to increase fishing mortality, while maintaining the nominal effort. This is modelled by means of a function relating the efficiency (or technological progress) with the capital invested in the fishery, and time. The model allows operating with technical and economic management measures and in the presence of different kind of events.

The program start-up requires, besides the biological and economic parameters, the establishment of an initial stock situation. This implies having the vectors of mortality (F) and the initial number of individuals by age class (N). In case that the user only has the catch matrix C (by gear and age), F and N can be reconstructed by means of a VPA on pseudocohorts starting from the steady state. Otherwise, the matrix F and vector N can represent a steady-state situation or not. The program allows starting up from such a situation, or generating a new vector N in equilibrium with F and starting up from that situation, and allow to select from a deterministic or a stochastic simulation. The biological parameters and vectors of mortality were first defined and analysed through VIT program described in Chapter III. Detailed analysis of the economic parameters can be found in Chapter IV.

Descriptions of the model fundamentals are detailed in Lleonart *et al.* (1999a) and Lleonart *et al.* (2003), and it will be described here as a matter to provide an understanding of the applied functions and boxes inter- and intra-relationships. This model was built in a modular way in a system of three boxes, *the stock box, the market box* and *the fisherman box*, and can be represented as follow:

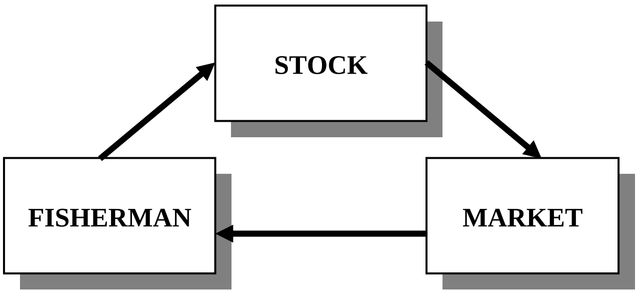


Figure V.1 – MEFISTO – *ME*diterranean *FI*sheries *S*imulation *TO*ol boxes.

V.2.1 - THE STOCK

This simulates the dynamics of a particular stock. The input is the fishing effort and the catchability (these coming from the fisherman's box) whose product constitutes the fishing mortality applied to the stock. The output is the catch that goes into the market box. The model is structured by fish ages, *a*, and gears, *g*. The fishing mortality at age *a* generated by a gear *g* (F_{ag}) is defined as:

$$F_{ag} = S_{ag} \cdot E_g \cdot q_{ag}$$

where S_{ag} is the selectivity factor accounting for the interaction gear-fish, E_g is the effort applied by the gear *g*, and q_{ag} the catchability that corresponds to the gear *g* and the age *a*, at time *t* and for capital *K*.

The total fishing mortality corresponding to age *a* is:

$$F_a = \sum_{g}^{G} F_{ag}$$

and the total mortality corresponding to age *a* is:

$$Z_a = F_a + M_a$$

where M_a is the instantaneous natural mortality rate at age *a*.

The dynamics of the number of individuals of a cohort responds to the following equation:

$$N_{a+1,t+1} = N_{at} \exp(-Z_{at})$$

where N_{at} is number of individuals of age class *a* at the beginning of the time *t*. Since the age *a* and the time *t* are measured in the same units, an individual of age *a* in time *t* will have age *a+1* in time *t+1*.

The average number of individuals during the interval of the class of the age *a* is:

$$\overline{N}_a = N_a \frac{1-\exp(-Z_a)}{Z_a}$$

The von Bertalanffy growth model is assumed:

$$l_a = L\infty\{1-\exp[-K(a-t_0)]\}$$

and the relative growth in weight is:

$$w_a = Al_a^B$$

With the mean weights by age, the stock biomasses by age can be calculated:

$$\overline{B} = \overline{N}_a \cdot \overline{w}_a$$

The total mean biomass for the cohorts, or the whole stock, is:

$$\overline{B} = \sum_{a=1}^{m} \overline{B}_a$$

The catches are also calculated by gear:

$$C_{ag} = F_{ab} \cdot \overline{B}_a ,$$

and the total catch by age, gear and both are, respectively:

$$C_a = \sum_{g}^{G} C_{ag}$$

$$C_g = \sum_{a}^{m} C_{ag}$$

and

$$C = \sum_{a}^{m} \sum_{g}^{G} C_{ag}$$

To carry out the simulation it is required to model the recruitment (N_1). Except for the case of constant recruitment, the number of recruit is a function of the spawning stock (*SSB*) that is calculated as the proportions of mature fish by age (I_a) of the mean biomass:

$$SSB_a = \overline{B}_a I_a$$

$$SSB = \sum_a^m SSB_a$$

Although three different forms of generating recruits are used: *constant recruitment*, *Beverton and Holt's model*, and *Ricker's model*, only the two formers where applied. The *constant recruitment* consider that for each simulation the same number of recruits *N1 = R* (constant) is generated. The *Beverton and Holt's model* follow the equation:

$$N_1 = \frac{1}{\alpha + \beta SSB}$$

As already mentioned, the input to the stock box and the output from the fisherman box are the fishing effort E_g vector and the catchability q_{ag} matrix. Since fishing effort is limited by the Mediterranean fisheries policy, the only mechanism fishermen have to increase catch without increasing effort is to increase their catchability by means of investment in technology, thus a function of capital (more wealth results in increased fishing efficiency) and time (technological progress improves with time and becomes more affordable). The model outlines the relationship between fishing effort with fishing mortality, through the elements contained within catchability.

According to Laurec and Le Guen (1981) these elements can be defined as follow:

- *Availability*, which is density-dependent on fish stock and fishing gear selectivity, thus independent of fisherman's behaviour;
  - ✓ *Accessibility*, which is related to geographical components, such as displacement from and to the fishing area;
  - ✓ *Vulnerability*, which is related with fish behaviour;
- *Efficiency,* which is dependent, among others factors, on the fishing strategy or fishing tactics and the one that the fisherman clearly can modify, through the utilised fishing gear, but in the model gear changes is excluded.

So, the catchability as a function of time *t* and capital *k* can be expressed through the following equation (Lleonart *et al.*, 1999a):

$$q_{t,K} = Q_0 \tau^t \frac{1-\exp(-hK)}{1-\exp(-hk_0)}$$

where τ, that express the dependence on time, and h, the modifying influence on capital, are parameters, and Q_0 and K_0 are the initial catchability and the initial capital (at t = 0), respectively. To make q_t constant, and equal to Q_0, it is necessary that $\tau = 1$ and $h \to \infty$. To make q_t only depend on time it is necessary that $\tau \neq 1$ and $h \to \infty$. To make q_t increase an annual p%, τ = 1+p/100. If $\tau < 1$ the catchability decreases with time. To make q_t only depend on capital it is necessary that $\tau = 1$ and $h > 0$, but not $h >> 0$ (in order for the effect to be seen, hK should be smaller than 5 and is recommended to be of the order of 1). Maximum catchability (for capital "infinite") is:

Q0/ (1-exp(-*h*·*K0*).

Thus, the two parameters have the following meaning:

τ (condition: $\tau > 0$, reasonable $\tau \geq 1$). Expresses the dependence on time, for example if we assume an annual catchability growth of 2%, τ=1.02. If τ=1 time doesn't intervene.

h (condition: $h > 0$). This is a modifying influence on capital in the calculation of catchability. If *h* is high, capital doesn't intervene. If *h* is very near zero the weight of capital is very important (even excessively). *h* cannot be zero.

The stock box can have diverse simultaneous boxes, because the model is multispecific and admits two broad classes of species: the main species, whose dynamics are completely explicit which allow that simulation can be conducted with the equations previously described and are those that each fleet derives its revenue from fishing, and the secondary species, whose catches are significant for the considered fishery from an economic point of view, because generates extra profits, and whose dynamics are not known but their yields are computed as a function of those of the main species. The model assumes an empirical relationship, or technical interactions, between the main and the secondary species, but no ecological interactions (such as predation or competition) in one of the two following ways: the multiplicative,

$$Y = aC^b ,$$

or the additive,

$$Y = a + bC ,$$

where *a* and *b* are parameters, which can be derived from actual catch data, *C* is the catch of the main species, and *Y* is that of the associated species. They define how many kilograms of accessory species can be obtained with one kilogram of the main species, so the average price per kg of the accessory species must be provided. *b* denotes the correlation between the catch of the main species and the economic yield of the secondary species, and when $b > 0$ the revenue obtained from the secondary species grows with increasing catch of the main species. When $b < 0$, then the reverse holds true and when $b = 0$ then the secondary species is independent from the main species to which it is associated. *a* is a scale parameter, which also holds the conversion of catch to revenue units.

V.2.2 - THE MARKET

This converts the catch into money with some price functions. MEFISTO support the consideration of the reference price, importance of the size of the individual fish, and importance of the size of the fish offer. The total revenues of a gear are calculated according to:

$$RT_g = \sum_{a=1}^{m} p_a C_{ag} + Y_{ag}$$

where p_a is the price of an individual of age *a*. This price is calculated as:

$$p_a = \gamma_1 \overline{w_a}^{\gamma_2} O^{\gamma_3}$$

where *O*, the offer, is the sum of catch *C* plus the imports of a given specie; the γ*'s* are parameters, being γ_1 the shadow price, γ_2 the size-price modifier (it will usually be positive, because a larger fish correspond a higher price, but if it is equal to zero, the price is independent of individual weight), and γ_3 the price-offer modifier (it will usually be negative, because bigger offers result in lower price, but if it is equal to zero the price is independent of the offer, i.e. the market doesn’t influence the price of the product).

V.2.3 - THE FISHERMAN

This simulates the fisherman's economic behaviour. Its input is the money coming from the market box; its output is the fishing effort that will be applied by the gear in the following unit of time, measured in number of fishing days x hours (E_g), the catchability of the fishing gear (q_{ag}), and the selectivity factor, over which the fisherman has certain control by way of function of his capital.

The basic assumptions of the MEFISTO Model of the fisherman/boat owner decision are simulated according to four procedures (Franquesa and Guillén, 2002; Lleonart *et al.*, 2003):

- The fisherman assume that the production depends on the effort and the catchability applied. Catchability is a function of capital and time and can be regarded as a traditional-dependent knowledge factor, e.g. the size and type of hook are determined by the target species;
- the revenues at the end of one period are used to cover the different costs of the fishing activity for the next period. Investment is a function of profits;
- there is a maximum legal limit for the number of days at sea. The number of ships, as well as their engine power, is also limited by the administration. Although it is true for Pernambuco State coastal fishery, what really occurs is a physical fishing effort limit, dependent on the autonomy of each fishing boat, because administration has no control over the number of days a boat remain fishing; and
- the fisherman intends to go fishing for the maximum number of days that the law and revenues allow. A large body of literature reports that only effective institutional controls (provided by the administration or by the fishers' organisations) can results in a reduction of effective fishing time. If this control is not effective in Mediterranean conditions (high price, reduced catch, weak financial capacity and nearness of fishing grounds) the total fishing time is all the time technically possible (excluded summer holidays and Sundays). In Pernambuco it seems that the limiting factor is the re-invested capital to go fishing and boat autonomy.

The parameters of the fisherman's box are contained at different levels: country, fleet, and vessel. The level country contains the most general economic parameters that embrace diverse fleets (such as cost of fuel). The level fleet contains the technical and economic parameters characteristic of each fleet (catchability and fishing mortality initial vectors, gross tonnage (GT) price, etc.). Finally, the last level, boat, allows particularisation of the characteristics of each boat. The expenses in which the fisherman should meet are described in Chapter IV, item IV.2, summarised in Table IV.1 for the analysis of costs, and the operation of the fisherman's box is represented in Figure IV.1. Thus, in the present chapter the equations and the mathematical structure are not cited, as it is already detailed as mentioned. Otherwise, a general description of data entry is provided.

The economic part of the fisheries system is organised around the fishing agent, i.e. the boat. Each boat can have different characteristics, which is reflected and allow the entry of specific data for each boat, but there are a number of features that are common to a set of boats (regarding a fleet). The concepts country, fleet and vessel are used in a general sense, as convenient boxes for organising the economic parameters of the fleets (or métiers) participating in the fishery. For example, in the context of the analysed fisheries, vessel will be called boat, regarding the artisanal scale of each physical unit. The monetary units are arbitrary, but must be consistent throughout data input.

The economic parameters of the fishery comprise, fundamentally, costs and revenues. In MEFISTO, the costs are specified in the three tab sheets discussed above (*country*, *fleet* and *vessel*), while the revenues are obtained from the sale of target fish (parameters specified in *Market*) and accessory or by-catch species (parameters and function specified in *accessory species*). Finally, the parameters that link the Fisherman model's box and the Stock model's box (fundamentally, the fishing mortality) are specified in the *Fishing Mortality* and *Catch* tab sheets.

General parameters are entered in the *Country* tab sheet. The *country* is defined as an area where some figures are common (fuel price, bank rates, etc.), so it does not need to be a real country; i.e. can be a region or even a port. In the present analysis, the defined country is the State of Pernambuco, specially the hand-line fleet settled in Jaboatão dos Guararapes City, at the State southern region, and the gillnet fleet, settled at Recife, the State capital, in the central region. In such a tab sheet the information entered concerns:

- *Maximum credit*, the percentage of the boat's capital that a financial institution (i.e., a bank) will credit to the owner;
- *Fuel price*;
- *Opportunity cost*, which represents the income that the ship owner could obtain from the capital invested in the boat if the capital were instead deposited in the bank, or invested elsewhere for a fixed term, at risk zero. The opportunity cost can be seen also as the cost of having foregone a best alternative for investment, i.e.

the price paid for not investing in a different economic activity or the income lost from missed opportunities. It is a function of the capital invested by the rate of the "Public Debt" in a specific moment and country. It indicates the revenues lost (or "opportunities" lost) to the fisherman by investing in the fishing activity; and

- *Financial cost*, which represents the cost to the ship owner to take a bank loan, expressed as the interest rate claimed by the financing institution when the boat has a credit debt. This percentage is the average rate of bank loan in a specific moment and country.

Parameters concerning the entire fleet are entered in the *Fleet* tab sheet. A *fleet* is defined as a group of boats with some common parameters, such as commercial cost or cost structure, independent of size (gross tonnage) or revenues. The components entered in this tab sheet are:

- *Commercial costs*: a percentage of all the costs related to first sale of the catch, such as fisherman's association taxes, social security, tax on revenues, etc. This is a percentage of Total Revenues from fish sale;
- *Owner's share*: percentage of the revenues after discounting commercial costs, daily costs and fuel costs that pertain to the owner, to pay for the costs incurred in the fishing operation (annual fixed costs, etc.). It is complementary to the crew share and is distributed among the crew as salary;
- *Fishing days*: number of actual fishing days per year;
- *Fishing hours*: number of actual fishing hours per day. The total fishing hours by fishing days is used in MEFISTO to modulate the fishing effort;
- *Dismissal price*: is the average price for a boat's gross tonnage (GT) paid by the administration to withdraw a boat. This can be used as an incentive to quit the fishery for boats whose benefits do not meet the maintenance costs. If the administration does not pay by GT to reduce effort, this figure is zero;
- *Daily ice expenses*: average daily cost of ice per boat in the fleet;
- *Annual increase of "q" (catchability)*: In MEFISTO, *q* can be made to increase annually by specifying a percentage of annual increase, representing the technological progress. The same investment can lead to an increase of catchability due to increased efficiency of the gears, enhanced knowledge, new electronic devices that help in some operations, etc; and

- *Modifier Capital ⇔ Catchability*: The catchability can additionally be modified in relation to a boat's capital by entering a percentage. The increase of the capital invested (by subsidies or profits) in the fisheries produces an increase in the catchability. This figure represents how much the catchability grows when the capital invested accrues.

Each fleet has one or more target species (from the list of available species created in the STOCK BOX, with a particular market function, and a set of accessory species. The revenues obtained from the accessory species are derived from the catch of the target species by specifying the parameters of a linear or a power function.

MEFISTO also requires entries of the fishing mortality vector (in the model defined as F_g) applied by this fleet by age class, the catch for VPA, which is the catch vector by age class when performing a VPA on pseudo-cohorts, and the selectivity factor, which means the corresponding factor a gear has upon a given resource.

Finally, the individual characteristics of a boat are entered in the *Vessel* tab sheet. For each individual boat the following parameters can be entered:

- *Boat identification*: can be a real register name or arbitrarily assigned by the researcher;
- *Gross Tonnage (GT)*: for individual boat;
- *Boat value (Capital)*: the initial sale value of the boat and is used in MEFISTO as initial Capital. This comprises the actual value of the boat and all of its components (electronics, gears, etc.);
- *Credit*: is the initial credit owed by the boat;
- *Crew size*: number of fishermen (persons) in the crew;
- *Fuel consumption*: this is the daily fuel consumption in litres, and the entry value is multiplied by the fuel price to compute the daily fuel costs;
- *Other daily costs*: costs other than fuel, ice or maintenance are entered here. Other aspects such as food, water, etc are here considered, but if they are paid from the owner's share; and
- *Annual costs*: total annual costs incurred by the boat paid from the owner's share. This total amount is divided in two parts: fixed costs (such as license, mooring, boat insurance, etc.) or maintenance costs (engine repair, shipyard, etc.). The fixed costs are conceptualised as those costs that are inevitable to pay yearly, while the

maintenance costs can be avoided when the benefits cannot cover maintenance costs, which is a way of reducing catchability.

V.2.4 – BIOECONOMIC SIMULATIONS

The MEFISTO model allow to run two types of simulations: deterministic and stochastic. In the deterministic simulation the parameters have a fixed value set up by the user, and the projection is carried out using these values. The results are fixed values. Although conscious of the paramount importance to run stochastic simulation, which seeks to analyse the effects of uncertainty of one or several parameters, it was not possible because no empirical evidence on stock-recruitment stochasticity are available for the species analysed, so only deterministic simulations were carried out.

The simulation, for the hand-line fleet as for the gillnet fleet, was conducted considering possible interactions between stocks, market and fisherman, which is the model's activated boxes normal operation described in Figure V.1, and a projection time unit was defined in 30 years.

A initial stock and fisheries simulation was ran, based on the current fishing operating system and fish prices with which boat owner pays as salary for the crewmembers. For such initial situations a deterministic scenario was set up, and recruitment was considered constant, aiming at validating the provided parameters, and simulations were projected over a 30-year period.

Six scenarios are presented, defined by different events, always introduced in the fifth year of the simulation, exception being the "Scenario 1" due to model limitation, in which the event was introduced in the first year. For each of the five scenarios, a deterministic simulation was set up and was applied the Beverton-Holt stock-recruitment relationship model, and simulations were presented in a 30-year period.

- *Scenario 1* – Simulations considered the strategy the owner takes to invest in the activity, through technological progress, by providing an increase in catchability by a constant factor of 1, which means that each year, the catchability will increase automatically by 1%. Also, it was simulated how much the catchability grows when the capital invested increase, in accordance to the boat's capital, because, as stressed by Maynou (1999)[17], the increase of the capital invested (by subsidies or profits) in the fisheries produces an increase in catchability. It was entered a value of 5%, which means that doubling the initial capital results in a 5% increase in catchability due to investment of profits;

- *Scenario 2* – A reduction in the fuel price by 80% was simulated, according to recent government law to subsidise the price of fuel to artisanal fishing boats, because it is the second most representative cost item for hand-liners (26.04%) and the most representative for gill-netters (38.39%). Thus, the entered value for both fleets was R$ 0.20/liter;
- *Scenario 3* – A reduction in the number of fishing days was simulated, by imposing a fenced season (biological closure of fishing), for a period of 1 month, simulated to occur during the rainy season in July, a month when generally fishing production declines due to bad weather. Such a closure means a reduction of 15 days of fishing for the hand-line fleet, approximately 7.9% of reduction in fishing effort, and 20 days of fishing for the gillnet fleet, or approximately 8.7% of reduction in fishing effort;
- *Scenario 4* – A reduction in the number of hand-liners and the gill-netters was simulated by deactivating the 4 largest hand-liners and the 3 largest gill-netters, which means a reduction in fishing effort of 22.2% and 30%, respectively;
- *Scenario 5* – A reduction by 10% in the catch of juveniles was simulated. Such a measure should be a powerful administration tool to create protected fishing areas, such as coral reef zones, known to be nursery areas or habitats of juveniles; and
- *Scenario 6* – The jointly implementation of three management measures aforementioned was simulated: the reduction in the price of fuel (Scenario 2); the biological fishing closure ((Scenario 4); and the reduction in the catch of juveniles by 10% (Scenario 5).

V.3 - RESULTS

As for the interest and the concepts established by the adopted model, follows a description of the chosen species and the necessary parameters to compose the model exigency, considering the specified boxes. Detailed analysis and explanation of the biological parameters can be found in Chapter III and only the necessary parameters for the bio-economic analysis is listed in Table V.1. Informations on the productive chain and the economics of the fisheries, that subsidise the economic parameters that filled up the fisherman box, can be found in Chapters II and IV, respectively, and for the sake to facilitate the present analysis, Table IV.3 is transcript below as Table V.4, with small modifications following the sequence of data entry in each box / *tab sheet*.

V.3.1 - THE STOCK

As already mentioned, from the bioeconomic point of view, there are species of two kinds: the main species, whose dynamics are completely explicit, and the secondary species, whose dynamics are not known but whose yields are computed as a function of the main species (Lleonart *et al.*, 1999a). The chosen groups of species was the first attempt to list groups of fishes of significant occurrence and commercial importance for the coastal fishery of Pernambuco, considering local biodiversity, and in agreement with the biological and ecological characteristics of each species and/or group of species. It is important to emphasise that the main objective being a bioeconomic analysis of the activity, what, undoubtedly, will only be possible to carry on with the species and/or groups of species for which the collected information are qualitatively and quantitatively significant, we considered that this group are well represented in the Pernambuco State captures.

Regarding the hand-line fishery, five species were considered for the bioeconomic analysis, due to their frequency on catch composition and economic importance for the commercial fleet, being three primary species and two accessory species. As for the purpose of calculating total revenue from the fishing activity, the species not described here were considered as less important and less abundant species on such a fishery and were grouped as OTHERS, and a relationship with the main species was established. The main species are composed by two coastal reef fishes, the yellowtail snapper, *Lutjanus chrysurus* (Bloch, 1791), and the mutton snapper, *Lutjanus analis* (Cuvier, 1828), and one coastal pelagic specie, the king mackerel, *Scomberomorus cavalla* (Cuvier, 1829). For the accessory species one coastal reef specie was chosen, the dog snapper, *Lutjanus jocu* (Bloch and Schneider, 1801), and the other a coastal pelagic one, the dolphin fish, *Coryphaena hippurus* (Linnaeus, 1758). The.

For the yellowtail and mutton snappers it was possible to construct the growth curve from the collected data and to estimate the von Bertalanffy growth parameters. The necessary information on the population structure concerning the number of individuals, the maturity ratio and the natural mortality (*M*) vector were defined through VIT program, described and applied in Chapter III. The von Bertalanffy growth parameters for the king mackerel were based on the study conducted by Nóbrega *et al.* (2001a), while the population structure followed the same procedure described by the snappers stocks. Aiming at validating the data provided to MEFISTO, a first simulation was run through a constant recruitment, afterward the Beverton-Holt spawning stock biomass and recruitment relationship model was applied.

For the gillnet fleet, only the Spanish mackerel, *Scomberomorus brasiliensis* Collette, Russo, Zavala-Camin, 1978, was considered as a primary species; whilst as secondary species the blue runner, *Caranx crysos* (Mitchill, 1815), the lane snapper, *Lutjanus synagris* (Linnaeus, 1758), and OTHERS. Growth parameters utilised for the Spanish mackerel were based on Lucena *et al.* (2001) and Nóbrega *et al.*, (2001b), while the population structure and the recruitment type followed the methodology described in the previous paragraph for the stocks caught by the hand-line fleet.

Table V.1 shows the von Bertalanffy growth parameters and the initial recruitment of the four main species for both fisheries, while the Table V.2 shows the initial conditions of the biological parameters for the main species considered.

Table V.1 – Summary of biological parameters of the main species as for bioeconomic analysis through MEFISTO. YTS – Yellowtail Snapper; MS – Mutton Snapper; KM – King Mackerel; SM – Spanish Mackerel.

	Parameter						
Specie	$L\infty$ (cm)	K	t_0 (years)	a	b	M	Recruitment
YTS	76.67	0.158	-0.728	0.0183	2.7753	0.112	78,478
MS	108.2	0.168	-0.89	0.01122	3.002	0.152	38,542
KM	142.8	0.137	-1.14	0.0219	2.7312	0.309	156,908
SM	103.86	0.165	-0.084	0.0094	2.9446	0.382	156,831

Through a standard VPA ran in Chapter III through VIT Program, and after converting the size-structure data set to an age-structure data set, 11 year-classes was created for the analysed sample of yellowtail snapper (Table V.2), from 1 to 11 year-old groups of individuals, and it was estimated that 73.8% of the individuals belonging to the age 2 year-class were mature, whilst all those on the 3+ year-class were mature. Natural mortality (*M*) was estimated to be equal to 0.112; the total mean biomass (*Bmean*)= 49.07 t; and the spawning stock biomass (*SSB*) = 38.05 t (Table III.10).

For the mutton snapper, the analysis conducted on Chapter III defined 9 year-classes for the sample, from 1 to 9 year-old individuals (Table V.2), and was estimated that 7% of the population reaches maturation during the first year of life, 83.6% of the individuals belonging to the 2 year-class were mature, whilst all those in the 3+ year-class were mature. Natural mortality (*M*) was estimated to be 0.152; the total mean biomass (*Bmean*)= 139.78 t; and the spawning stock biomass (*SSB*) = 119.64 t (Table III.11).

For the king mackerel, 12 year-classes was defined, from 0 to 11 year-old individuals (Table V.2), and Nóbrega *et al.* (2001a) estimated that maturation in this species starts at age-class 3, where 20.2% of the individuals were mature; 73.1% were mature at age-class 4; 96.5% at age-class 5; whereas full maturation occur at age-class 6+. Natural mortality (*M*) was estimated to be equal to 0.309; the total mean biomass (*Bmean*) = 795.36 t; and the spawning stock biomass (*SSB*) = 507.08 t.

As for the Spanish mackerel, 9 year-classes were defined, from 0 to 8 year-old individuals (Table V.2), and Lucena *et al.* (2001) and Nóbrega *et al.*, (2001a) estimated that maturation for this species starts at age class 2, where 13.3% of the individuals were mature; 85.5% were mature at age class 3; whereas full maturation occurs at age class 4+. Length of first maturation was calculated to be 41 cm in fork length (FL), corresponding to the year-class 3. Natural mortality (*M*) was estimated to be equal to 0.382; the total mean biomass (*Bmean*)= 106.88 tons; and the spawning stock biomass (*SSB*) = 76 t.

Additive relationships between the main and the secondary species for both hand-line and gillnet fisheries were established and are shown in Table V.3. For the purpose of data entry, the results presented were calculated simply dividing the catches of the accessory specie by those of the main species and were defined the parameter *b* of the equation. The parameter *a* was considered equal to *zero*, because it can only be estimated when a time series of catches and prices is available, which was not the case, and means that when catches for the main species do not occur, there is no catches for accessory species.

Table V.2 – Initial condition of the biological parameters. Yellowtail snapper, mutton snapper and king mackerel are caught by the hand-line fleet, whereas the Spanish mackerel by the gillnet fleet. *N* = number of individuals in the population; *F* = fishing mortality by age class; *C* – catch by age class (t).

	Yellowtail Snapper			**Mutton Snapper**			**King Mackerel**			**Spanish Mackerel**		
Age	*N*	*F*	*C (tons)*	*N*	*F*	*C (tons)*	*N*	*F*	*C (tons)*	*N*	*F*	*C (tons)*
0	-	-	-	-	-	-	156908	0,035	0.98	156831	0.011	0.01
1	72478	0.001	0.01	38542	0.127	2.21	111237	0.033	2.01	105911	0.037	0.34
2	64729	0.144	1.99	29150	0.502	12.21	79001	0.017	1.50	69668	0.15	2.85
3	50093	1.049	12.61	15162	0.419	9.65	57013	0.042	4.30	40941	0.259	5.77
4	15693	1.184	6.32	8562	0.294	6.07	40131	0.059	6.08	21569	0.234	4.65
5	4294	0.466	1.27	5480	0.333	5.84	27775	0.061	5.77	11653	0.393	5.71
6	2408	0.244	0.53	3373	0.326	4.46	19187	0.05	4.12	5369	0.276	2.60
7	1686	0.112	0.22	2092	0.335	3.41	13401	0.033	2.31	2779	0.185	1.17
8	1347	0.218	0.37	1285	0.279	2.07	9518	0.024	1.40	1576	0	0
9	969	0.929	0.93	835	0.2	1.13	6821	0.055	2.53			
10	342	0.292	0.15	-	-	-	4742	0.076	2.69			
11	228	0.067	0.03	-	-	-	3228	0.007	0.20			

V.3.2 - THE MARKET

The base (shadow) prices (γ_1) utilised for the chosen species are listed in Table IV.4, and were obtained through the official statistics bulletin for the year 2002 (IBAMA, 2003).

As for the estimation of the modifier price related to size (γ_2) and the modifier price related to supply (γ_3), as it is necessary a data series of price / total supply / size of each species, which is not available, both were considered *zero*. Otherwise, it was possible to verify that price is higher for larger individuals at a very low level (ca. 10%), especially for the gillnet fishery, and that price is not affected by supply. Also, it could be visualised that local fishery production meets approximately 10% of Pernambuco State demand, and supply from others Brazilian States and from abroad is commonly practised among wholesalers because demand is always high. An interesting point concerning supply and demand is that during Easter week and summer, consumption increases sharply, especially during Easter, and although supply also increases, prices rise and in most of the cases it does not fall to previous price levels after those periods. This seems to be part of retailers and wholesalers practice to increase profits, and as it occur in a specific time of the year, it can be considered γ_3 equal to zero, because uncertainty on fish price and offer is high.

Table V.3 – Additives relationships between the main and the accessory species for hand-liners and gill-netters ($Y = a + bC$).

Fleet	Specie Relationship	Additive Relationship
Hand-line	YTS X DS	0.6169
	YTS X DF	0.565
	YTS X OTHERS	1,011
	MS X DS	0.4836
	MS X DF	0.4429
	MS X OTHERS	0.7928
	KM X DS	0.5233
	KM X DF	0.4793
	KM X OTHERS	0.858
Gillnet	SM X BR	0.114
	SM X LS	0.124
	SM X OTHERS	0.793

V.3.3 - THE FISHERMAN

Most of the parameters herein presented were obtained through the analysis conducted in Chapter IV, but some will be listed for the sake of clarity during the bioeconomic analysis. Economic parameters can be found in Table V.4, and the related description can be found in item IV.3. Prices are considered in Brazilian Reais (R$).

Table V.4 – Costs incurred by the hand-line and gillnet fleets in Pernambuco State, North-eastern Brazil. Values in Brazilian currency (Reais - R$). Change rates as in December/2002: 1.00 € = R$ 3.50

Fishermen Expenses	Parameter	Hand-line Fleet	Gillnet Fleet
Country	Maximum Credit	30%	30%
	Fuel price (2002 average)	R$ 0.95/l	R$ 0.95/l
	Opportunity cost	5.9%	5.9%
	Interest (financial cost)	Zero	Zero
Fleet	Commercial cost	10%	zero
	Owners share	25%	37.5%
	Fishing days	190	230
	Daily fishing hours	10h	10h
	Dismissal price	Zero	Zero
	Daily ice expense	R$ 6.60	R$ 1.00
	Annual increase of *q*	0	0
	Modifier capital ⇔ catchability	0	0

The fisherman expenses according to the local economic conditions, denoted as *country*, are listed below. All these parameters were already described in Chapter IV following the concepts of the fisherman box from a theoretical point of view, insofar the development of the mathematical formulation thus requires, and here are described in accordance of data entry in each tab sheet of MEFISTO model. In order to give a better comprehension for the present chapter, a summary will be presented.

- *Maximum credit*. Financial costs are raised by boat owners seeking better markets for fishing products or with few small investors, that pay the expenses to fish, with a guarantee to receive the boat production as an informal and personal compromise, and fish price is maintained the same as those applied locally. Those credits, as from boat owners or small investors, are not calculated according to boat value, but as the sum of expenses to go fishing, and correspond, in average for a whole year, to approximately 30% of the boat value, according to collected information;

- *Fuel price*. Estimated as an average value for the year 2002 as R$ 0.95/liter.
- *Opportunity cost*. Money cost in Brazil is measured through the *Selic* rate, which origin comes from the interest taxes effectively observed in the internal market system. In 2002 the accumulated *Selic* rate was as high as 19.2%, but the real rate, taking off the inflation calculated by the IPCA - Índice Nacional de Preços ao Consumidor Amplo (National Ample Index of Prices to the Consumer), or the public debt rate, was 5.9%, the lower level since 1990.
- *Financial cost.* Direct money interests do not exist, and boat owners' and investors' gains are taken from the fish production commercialisation. So, for this item this percentage may be considered *zero*.

The methodology concerning data entry for the *fleet* tab sheet was the same as those for *country*, described as follow:

- *Description.* Hand-line or Gillnet.
- *Commercial cost.* Landing cost was the only observed cost for the hand-line fleet, estimated as 10% of total catch. For Gillnet it was not observed such a cost, so it was considered equal to *zero*.
- *Owner's share.* As explained in Chapter IV, for hand-liners, it was estimated as 25%, whereas for gill-netters as 37.5%.
- *Fishing days.* 190 days for the hand-line fleet and 230 days for the gillnet fleet.
- *Daily fishing hours.* 10 hours for both fleets.
- *Dismissal price.* No dismissal policy exists in Brazil as a whole, so this item was considered *zero*.
- *Daily ice expense.* For hand-liners, daily ice expense was calculate as R$ 6.60, whereas for gill-netters as R$ 1.00.
- *Annual increase of "q".* No investment in technological progress to increase catchability was observed, so it was considered equal to *zero*. Fishermen always go for increasing catches by increasing catchability, as effort is practically constant, but using their empirical knowledge, and it is known that boat owners do make some small investment in electronic devices, such as radios and GPS (Global Positioning System). Such investments are not reported and, if it exists at all, only a very reduced number of boats can handle it.

- *Modifier capita ⇔ catchability*. There is, of course, no information on the increase of capital invested, so it was also considered equal to *zero*.

The same methodology was adopted for the *vessel* tab sheet. For the hand-line fleet, 18 boats were followed, whereas only 10 gill-netters were possible to obtain bioeconomic data. Detailed information for each fishing boat per fleet are depicted in Table V.5. For all accompanied boat, credit was equal to zero, and fixed and maintenance costs where equal so were not entered in the following table.

- *Boat identification*: hand-line fishing boat is identified as “HL”, whilst the gillnet as “GN”;
- *Gross Tonnage (GT)*: reported directly by interview with boat owners;
- *Boat value (Capital)*: As, in MEFISTO, this is the initial sale value of the boat and is used as initial capital, an average value was entered for each boat. This estimation took into account the real value of the boat, listed in Table V.5, the daily cost of each boat, and the value of the boat *Estrela da Manhã* (R$ 7,000.00), code HL-4, for which detailed informations on costs and revenues were more precisely provided;
- *Credit*: insofar credit is rarely taken through bank loan and direct money can be raised through small investors, such informal relationship is not well clarified or reported. If such credit exists it is quite small, thus can be considered zero;
- *Crew size*: obtained through boat owner or fishing master interview;
- *Fuel consumption*: also through the conducted interview;
- *Other daily costs*: as food, water, etc are paid from the owner's share in Pernambuco State coastal fishery, such costs were totally entered here as shown in Table V.5;
- *Annual costs*: the total annual costs incurred by each boat and paid from the owner's share were calculated and are listed in Table V.5. Otherwise, the value entered corresponds to the fixed costs which, as already mentioned, were the same for boats and fleets, corresponding to ca. R$ 500,00.The amount concerning fixed costs (such as license, mooring, boat insurance, etc.) was estimated as 15% (R$ 71,41). The only fixed costs fisherman has are compulsories licences, nowadays corresponding to R$ 26.00 for boats, and a fixed yearly insurance tax is also compulsory (R$ 45.41). Very low expenses to maintain fishing boats in operation were observed, because they are always avoided by owners and fishermen; the maintenance costs (engine repair, shipyard, etc.) were calculated as 85% (R$ 391,44).

Table V.5 – Description of fishing boats characteristics of the hand-line and gillnet fleets utilised in the bio-economic analysis. HL – Hand-liners; GN – Gilnetters. R$ - Brazilian Currency (Real).

Boat	Gross Tonnage (GT)	Boat Value (R$)	Crew Size	Fuel Consumption(l/day)	Others daily costs (R$)	Annual costs (R$)
HL-1	2.85	17,000	3	4.85	15.00	6,100
HL-2	3.75	10,000	3	9.70	16.00	6,300
HL-3	2.85	20,000	2	6.45	12.00	5,800
HL-4	3.28	7,000	3	9.70	15.50	6,100
HL-5	2.35	4,000	1	3.20	8.00	5,000
HL-6	3.75	9,000	3	9.70	15.50	6,100
HL-7	4.20	35,000	3	16.10	16.50	7,900
HL-8	4.20	17,000	3	16.10	17.00	7,200
HL-9	2.60	7,000	3	4.85	15.00	5,700
HL-10	3.70	9,000	3	9.70	15.50	6,200
HL-11	2.85	20,000	3	6.45	15.00	5,900
HL-12	2.60	5,000	2	6.45	12.00	5,200
HL-13	3.10	9,000	3	16.10	16.00	6,300
HL-14	2.20	2,500	2	4.85	12.00	5,100
HL-15	2.60	5,000	3	6.45	15.00	5,900
HL-16	4.20	10,000	3	16.10	16.50	6,800
HL-17	2.20	4,000	1	6.45	10.00	5,100
HL-18	4.30	9,000	3	19.40	17.00	7,500
GN-1	3.30	8,000	3	14.7	19.10	5,200
GN-2	3.50	9,500	3	15.2	19.50	5,100
GN-3	2.90	12,000	3	9.7	18.90	5,000
GN-4	2.85	10,000	3	8.45	18.70	4,800
GN-5	3.60	13,000	3	15.8	19.50	5,400
GN-6	2.60	7,000	2	9.5	18.00	4,800
GN-7	2.70	7,000	2	9.5	17.20	4,800
GN-8	2.85	8,000	3	9.45	18.60	5,100
GN-9	2.5	6,000	2	8.5	17.00	5,000
GN-10	3.20	9,000	2	13.5	17.20	5,100

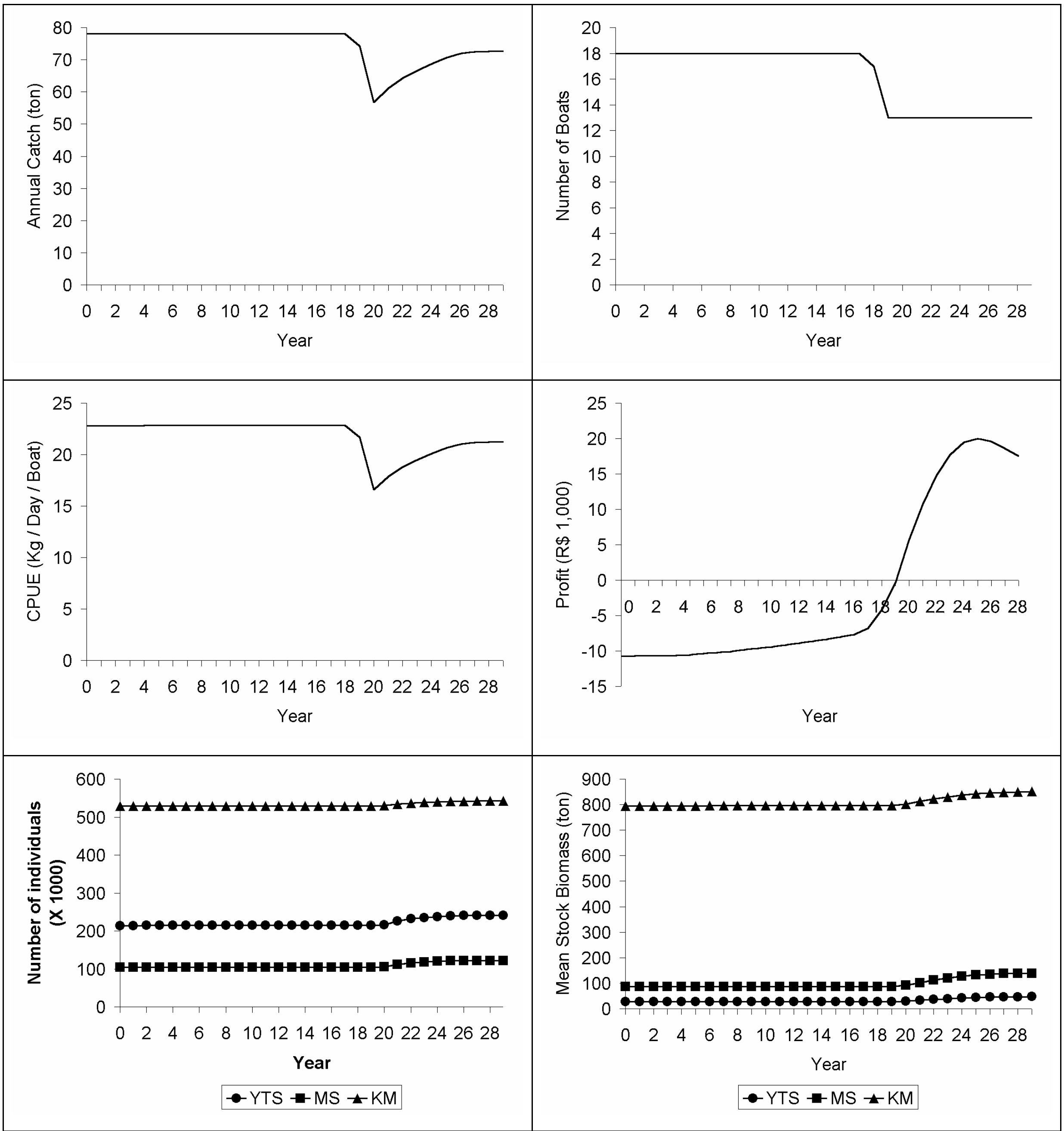
V.3.4 – BIOECONOMIC SIMULATIONS

Data showed that no catch interaction among fishing gears exists, specially for the catch of the main species, that is to say that there is no gear competition for the same resource. Thus the results of the defined simulations will be presented separately, for the hand-line and for the gillnet fisheries.

V.3.4.1 – INITIAL SITUATION

Figures V.2 and V.3 show the initial conditions in a 30 years projection with no management measure, for the hand-line and the gillnet fisheries, respectively. It can be seen that stocks and catches for the hand-line fishery maintain a constant value until year 18, whereas the gillnet fishery until year 17. A sharp decrease in total annual catches and the catch per unit of effort by an order of ca. 30% and ca. 45%, respectively for the hand-line and the gillnet fisheries, can be observed until year 20, slowly increasing afterward until year 30, reaching values ca. 10% and ca. 26% less than that observed in the initial condition of the simulation, respectively. In the same period, both fleets are operating with losses, slightly recovering. Afterward, a sharp increase can be observed attaining a maximum in year 25 and 22, respectively, and from this year onward with decreasing trends towards a positive profit equilibrium.

After year 20, it can be observed that stocks slightly increase. For yellowtail snapper (YTS), such trend is more evident, specially the increase in the spawning stock biomass (SSB), with an increase of 86.1%, while the number of recruits projects an increase of 12.7%. For the mutton snapper (MS), such increase was 64.7% for SSB, whereas for the number of recruits of 17%. For the king mackerel the projected increases were, respectively, 9.5% and 2.6%. Otherwise, the increase projected for the Spanish mackerel stock in the gillnet fishery were 46% for SSB and 5.8% in the recruitment level. The favoured condition with decreasing fishing effort that allows for the recuperation of the spawning stock biomass for snappers seems to confirm the assumption raised in Chapter III that the stock-recruitment relationship is density-independent. However, although it has been observed that recruitment for coastal pelagic species is stock density-dependent, the results showed that such a pattern is likely to occur for the king mackerel, while it is not so evident for the Spanish mackerel.



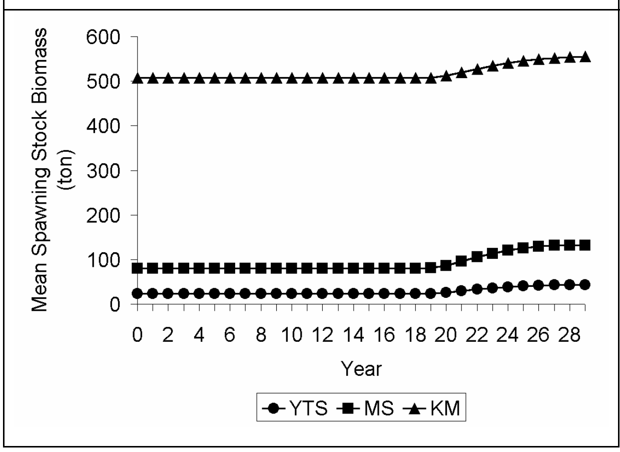
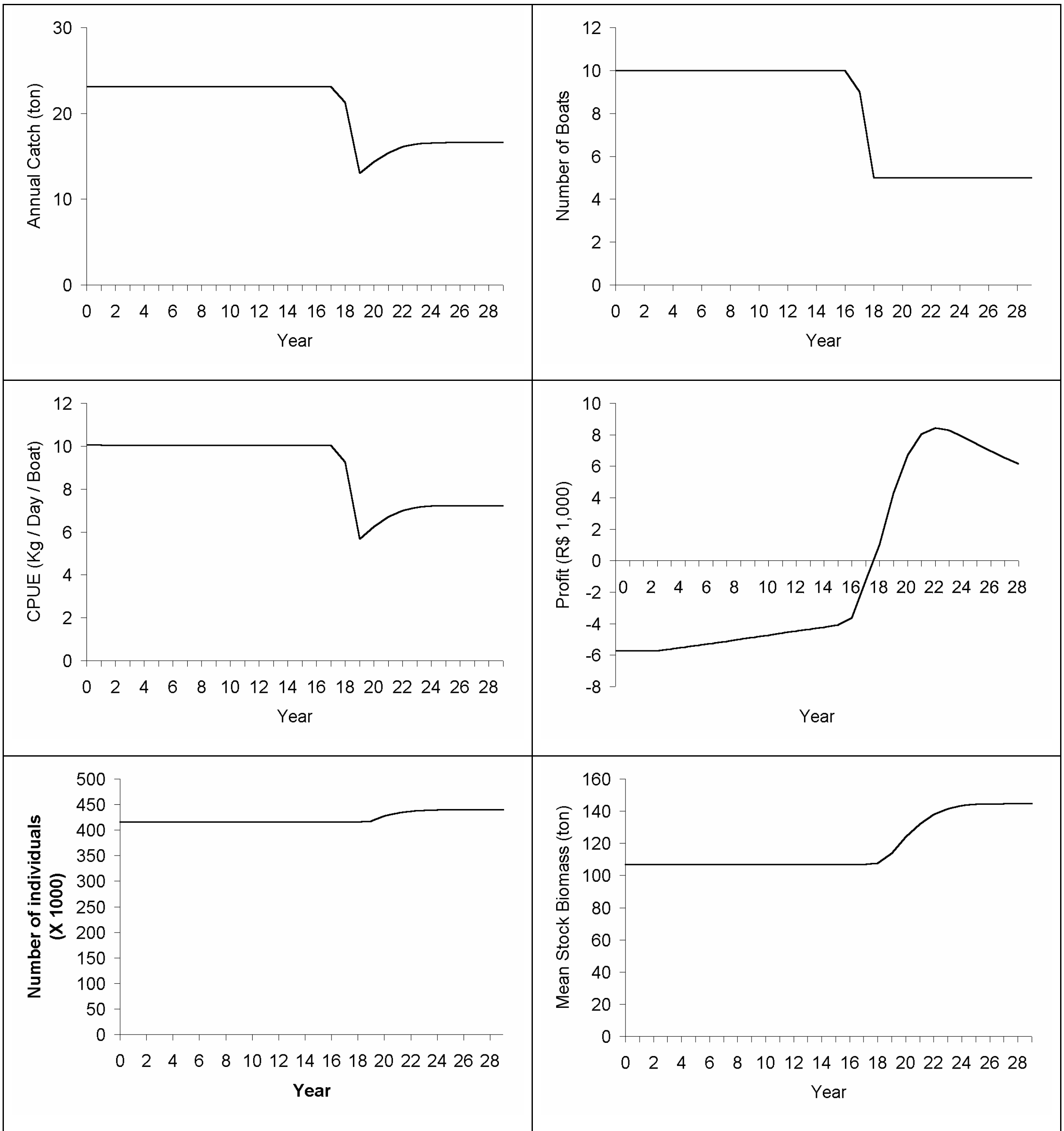


Figure V.2 – Initial situation of the hand-line fishery for the yellowtail snapper (YTS), mutton snapper (MS) and king mackerel (KM) stocks, in a 30-year projection.



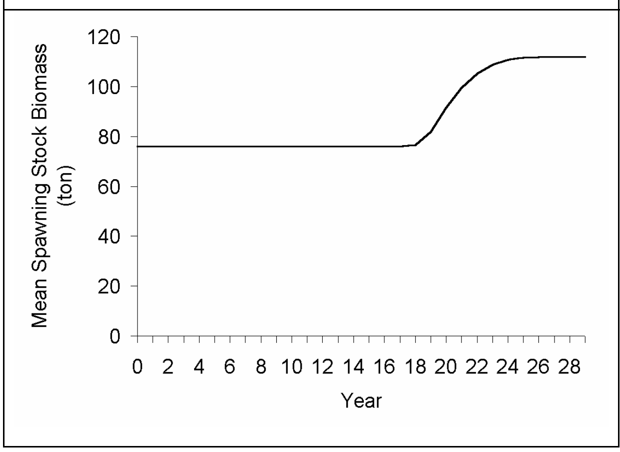


Figure V.3 – Initial situation of the gillnet fishery for the Spanish mackerel stock, in a 30-year projection.

An explanation for such a trend should be the assumption raised by Pereiro (1995), for whom high mortality in the planktonic phase makes it very difficult to find a significant correlation between spawning stock and recruitment in most stocks.

Such a trend is followed by a decrease in the number of active boats, from 18 to 13, in the first 20 years of projection for the hand-line fleet, and from 10 to 5, in the first 18 years for the gillnet fleet. As 4 out of 5 hand-line boats, whereas 3 out of 5 gillnet boats, that disappear from each of the fishery are the largest ones (HL-7, HL-8, HL-16, HL18; and GN-1, GN-5, GN-10), the exception being the hand-line boat HL-13 and the gillnet boats GN-7 and GN-9 that are smaller or medium size boats regarding the analysed fleets, the possible explanation is that these boats, whose catching power are the highest among the analysed fleets, operates with excessively higher costs, because individual profits for these boats are the lowest, considering the economic structure of the fishery, as well the resource availability and the fishermen efficiency. That is why the remaining smaller boats obtain a higher profit, due to reduced operating costs, and through a sharp increase in their catches, raising individual total income by an average of ca. 40%. The greater fishing power of the larger boats seems also to more strongly exert their fishing pressure on the adult portion of the target species stocks, which would be more favoured with these boats deactivation. Target species represent 40% of the hand-line fleet total income and 50% of the gillnet fleet total income, so stock recovery probably would benefit the remaining boats with higher catches and income, that can also explain this sharp increase in profits.

Such high increase in profits can also be explained through the assumption that the MEFISTO model was designed for a more stable country economic situation, where money cost, or the public debt, is not so high, as it is the case of Brazil, where money cost is as high as 5.9% (i.e. in Spain the public debt is around 3%). Nevertheless, such rates, as well as the absence of interest rates to borrow money, seems not to affect the local fishery system, whose internal economic relationships and functioning looks like to have adapted itself to very strictly social and economic conditions of these fishermen villages. Otherwise, this initial situation implies that the present condition have found an equilibrium but it is not sustainable in the long-run, because some boats would disappear in the absence of management measures. Other assumption that can be withdrawn from the results obtained is that larger boats represent over-capacity and over-capitalisation of the fleet that, if maintained, would put the fishery in a dangerous unsustainable situation.

V.3.4.2 – SCENARIO 1 – INCREASE IN CATCHABILITY

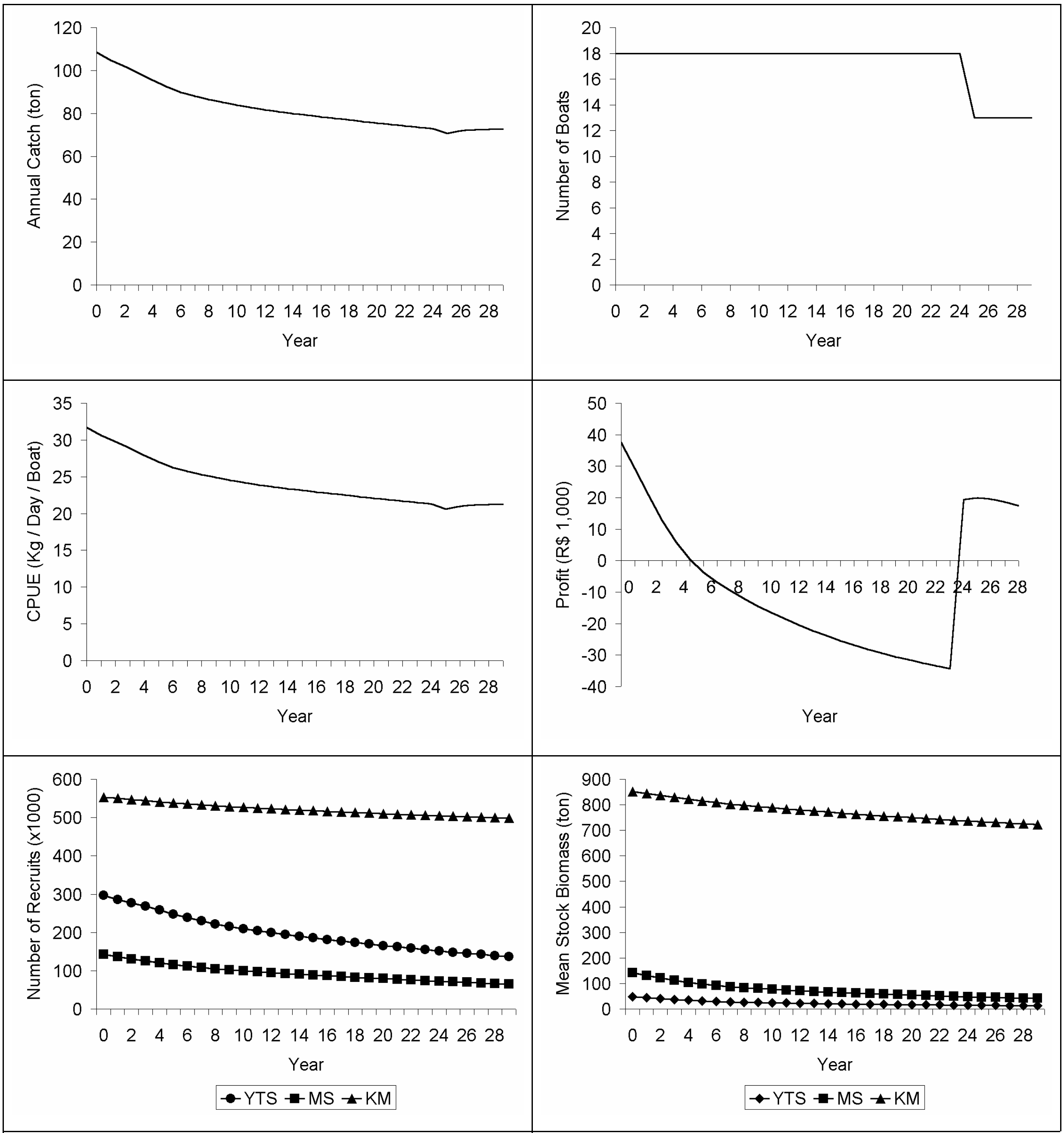
In this scenario, values were set to run deterministically, the simulation established a yearly increase of 1% in catchability and of 5% in the capital invested in catchability, and the Beverton-Holt model was defined to describe the stock-recruitment relationship. Results are presented in Figures V.4 for the hand-line fishery, and V.5 for the gillnet fishery.

For the hand-line fishery a decreasing trend in catches and catch per unit of effort (CPUE) can be observed. Such decrease in the fishing production led to a sharply high decreasing in profits, which became zero in year 5 and negative afterward. Such losses makes that the five aforementioned hand-line larger boats disappear from the fishery, what made possible that the remaining boats come to obtain profits after year 25. It can also be observed that after this year catches and CPUE seems to stabilise. All three analysed stocks showed decreasing trends in recruitment, mean biomass and spawning stock biomass, denoting that any increase in catchability would affect stocks sustainability and probably would drive the snappers stocks to extinction, and may indicate that currently these stocks are fully exploited. Whereas the king mackerel presented a reduction of 9.9% in recruitment, of 15% in biomass, and of 17.9% in the parental stock, the yellowtail snapper presented reductions of 54%, 73.2%, and 75.7%, respectively, while the mutton snapper of 54.2%, 70.8% and 72.1%, respectively. Such decreasing trends are in accordance with reductions in production, CPUE and earnings.

As for the gillnet fishery, the picture for the present simulation seems more stable than the one presented previously. Although a decreasing trend may be visualised for the fishery and the Spanish mackerel stock, it is not as accentuated as for the hand-line fishery. Profit had a decreasing trend, but seems not to affect boats profitability in the long run (maybe a longer scenario, i.e. 50 years, would affect boats efficiency). The recruitment of the Spanish mackerel stock, otherwise, would decrease by an order of 14.1%, while its mean biomass by an order of 25.6%, and the parental stock by 30%, probably denoting, through this simulation, that the stock-recruitment relationship is density-dependent.

V.3.4.3 – SCENARIO 2 – REDUCTION IN FUEL PRICE

In this Scenario 2, values were set to run deterministically, and a reduction in fuel price by 80% was simulated, being stipulated a value of R$ 0.20/liter (normal values per



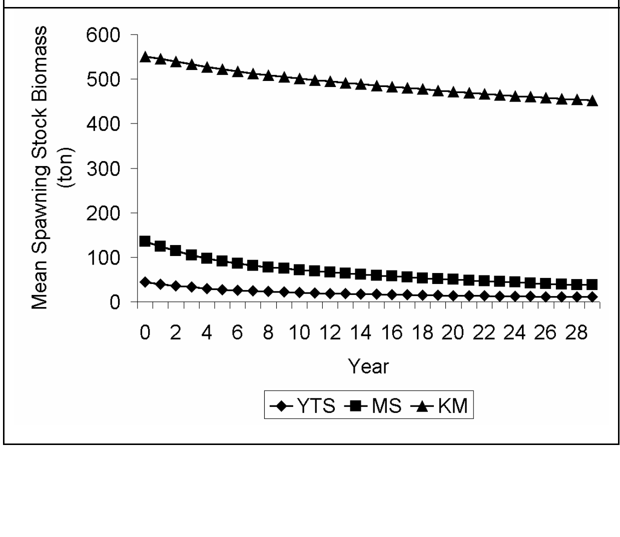


Figure V.4 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performances with the scenario 1, considering a yearly increase in catchability by 1% and a 5% modifier capital (or the capital invested in catchability), in a 30-year projection and with deterministic simulation.

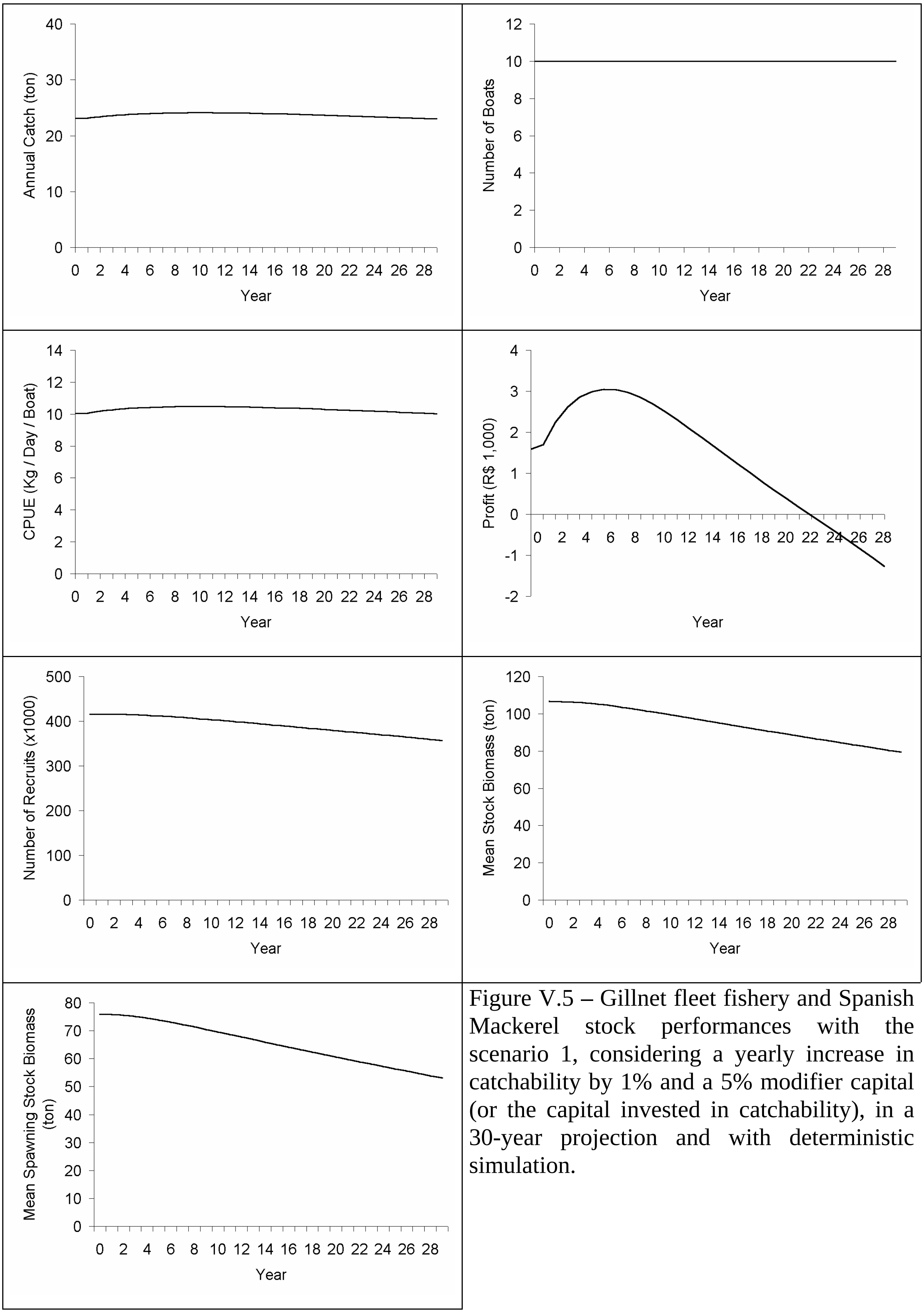


Figure V.5 – Gillnet fleet fishery and Spanish Mackerel stock performances with the scenario 1, considering a yearly increase in catchability by 1% and a 5% modifier capital (or the capital invested in catchability), in a 30-year projection and with deterministic simulation.

litre is R$ 0.95), and the event was introduced in the fifth year. Results of the simulation are presented in Figures V.6 and V.7 for the hand-line and for the gillnet fisheries, respectively.

The reduction in the price of fuel seems to drive the hand-line and the gillnet fisheries to an economic stability, clearly visualised for the latter. The smooth downward production and CPUE curves for the hand-line fleet showed a decrease of 17.4% in the first 5 years, and 11.8% afterward. Profits, before year 5, decrease sharply, smoothing afterward with losses that seems to be affordable by hand-line boat owners, as none disappear from the fishery. Such stabilisation, although not as detrimental as the previous simulation, leads to an increase in the level of exploitation of the three studied stocks, whose decrease in the level of recruitment were by an order of 42.7%, 36.5% and 6.4% for the yellowtail snapper, mutton snapper and king mackerel, respectively; in the level of biomass by an order of 42.7%, 38.6% and 6.4%, respectively; and in the spawning stock biomass by an order of 45%, 39.8% and 7.7%, respectively.

For the gillnet fleet, with the exception of the profit curve, that sharply increase to a maximum in the same year of the introduction of the scenario and than slightly decrease towards a stabilisation, the others curves (production, CPUE and stock;-recruitment relationships) did not show difference from the initial condition, denoting that such a measure should have an important impact on such a fishery, maybe because fuel is the most expense item in the costs of the gillnet fleet.

V.3.4.4 – SCENARIO 3 – FENCED SEASON

A biological fishing closure, in a 30-year projection and with deterministic simulation always introduced in year 5 was the condition defined for this third scenario. Results of the simulation is presented in Figures V.8 and V.9 for the hand-line and for the gillnet fisheries, respectively.

The results show that the gillnet fishery seems to better take advantage of such a management measure, with stabilised production and productivity, even though one boat disappears from the fishery (the largest one – GN-5), but showing, in the long run, profit and increasing trends for the Spanish mackerel recruitment, biomass and spawning stock biomass. All curves show two inflection points, one which represent year 5, when the event takes place and the other in year 15, when the gill-netter boat GN-5 disappear from the fishery. In the hand-line fishery, none of the 18 boats disappear from the fishery and after year 5 the results

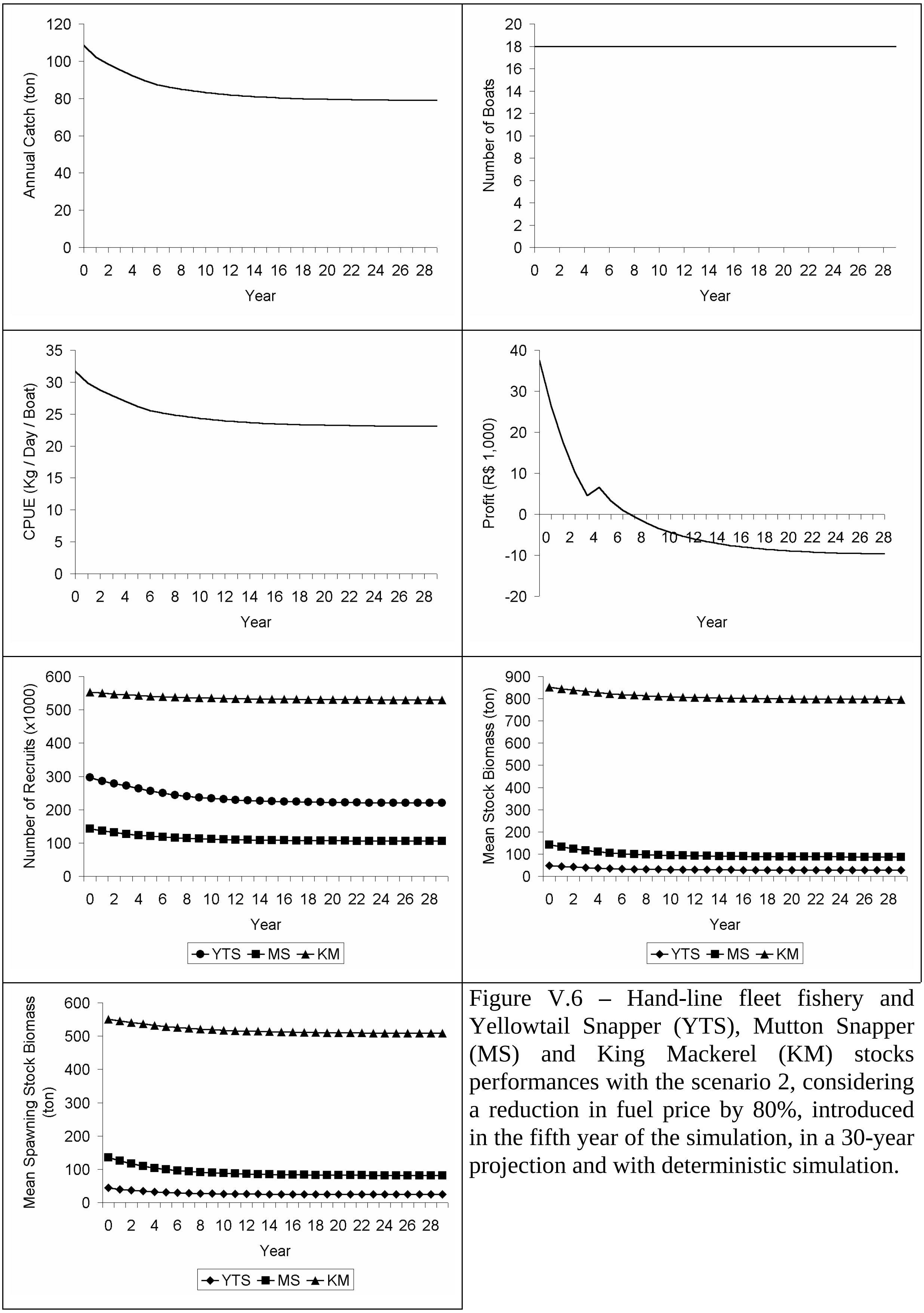
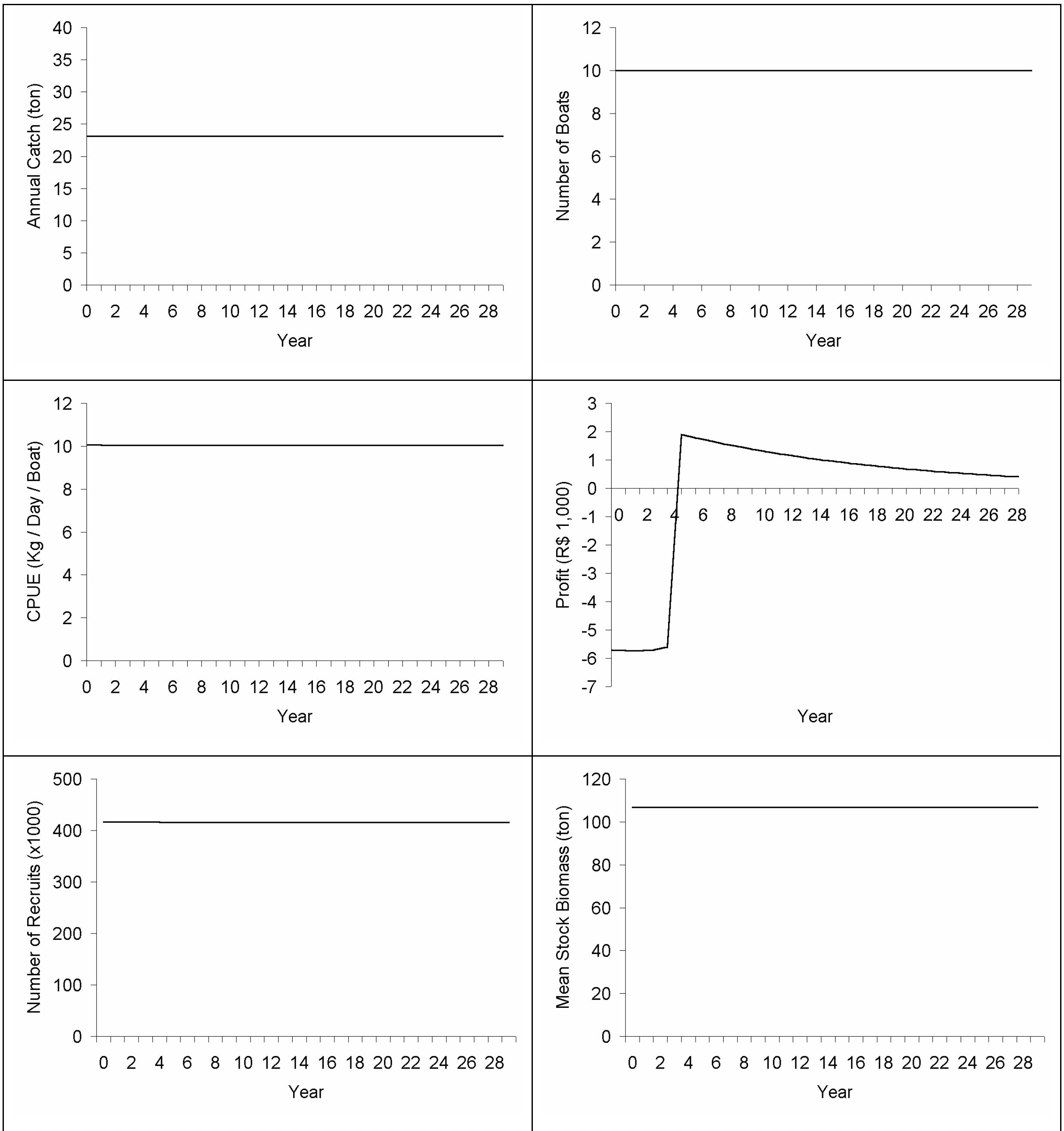


Figure V.6 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performances with the scenario 2, considering a reduction in fuel price by 80%, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



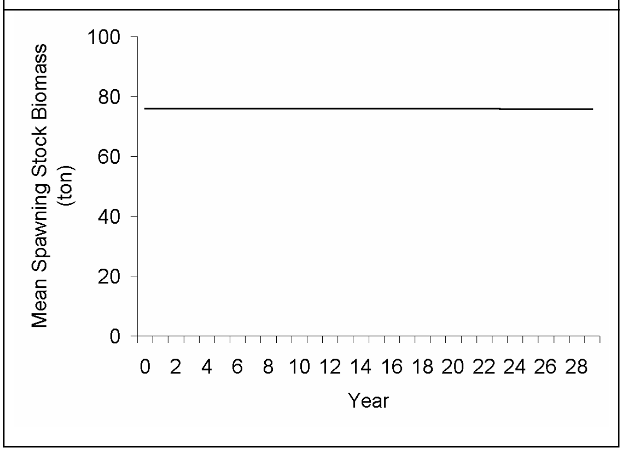
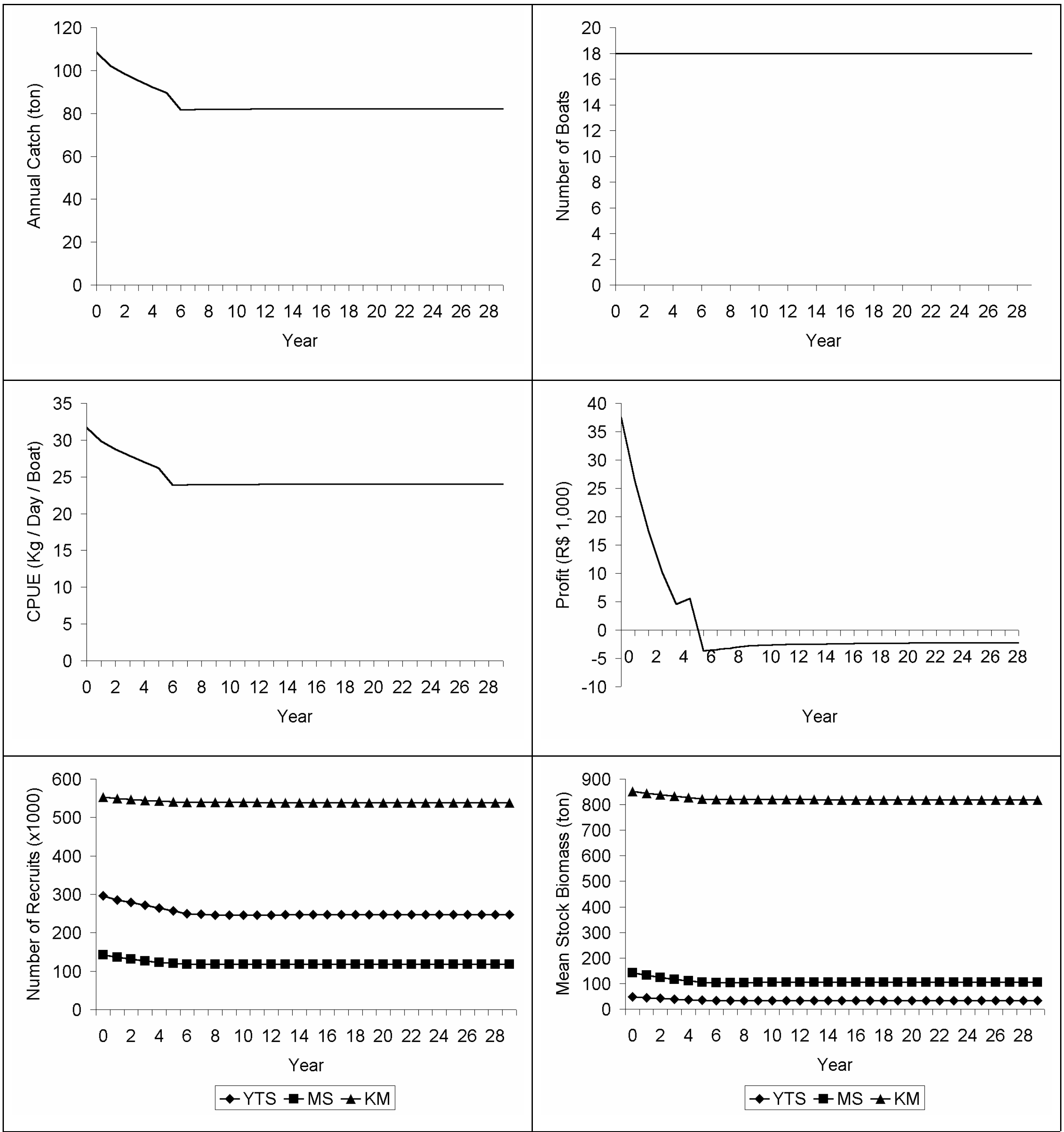


Figure V.7 – Gillnet fleet fishery and Spanish Mackerel stock performances with the scenario 2, considering a reduction in fuel price by 80%, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



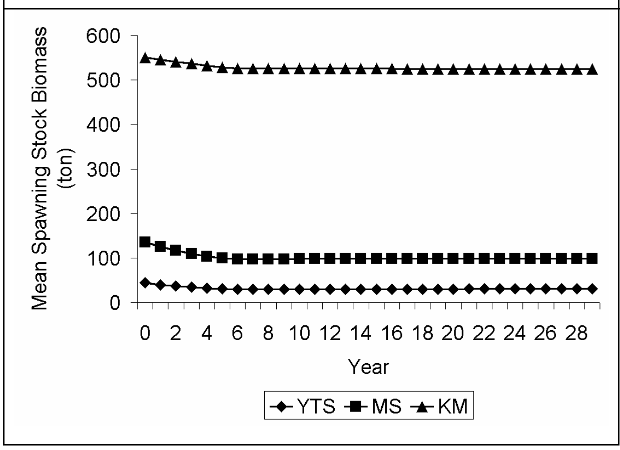
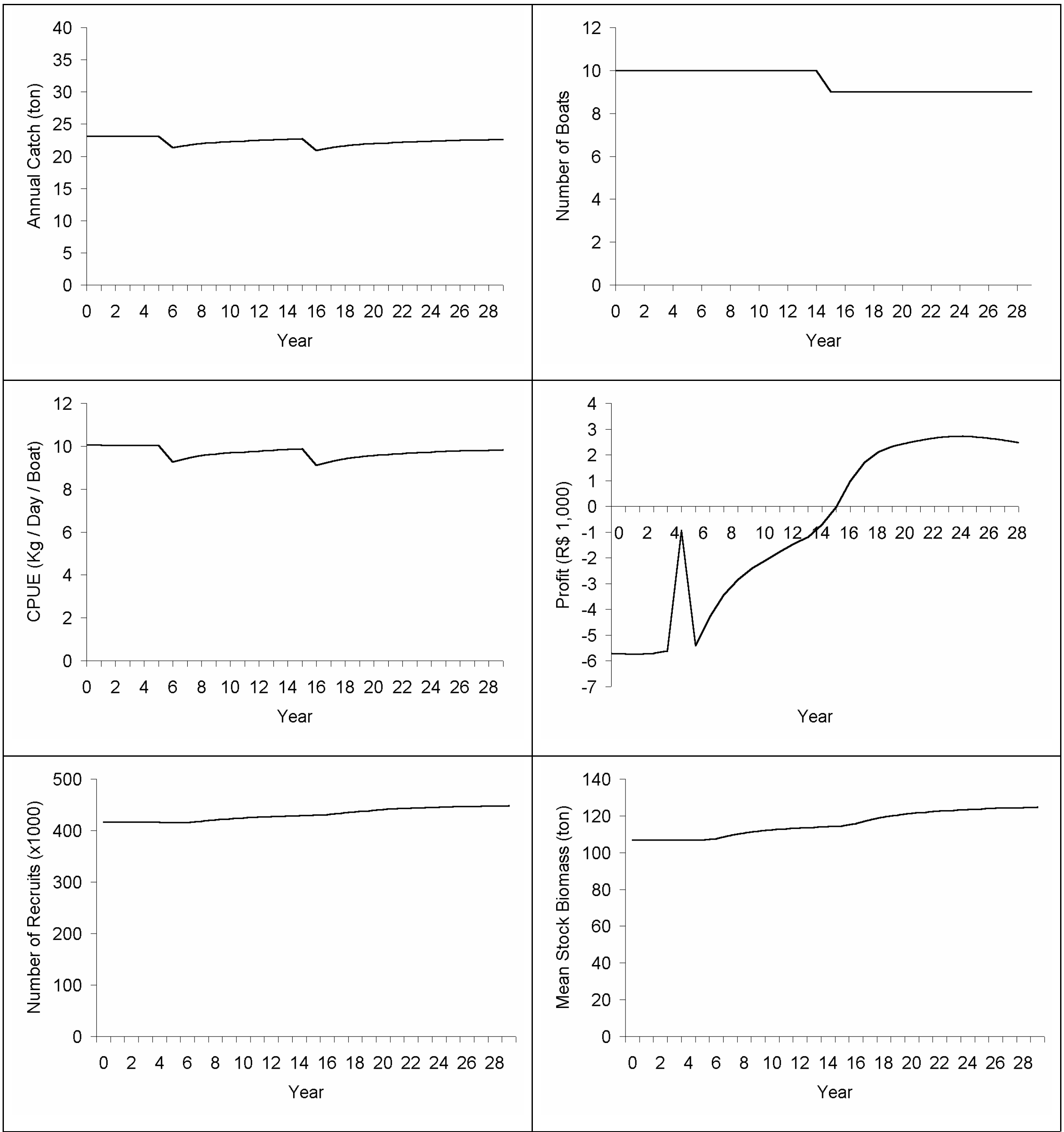


Figure V.8 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performances with the scenario 3, considering a fenced season, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



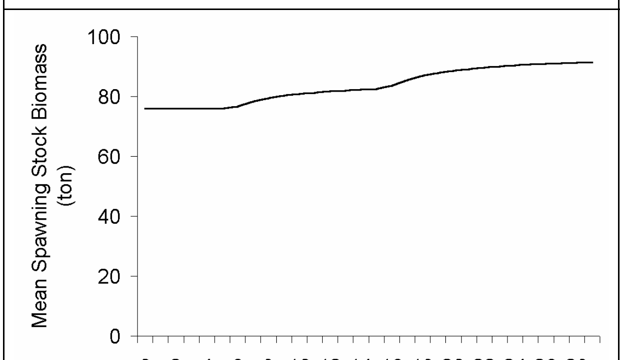


Figure V.9 – Gillnet fleet fishery and Spanish Mackerel stock performances with the scenario 3, considering a fenced season, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.

show a clear stabilisation of the fishery and in the stocks levels. Reduction in the stock level practically occur before measure implementation, and recruitment, mean biomass and spawning stock biomass, for the yellowtail snapper, mutton snapper and king mackerel, decrease, respectively, by the following magnitude: 16.6%, 17% and 2.6%; 29.3%, 26% and 3.8%; and 31.1%, 27% and 4.6%. It can be seen that stabilisation took place after year 6, just the year after implementation of the management measure.

V.3.4.5 – SCENARIO 4 – BOATS DEACTIVATION

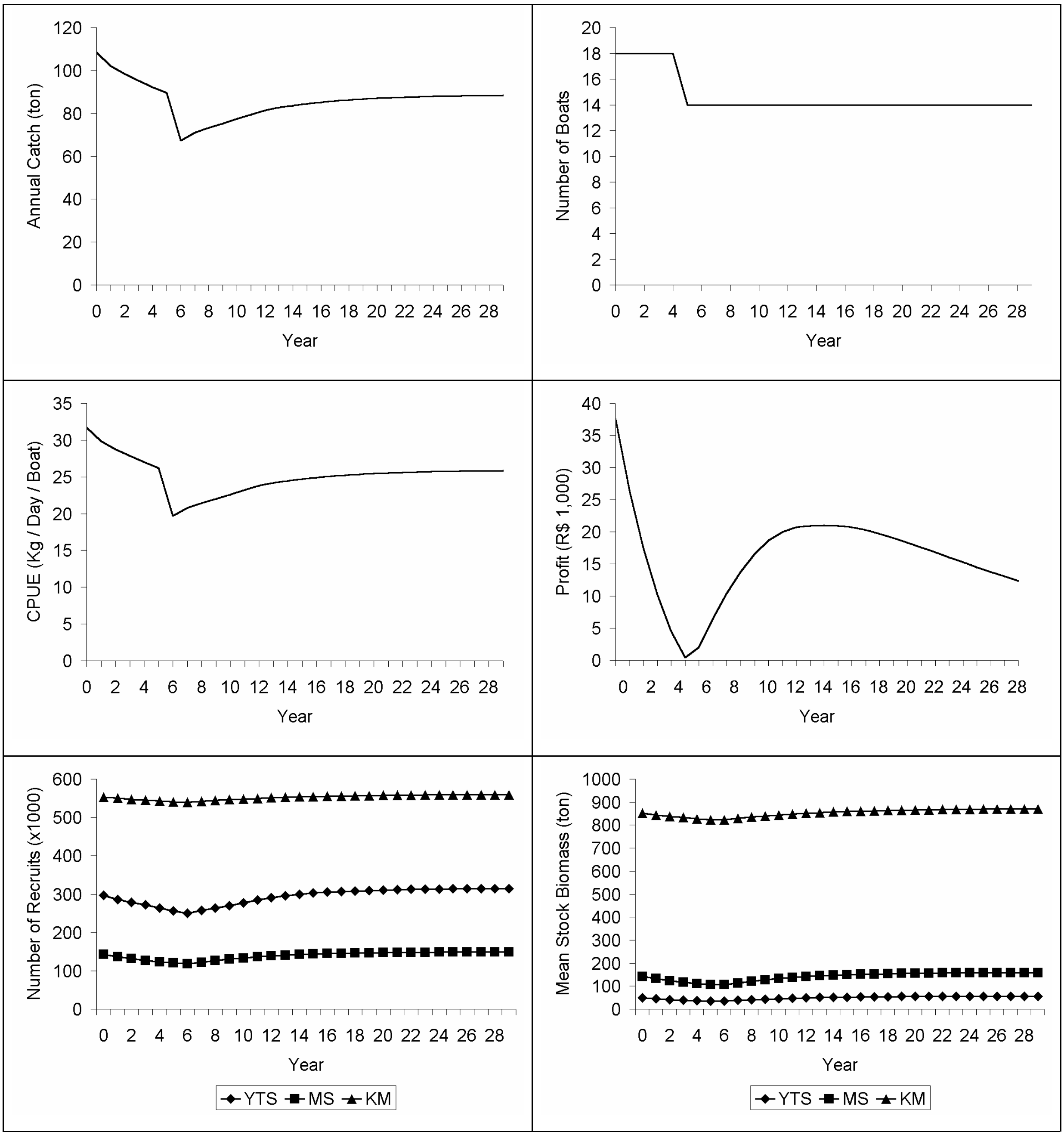
The scenario 4 presents a simulation aiming the reduction of fishing effort by withdrawing the less productive boats, the ones that, in both fisheries, disappear in the long run if the present fishery condition is to be maintained. The results are shown in Figures V.10 and V.11 for the hand-line and the gillnet fisheries, respectively.

Although such a management measure denote a direct unemployment and is always socially undesirable, is the one that, after implementation, showed clearly an increase in fishing production, productivity and profit, as well as in the stocks levels, for both fleets, as production stabilise in the long term, due to the biological and economic stabilisation of the stocks levels. For the hand-line fleet, the three analysed stocks stabilise at levels registered for the initial condition, while in the gillnet fishery the Spanish mackerel stock stabilise at higher level, at an order of 14.2% in the recruitment level, of 32.7% in the stock biomass, and of 40.1% in the spawning stock biomass. Once more it seems that the gillnet fishery takes more advantage with the implementation of management measures.

V.3.4.6 – SCENARIO 5 – REDUCTION IN CATCHES OF JUVENILES

For the fifth scenario, it was simulated a reduction of 10% in the catch of juveniles, what could be implemented through the establishment of protected areas known to be nursery grounds or habitats of juveniles fishes (e.g. coral reefs). The results are shown in Figures V.12 and V.13 for the hand-line and the gillnet fisheries, respectively.

Such a management measure, according to the results obtained, seems to go effectively towards a stabilisation of the fisheries and the studied stocks after its implementation in year 5 of the simulation. Figures V.12 and V.13 clearly show such a trend,



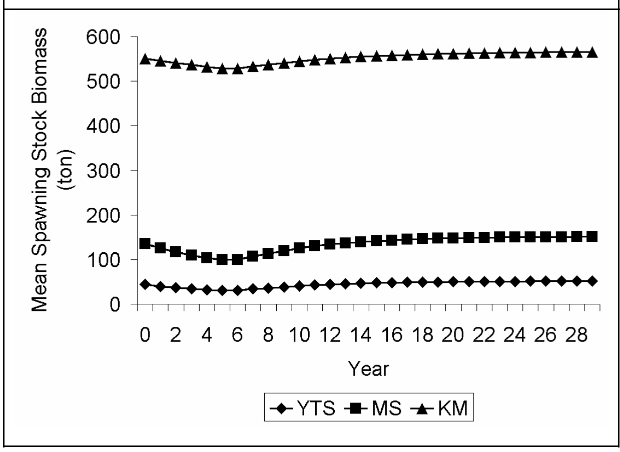
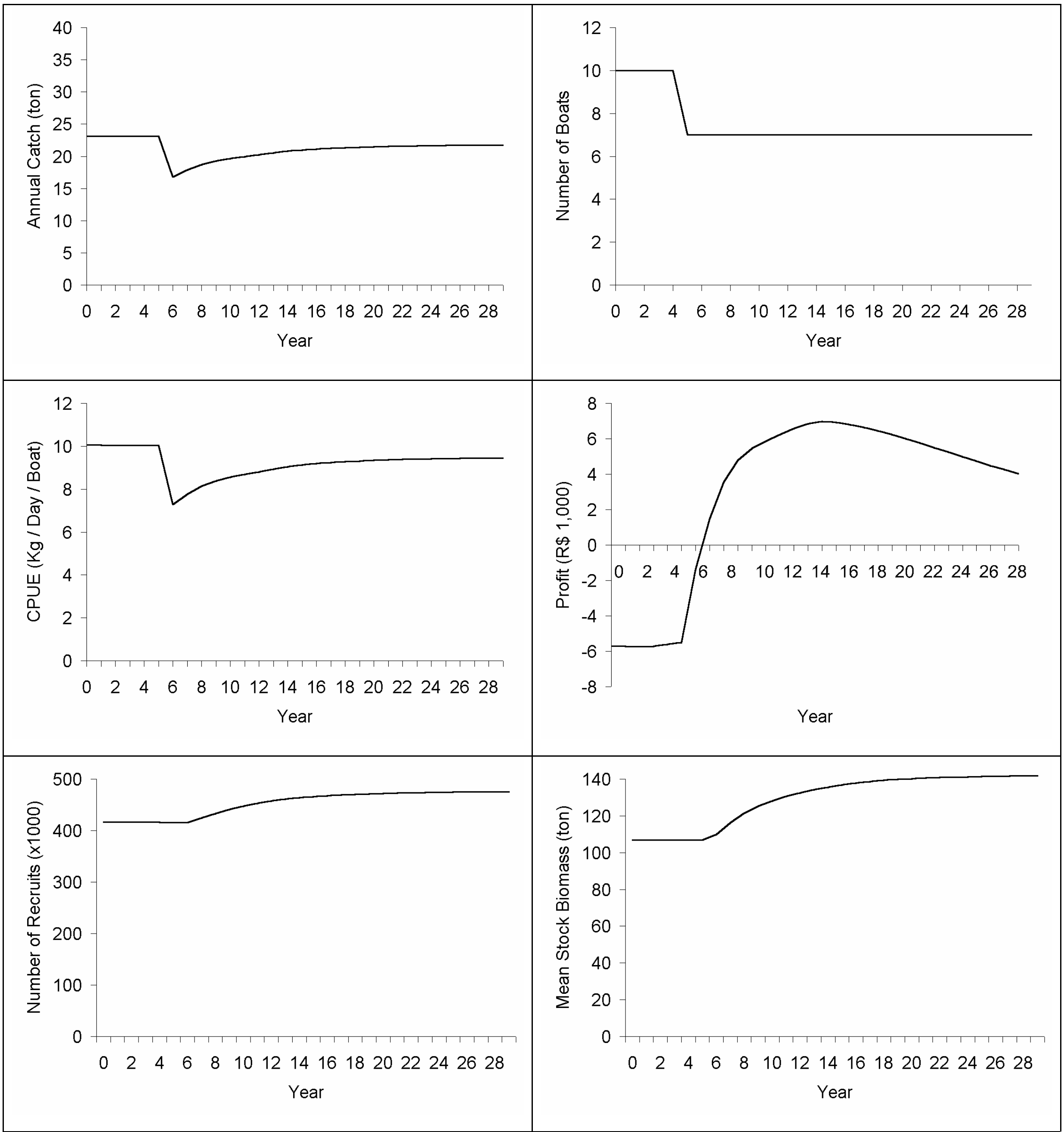


Figure V.10 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performances with the scenario 4, considering reduction in the number of boats, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



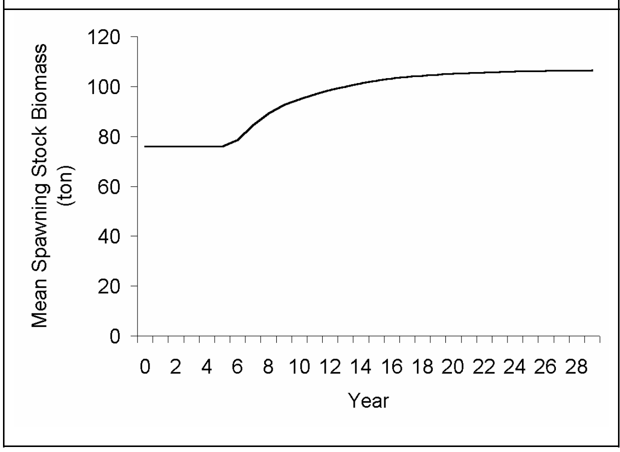
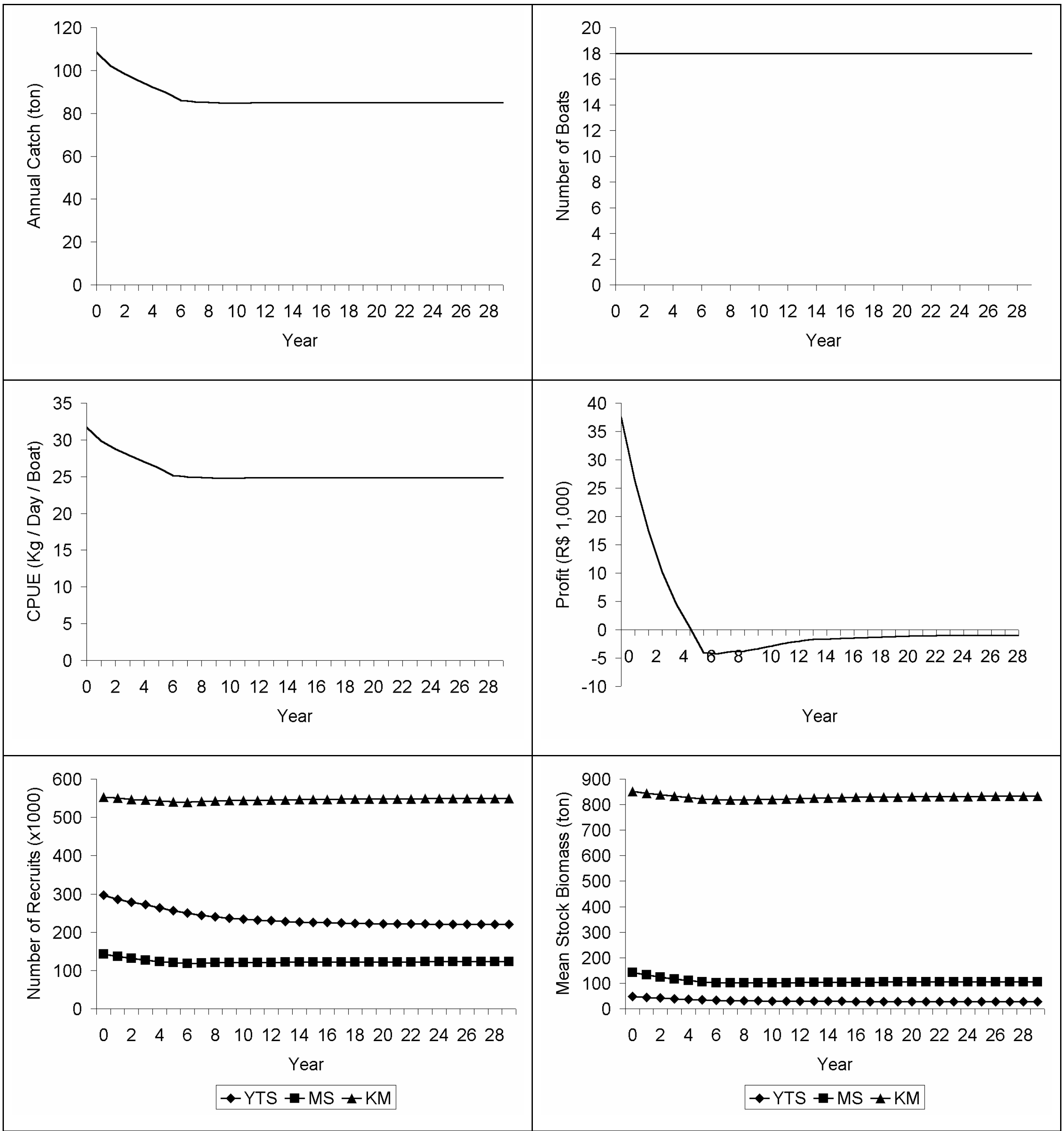


Figure V.11 – Gillnet fleet fishery and Spanish Mackerel stock performances with the scenario 4, considering a reduction in the number of boats, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



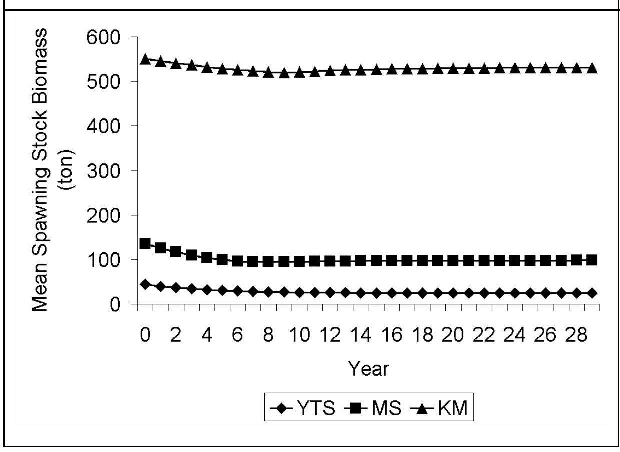
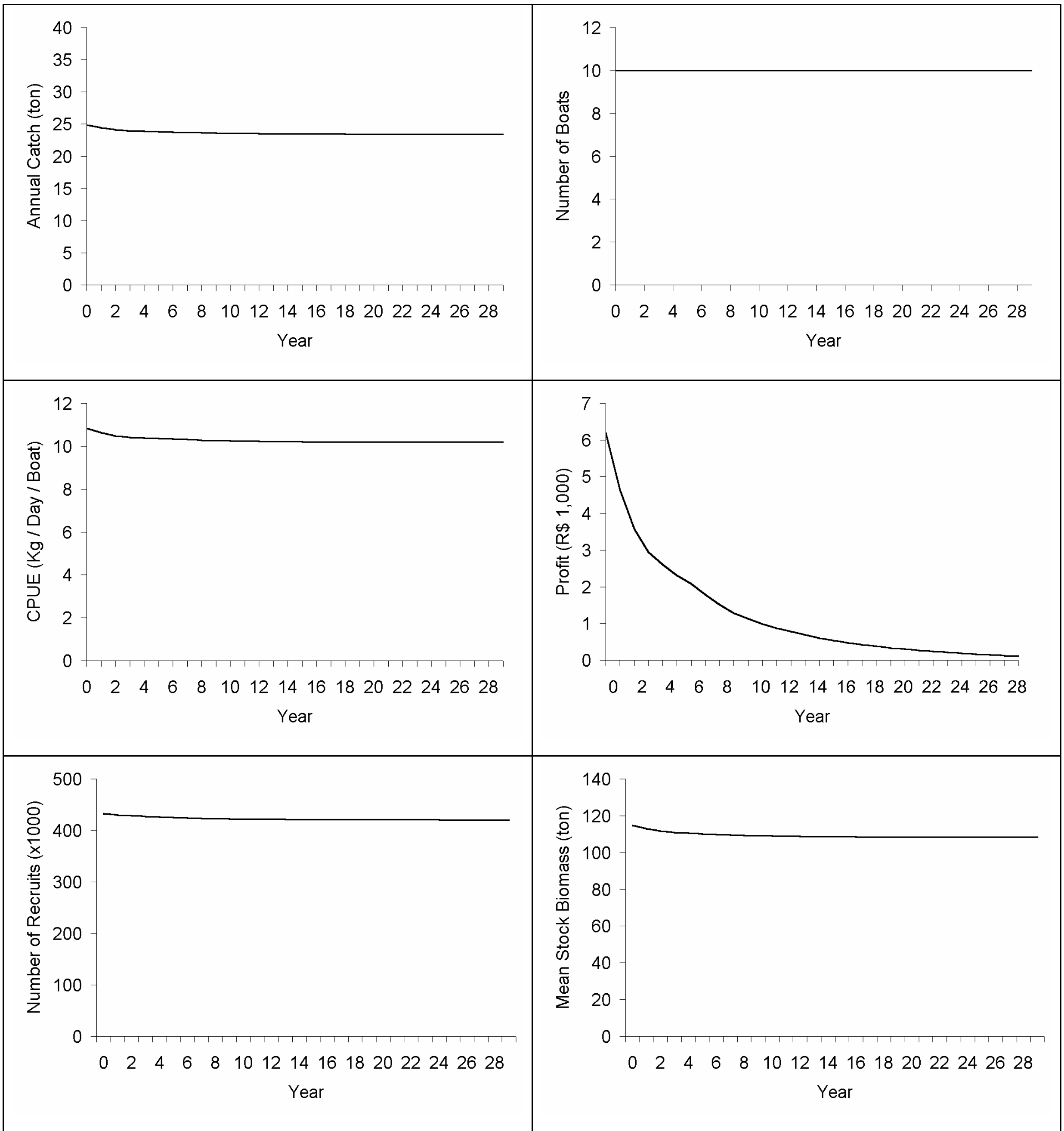


Figure V.12 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performances with the scenario 5, considering a reduction in catch, by 10%, of juveniles, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



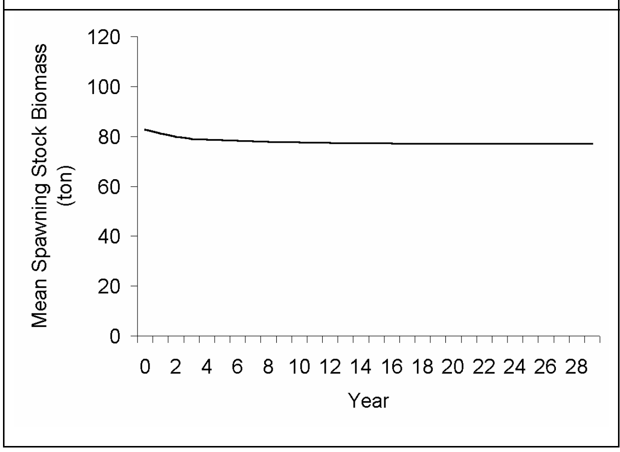


Figure V.13 – Gillnet fleet fishery and Spanish Mackerel stock performances with the scenario 5, considering a reduction in catch, by 10%, of juveniles, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.

with stable catches and profits, and all boats remain in the activity, which seems socially desirable. Nevertheless, the stocks caught by the hand-line fleet show a different trend, with decreasing recruitment (11.9%), biomass (16.3%) and spawning stock biomass (17.2%) presented by the yellowtail snapper stock, and increasing recruitment (4.5% and 1.8%), biomass (2.5% and 1.6%) and spawning stock biomass (2.4% and 1.1%) for the mutton snapper and king mackerel stocks, respectively, although at low levels. The Spanish mackerel stock, caught by the gillnet fleet, presented slightly decreasing trend after the implementation of the management measure, by 0.9%, 1.4% and 1.7%, for the recruitment, stock biomass and parental stock, respectively, which can be considered of not significant. Such results demonstrate the efficacy of the present scenario, and seem to indicate that the mutton snapper and king mackerel stocks would take advantage if this management measure would be implemented, and that probably the hand-line fleet more heavily exploits juveniles of these species.

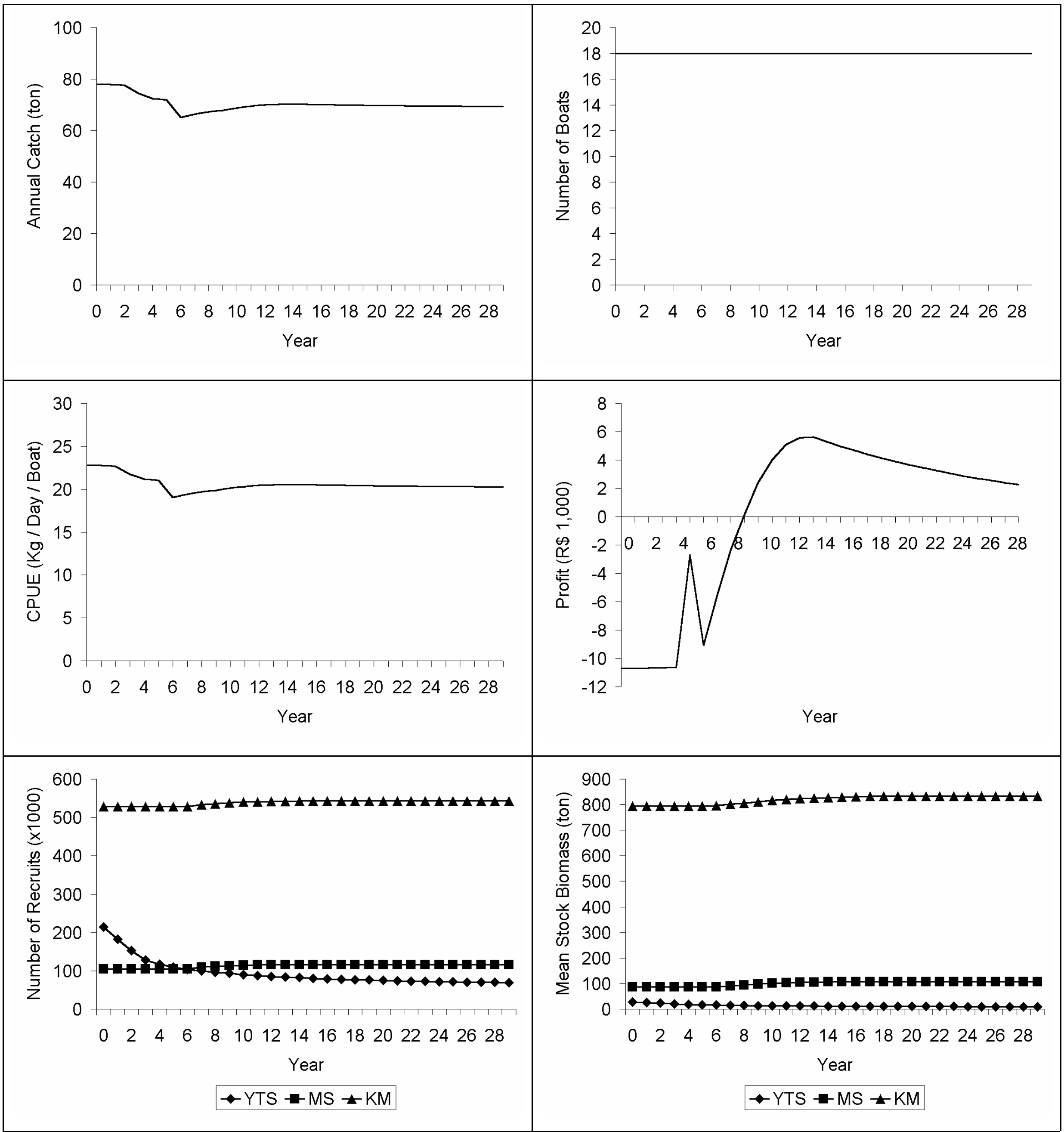
V.3.4.7 – SCENARIO 6 – IMPLEMENTING DIFFERENT MANAGEMENT STRATEGIES

From the aforementioned results, a sixth simulation was idealised, joining three scenarios: Scenario 2, reduction in the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, protection of young fishes, by reducing their catches by 10%. The proposed simulation is justified for two reasons: (1) the reduction of the price of fuel, through subsidies, is an old fishermen claim, and it was recently approved by the Brazilian Government a ca. 80% reduction in the price of fuel for motorised boats; (2) Scenarios 3 and 5 demonstrated to have positive effects on the resources as well as for the fishermen and administration. The proposal is to fix the total government incentive by the amount obtained that it should lose in concept of taxes through fuel subsidies for the analysed fleets, which totalled R$ 44,903.88.

A one-month close fishing, of course, would have other consequences that must be overcome by the administration. No production means no money to live for a month and the government must pay such a fenced season. A figure can be produced on the assumption that the government shall be obliged to pay, at least, the Brazilian minimum salary for those directly engaged in this activity. For the hand-line and gillnet fleets analysed, and according to the collected data, there are 73 fishermen and 28 fishing boat owners, or a total of 101 persons directly engaged in these fishing activities. The minimum Brazilian salary in the present analysis was considered equal to R$ 240,00, which means that if the Government pays a minimum salary for each of the 101 engaged fishermen and boat owners, the investment to implement such a biological fishing closure (Scenario 3) would be R$ 24,240.00. On the other hand, if Scenario 2 would be implemented (reduction by 80% of the price of fuel, which means that the Government is taking off taxes over fuel), the figures would be: the 18 analysed hand-liners consume 172.6 litres daily and 32,794 litres annually (190 days of fishing), whereas the 10 analysed gill-netters 114.3 litres daily and 26,289 litres annually (230 days of fishing), whose total annually consumption by both fleets is 59,083 litres; as the price of fuel utilised for the present simulation was R$ 0.95/liter, the total cost in fuel is R$ 56,128.85; so 80% in concepts of taxes would be R$ 44,903.08, what means a value 85.2% higher than the value calculated previously. This means that if Scenario 2 would be implemented, the administration would loose in concept of taxes R$ 44,903.08. On the other hand, if Scenario 3 would be implemented, the administration would have to pay R$ 24,240.00 in concepts of salary for each of the temporary unemployed fishermen and boat owners.

Thus, considering as subsidies only the difference between this value and the one calculated to Scenario 3 (R$ 24,240.00), the simulation joining these three scenarios will consider a total government investment as the one calculated for Scenario 2 (R$ 44,903.08). The assumption is that, if the Brazilian Government has already approved a recent law imposing the withdrawing of taxes from the fuel to benefit the motorised artisanal fishing boats, it is willing to pay for such a reduction in concepts of losing taxes. The proposal, thus, regarding that Scenario 2 would increase the exploitation level but that fishermen claim should be taken into account, is to use part of such subsidies to implement other more conservationist measures, that could have positive impact for all at the medium and long terms.

Such an assumption means that the new value for Scenario 2 is R$ 20,663.08 (that represents 46% of the total), in concepts of tax reduction, which means that the tax reduction would represent 36.8%, what makes the price of fuel to be R$ 0.60/l; for Scenario 3 the set value is the same (R$ 24,240.00, that represents 54% of the total), in concepts of payment of 1 month of the Brazilian minimum salary for the affected fishermen and boat owners; and for Scenario 5, no value is attributed for the definition of protected areas because, although a cost to implement and to control the access must exist, it was considered that, if implemented, shall be obeyed by everyone and controlled by fishermen organisations. Such a reduction in the price of fuel would represent now a 36.8% less of fisherman fuel cost and will represent an augment in profit of 29.6% for hand-liners, and 31.2% for gill-netters, which should still



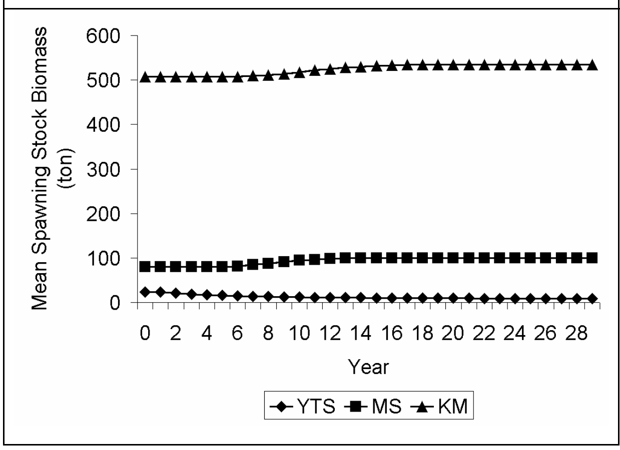
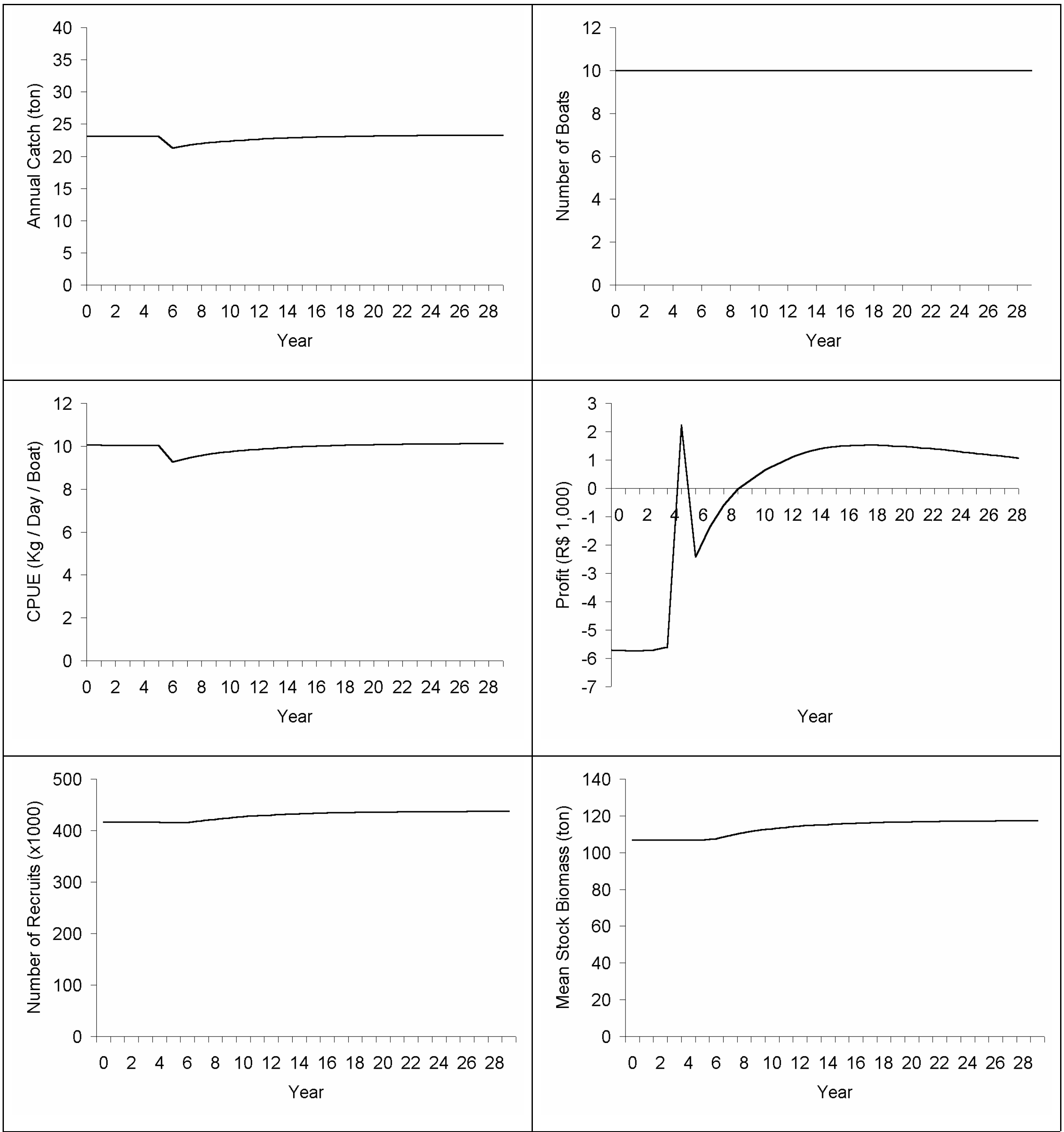


Figure V.14 – Hand-line fleet fishery and Yellowtail Snapper (YTS), Mutton Snapper (MS) and King Mackerel (KM) stocks performance, simulating the joint application of three management measures: Scenario 2, reduction in the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, reduction in the catch of juveniles by 10%, introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.



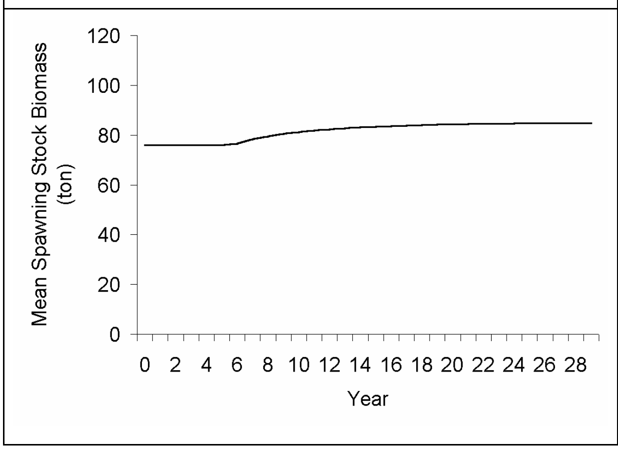


Figure V.15 – Gillnet fleet fishery and Spanish Mackerel stock performance simulating the joint application of three management measures: Scenario 2, reduction in the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, reduction in the catch of juveniles by 10%, , introduced in the fifth year of the simulation, in a 30-year projection and with deterministic simulation.

be considered a reasonable increase in profit. The results are shown in Figures V.14 and V.15, for the hand-line and for the gillnet fleets, respectively.

It can be seen, from the results shown in Figures V.14 and V.15, that decision making at implementing different management strategies could have positive results for all. The joining of a reduction of fuel price, which would satisfy fishermen wishes, with the establishment of a fenced season and the protection of young fishes, which should allow the reconstruction of the populations of the analysed stocks in the long run, would have positive effects. It can be seen that, from the sixth year onward, all boats remain actively fishing, with positive effects in total catches and in the CPUE's, with an increase in the projected period of 6.4%, and 9.3% for hand-liners and gill-netters, respectively; profits have an increase, by an order of 124.9% for hand-liners and 144.4% for gill-netters; and the stocks caught by hand-liners showed two different curves, from year 6 to year 10, and from year 11 to year 30, while the Spanish mackerel showed an increase trend for the whole projection, from year 6 to 30, with a more stabilised scenario. These trends for each analysed stock are shown in Table V.6. The results show that the yellowtail snapper stock suffers a negative impact, while the other stocks showed increasing trends. Such scenarios for the yellowtail snapper must be related to an increase in catch and profit from year 5 to 6. It seems that the measure of reduction in fuel price (Scenario 2) has an immediate impact on fishermen strategy, whereas the other two stocks only from year 6 onward, because a paramount increase in profit can be observed, which seems to stimulate an increasing effort, with negative effect especially for yellowtail snapper. The result is a decrease in profits and catches from year 6 to 7 towards equilibrium at higher and positive levels. Such a management strategy seemed to have positive impact for mutton snapper, king mackerel and Spanish mackerel stocks, while did not result any benefice for the yellowtail snapper stock, denoting such stock susceptibility to any increase in fishing effort, due to spatial and temporal stock variability, that is not analysed here, but must be of great concern as well as the need to implement more conservative management measures.

V.4 - DISCUSSION

The objective of the present chapter was to conduct a bioeconomic analysis of the Pernambuco State, North-eastern Brazil, hand-line and gillnet coastal fisheries, through the application the MEFISTO – Mediterranean Fisheries Simulation Tool Model for the characteristics and peculiarities found in such a region. Modelling such a fishery allowed the reproduction of the bioeconomic conditions in which the fisheries occur, and it was possible to carry out projections and simulations for alternative management strategies, starting from the current situation that better describes the local bioeconomic reality. It was then forwarded into the future, in a 30-year projection, with the purpose of analysing the behaviour of the fishery under different conditions, particularly with the implementation of different management measures.

Table V.6 – Percentage values of the trends in recruitment (*R*), mean stock biomass (*Bmean*), and spawning stock biomass (*SSBmean*) for the Yellowtail Snapper (YTS), Mutton Snapper (MS), King Mackerel (KM) and Spanish Mackerel (SM) stocks analysed off Pernambuco State continental shelf, North-eastern Brazil, with the Scenario 6, simulating the joint application of three management measures: Scenario 2, reduction in the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, reduction in the catch of juveniles by 10%, in a 30-year projection and with deterministic simulation.

	YTS		MS		KM		SM
	Year 6-10	Year 11-30	Year 6-10	Year 11-30	Year 6-10	Year 11-30	Year 6-10
R	- 10.3	- 23.2	+ 8.7	+ 1.1	+ 1.8	+ 0.6	+ 5.1
Bmean	- 14.0	- 27.2	+ 12.0	+ 5.9	+ 1.8	+ 2.0	+ 9
SSBmean	- 14.5	- 27.8	+ 12.6	+ 6.3	+ 1.2	+ 3.1	+ 10.6

The analyses permitted to identify the components necessary for applying a bioeconomic model for Pernambuco State coastal fisheries, based on the concepts of those developed through BEMMFISH[5] for the Mediterranean fisheries, that has MEFISTO as a starting bioeconomic model. Multispecies biological models with technical interactions are clearly of general applicability to Mediterranean fisheries and, as it is the case for Pernambuco fisheries, its feasibility and consistency was considered for the proposed analysis. Mackinson *et al.* (1997) emphasised in their studies the key point that economic factors are important driving forces in fisheries, but they must be incorporated into suitable biological models when modelling the dynamics of fisheries.

As mentioned in the *First Intermediate Report* of the BEMMFISH Project (Anonymous, 2002), and again applicable for Pernambuco State fisheries concerning the similarities with the Mediterranean fishery already stressed, the existence of data limitations that preclude the applicability of the more-detailed age-structured models has led to the incorporation of three types of biological sub-models in the BEMMFISH model: age-structured, partially age-structured and global models, in order to encompass all the situations, from data-rich to data-poor scenarios. Regarding the economic part of the model, although the general structure of cost-benefits is applicable to Mediterranean fisheries, it was necessary to proceed with some adjustments to Pernambuco State local fisheries reality and specificities regarding the commercial and the socio-economic structures, but brought about a series of interesting relationship aspects that allowed to run the proposed bioeconomic model, which focuses in the individual boat and its fishing capacity as the main economic agent. In this sense, and as stressed in the Report, it was necessary to specify a set of *fishermen's behavioural rules* that drive the economic part of the model. The model allowed to assess the problematic of Pernambuco coastal fisheries, to understand the local institutional and productive structures and to propose assessment and management measures that would lead to sustainable development of the fisheries, which allowed to identify the shortcomings of present assessments and the non-existence of management policies.

As stressed by Ulrich *et al.* (2002) considering the improvement of BECHAMEL Model (BioEconomic CHAnnel ModEL), developed by Ulrich *et al.* (1999), provided for the management of multi-specific fisheries, it holds true for the Pernambuco State bioeconomic fishery case study, whose benefits are twofold: first, it represents the first attempt to model a fishery including different fleets, gears and a diversity of species and life history characteristics, and with such a low level of previously available and reliable data; second it highlights the potential benefits of multidisciplinary and collaborative work. It was possible, thus, to adapt MEFISTO model that could accommodate both biological and economic considerations for the analysed fleets. It represents an improvement in the emerging, and yet scarce, knowledge on this fishing area without precedent.

During the process of analysis, the sources of uncertainty are certainly valuable to know, but together with the nature of uncertainty you get the understanding of the risks you must face during data collection and analysis. Hauge (2002) analysed the following characterisation in science for policy: measurement uncertainty, process uncertainty and ignorance. Uncertainty does not necessarily mean low quality in scientific information in policy context, and high quality does not require the elimination of uncertainty, but rather its effective management. Statistical tools calculate only measurement uncertainty, and the model’s robustness can be investigated by sensitivity analysis to some extend and thereby discover some of the uncertainty. But, it’s impossible to test every combination. In predictions one will face the problem to predicting surprise, both due to human and ecosystem behaviours. Nevertheless, must be understood that in the statistical model there are several assumptions that need to be fulfilled: (1) the collected data must fit a certain statistical distribution; (2) the collected data are not biased and there are enough to present the problem properly; and (3) several model assumptions.

However, parameter estimation remains uncertain for various inputs, and some basic hypothesis would deserve further validation. Problems of overlapping stocks still unknown and data collection on relevant economic indicators must be improved. The resulting heterogeneous level of existing data prevents the use of improved assessment methods, as no relevant long catch effort time series exists, and modelling abilities are limited by the less known elements of the fishery. An increase of this fisheries quantitative knowledge can be derived only from a constant comparison between available data, which allow inputs parameterisation, and the modelling process, which in return points out main gaps and deficiencies which deserves particular scientific and administrative effort (Ulrich *et al.*, 2002).

Ludwig and Walters (1981) pointed out the uncertainty about parameter values cannot be ignored in formulating management policy. These principles are valid even if observations are made with perfect accuracy. However, large observation errors, which are presented in most fisheries data, results in substantial uncertainty in parameter estimates. The parameter uncertainty frequently overwhelms effects of density dependence in the stock-recruitment relationship. In such situation, more information is required before a rational strategy can be determined. Then the first task of the manager is to obtain such information.

According to the defined inter- and intra-specific biological and technical, or technological, interactions, it seems that both types can be found at lower levels for the analysed fisheries, where the presence of one fishing unit displaces or interfere with another fishing unit’s operation. All these aspects allow the estimation of the positive or negative impacts of any management policy applied to one given part of the fishery on other related species and fleets, both in terms of catches and revenues. These interactions, however, are sometimes or poorly understood at all, especially in some small-scale fisheries, which qualitative informations are available, but lacked quantitative data to accurately analyse interactions among species and fishing activities involved in the whole fishery, because they all rely on a preliminary precise description and delineation of fishing activities. As mentioned in Chapter I and as stressed by Ulrich *et al.* (2002), new trends in fisheries sciences focused on integrating various intrinsic relationships within and between the different components of the fisheries, i.e. the resources and the fishers, whose relationships should be biological, economic or social.

For bioeconomic modelling purposes and analysing the behaviour of a stock, expressed by its abundance (number of individuals, biomass, etc.), it must be transformed to expresses economic behaviour. Thus, this biomass is transformed into money, multiplying the volume of biomass of the resource by its price per unit ($ per kilo). These and previous assumptions may indicate the existing inter-relationship between the biological and economic sciences for a joint study of natural renewable resources. As stressed by Willmann and García (1986), aiming to handle realistic values during an economic analysis, it’s possible to calculate the general level of recruitment by dividing the annual average catch registered during a period of stable effort by the yield-per-recruit calculated for the correspondent fishing mortality. In a broad sense, the biological stock herein studied seems to be fished at sustainable levels, considering the historical data series and the levels of recruitment and biomass presented, because the low number of initial recruitment estimated through VPA for the snappers may be related to the small individuals sample taken for the estimation of the von Bertalanffy growth parameters through length frequency distribution (529 for yellowtail snapper, and 252 for mutton snapper).

Otherwise, it must be emphasised here that, due to the high individual weight attained by the mutton snapper and the dog snapper, the mutton snapper surpass the yellowtail snapper total production in weight but, in number, the higher frequency for yellowtail snapper is evident. The total stock biomass and the spawning stock biomass appear to reach sustainable biological level, although fully exploited, because any increase in fishing effort would drive stocks to an unsustainable situation, and some, as the snappers, clearly demonstrates that if effort increases the stocks would be driven to extinction, as described in Chapter III, because total effort will decrease only when the increased cost makes it unprofitable. Effort must change with changes in the population size in other to keep an equilibrium, and, on the other hand, as pointed out by Pereiro (1995), a reduction of fishing mortality would increase the spawning biomass, and thus future recruitment, because a density-dependent effect on the increase of eggs on larval mortality is not probable, at least at low levels of abundance.

Fixed locally by those involved in the activity, the capital invested in the small-scale fishery in Pernambuco State is low to meet a necessary profitability to continue fishing, and generally indicates revenues lost. As stated by Anderson (1977), the level of effort that leads to the maximisation of revenues minus costs in every period will not maximise the present value of the returns to the fishery for two basic reasons: (1) the nature of growth rate of fish stocks; and (2) the difference in value of today's money of net revenue as against one sometime in the future, which can be evaluated using the interest rate.

Anderson (1977) then stated that the total revenue expresses the catches of a live resource multiplied by their price. The resource reacts due to an increase in capture due to an external factor - the fishing effort - by increasing its reproduction rate. At a stable level, when catches or mortality increase, the resource exerts a lower demographic pressure on the environment and will be able to reproduce more easily (more light, plankton, etc.). This increase is proportional to the pressure suffered by the resource, however beyond a certain point, if the pressure on the resource increases, then it would have difficulty in reproducing: slow reproduction against mortality, lack of density for reproduction, etc. From this biological maximum onwards, the reproduction level of the resource will be lower, and the resource will not be able to reproduce after fishing. If the catch rate continues to increase, the resource reaches its point of extinction.

On the relationship of cost and revenue, however, it seems that fishermen have developed a self-protection aiming to obtain profit, because as production falls after years of increasing effort they may understand that if effort rise even more, production would continue to fall and the resource shall be wasted. Otherwise, as point out by Bonzon (2000), low or negative profitability would usually indicate that fisheries resources are exploited in an economically wasteful way, often through excessive fishing capacity and effort.

The results presented show that for the current coastal hand-line and gillnet fisheries boat owners are accumulating losses, although at a very low levels. The explanation for this situation is two-fold: (1) as the informal trade and labour relationship denote for the absence of interest for borrowing money, the fishing production being the investors guarantee, from an economic point of view it seems that the boat owner borrow money continuously to pay for the expenses to go fishing, and this only stops when fishing production value does not cover expenses and investors can not support continued losses; (2) most of the local boat owners are middlemen and retailers, also owners of small fish shops, where they can make extra money. Nevertheless, this part of the fishery system, as well as the productive chain, was not analysed in the present study because MEFISTO is modelled to analyse the fishing activity.

This demonstrates one of the main characteristics of the artisanal fisheries, where market forces regulating prices affect the potential value of the catch. Such temporal heterogeneity of the economic potential was emphasised by Rueda and Defeo (2003) studying the spatial-temporal structure of a estuarine small-scale fishery, who emphasised that such heterogeneity determined that fishers had moderate probabilities of realising economic losses from their fishing activity, whereas the risk of falling bellow an undesirable threshold of rent expected was always high.

As it should be a manager or fisherman decision is not as important to understand that, in most of the cases, it is not possible to be certain about either future prices and costs or about the changes in the growth pattern in the fish stock, fishermen decision is to maintain the present level of effort and the guarantee of a present value of profit. When there is true uncertainty, the manager or fisherman must weigh the potential decrease in profit from changing effort against potential increase. As profit in Pernambuco State coastal fishing is very low this, of course, may limit such decision because the low level of profit shall indicate that it is not possible to cut down the current individual income, and the best policy is to leave things as they are to insure against a possible large decrease in profits.

Quoting Smit (1996)[54], Lleonart *et al.*, (2003) recognised that the potential fishing capacity of a boat can be measured as the gross proceeds of the boat. If the investment is related to the proceeds, the proposition is that the total investment in the boat (capital) is related to the fishing capacity (catchability). In accordance with this hypothesis, the concept is that a bioeconomic model, rather than a biological one, is justified and is the more appropriate to simulate the local fishery, since it is in certain measure self-managed by the fishermen through economic mechanisms.

Such trends can be clearly identified in Scenario 1, where a yearly increase in catchability of 1% and of 5% for the capital invested were simulated. Production not only falls, but also boats disappear, losses appear and the stocks become more heavily exploited, specially the yellowtail and mutton snappers that could collapse. In all cases these undesirable results stem from an open access nature of the fishery, because the increase in profits that these changes provide encourages changes in the level of effort. It is worth stressing that both before and after the change, the fishery is operating at a sub-optimal position. Pauly *et al.* (2002) stressed that the technological advances, and the resulting increase in catchability, is also the reason why fishers often remain unaware of their own impacts on the resource they exploit and object so strongly to scientist claims of reduction in biomass.

In Pernambuco State coastal fishery it seems that catchability can be regarded as a traditional-dependent knowledge factor, because e.g. the size and type of hook are determined by the target species and on the fisherman empirical knowledge. As local administration has no infrastructure to control the activity, such an empirical relationship prevails as in the determination of the technological process as well as on effort control. Although it is true that the number of boats is known by the administration, through boat licenses, the effort in terms of limited number and engine power is not controlled. What really occurs is a physical fishing effort limit, dependent on the autonomy of each fishing boat, because administration has again no control over the number of days a boat remains fishing. In Pernambuco it seems that the limiting factor is the re-invested capital to go fishing and boat autonomy.

As one of the main assumptions of MEFISTO is that fishermen always try to increase catchability as a way to increase production, as the mechanism to increase fishing mortality, because in the Mediterranean it is not allowed to increase nominal fishing effort, in the short-run technological advances will provide an increase in marginal catch, costs and revenue, thus leading to an impression that large increase in profit is worthwhile. Otherwise, Anderson (1977) shows that increasing productivity, through the reduction of effort and technological advance, will increase marginal cost beyond marginal revenue. Thus, in the long run, improvement in the productivity will not benefit the individual fisherman, and effort, defined in terms of its effect on the stock, will be increased but nominal effort and catch may increase or decrease depending upon the relationship between cost and revenue. Also, prices increases, like cost decrease and productivity improvements, will not help the individual fisherman and may even lead to a decrease in catch due to an adverse effect on the fish stock. When fishers behave so as to maximise profit, Mackinson *et al.*, (1997) found out that fish stocks that exhibit density-dependent catchability are at greater threat of collapse. When catchability is constant, catches decline with stock

[54] Smit, W. (1996) An economic approach to measuring fishing effort: application to a Dutch cutter fleet. *Marine Resource Economics*, **11**:305-311.

abundance, and so do profits. When catchability increases a high catch and hence high profit is maintained.

But, as questioned by Anderson (1977), how fast improvement in method should be introduced? He explain that this problem is faced by every industry, but in the case of fishery the common-property aspect adds a special dimension. Since no one owns the fish stock, a race to catch the fish may deny any participant the option of waiting until his old gear wears out. This means that: (1) perfectly good equipment is abandoned much earlier than necessary, constituting a waste of resources from an economic point of view. If the equipment cannot be put to alternative use, it should continue in service as long as the returns are greater than variable costs, or adopt new technologies too rapidly, there is some justification for restricting the introduction of new methods – but only long enough to allow existing equipment to wear out. Any permanent or long-term ban prevents maximum output and discourages innovations; (2) since each participant will be guaranteed a portion of the catch regardless of his method, it will obviously be to his advantage to keep using his old gear if it is earning enough to cover its variable costs. Only when he sees that increased profit can offset the costs of the new equipment will he have reason to introduce the new technique.

An example of mismanagement was what Pauly (1998) documented in a situation of rise and fall of demersal fisheries. A measure for the reduction in mesh size was implemented; this resulted in a large trash fish industry from the by-catch. The ‘trash fish’ catch increased dramatically because high value shrimp subsidises the harvest of fish at population levels much lower than would otherwise be economically feasible. That is, modern shrimp trawling operations led to a decrease in marketing of by-catch species and an increase in discards – thus high technology can add to the waste problem. And, consequently, this ensures a continued highly destructive by-catch, both by technological and economical means.

Fiscal and taxes exemptions are instruments of economic policy applied world-wide for the promotion and development of sectors and areas considered priorities. Unfortunately those instruments are poorly managed in Brazil, and when applied are allocated with questionable and manipulated criteria. In most of the cases the entrepreneurship with no economic feasibility and no biological sustainability had been systematically supported, resulting in insolvency and discredit.

A problem that poses when any regulation program based on taxes is imposed is that boats removed from the fishery are those having the lowest opportunity cost. This is especially relevant for the most impoverished and small fishing villages, where opportunities for other employment are minimal. The vessels that remain in the fishery any be capable of handling large volume of fish but it does not necessarily follow that they are the most efficient in term of opportunity cost. Therefore the program may result in a needlessly high total cost of harvest (Anderson, 1977).

Government subsidies, as simulated in Scenario 2 by the reduction of 80% in the price of fuel, showed that although there is no withdrawal of boat from the analysed fisheries, profit would only be attractive at a short-term basis and the resources are negatively affected, also threatening the snappers stocks. As stressed by Lleonart *et al.* (2003), building the stock to sustainable levels, probably given higher yield, implies overcoming a short-term crisis. The evaluation of the biological and economic consequences of the various alternative transition processes to bring about recovering a stock should be an interesting issue for the decision-maker. With such a measure, profit for hand-liners owners shall increase by an order of 37.4%, whereas for gill-netters owners by 42.5%, which is rather attractive and seems advantageous, but although higher profits can be reached and hence accrued, in the long run the whole fisheries can collapse, as shown in Figures V.5 and V.6. That is why, on the assumption of the results obtained from the model, such a measure should not be properly implemented.

That is why there is a growing awareness from the scientific community against subsidies. Pereiro (1995) pointed out that in a situation of overfishing, moderate increases of fishing mortality would lead to a small reduction of biomass and CPUE, which would be undetectable with the tools available to measure them, especially if they could be masked by natural fluctuations of recruitment and natural mortality. The opposite would occur with moderate reductions of fishing mortality, and, in both cases, it would be not possible to see in the short term the benefical consequences of moderate reductions in effort. According to Mackinson *et al.*, (1997), conducting a bioeconomic analysis that consider a constant CPUE model, when fishers fail to co-operate or are subsidised, profits accrue so quickly to fishers that they continue to invest in fishing even when a stock collapse is imminent.

A consistently measure not only shall be implemented, based on scientific advise, but also strengthen due to the above mentioned. There is not always that a powerful and biologically correct management measures responds for increasing production and profitability in a short-term basis. Biological fishing closure seems quite effectively, according to the obtained results, because it should allow the maintenance of a sustainable fishery from the biological and economic point of view. As already stressed, one-month fishing closure, of course, would have other consequences that must be overcome by the administration, because no production means any money and subsidies must be available.

Considering the law recently put into force by the Brazilian Government to take off taxes from the fuel to favour motorised fishing boats, another exercise may be realised regarding the Pernambuco State motorised artisanal boats. For instance, according to official data (IBAMA, 2003), there are 625 motorised boats, and based on the collected information, in average, 2.7 fishermen work on board, what means a direct employment of 1,688 fishermen. Considering, also, the owner and that owner is not a fishermen (there is a decreasing trend, but some boat owners are still fishermen), the amount of person directly working in the fishing activity is 2,313, what means that the total Government investment to implement the biological fishing closure (Scenario 3) in the State of Pernambuco would be R$ 555,120.00. On the other hand, if Scenario 2 would be implemented (reduction by 80% of the price of fuel, which means that the Government is taking off taxes over fuel), the figures would be: the average yearly cost in fuel for a hand-liner (R$ 1,462.50) and for a gill-netter (R$ 1,860.00), based on Table IV.2, is R$ 1,660.00; considering that 625 motorised boats will paid only 20% of the fuel price, each boat would economise R$ 1,328.00, in average as a concept of reduced taxes, which means that the Government would reduce its gate in concept of taxes by R$ 830,000.00, or an amount greater than the previous analysis by an order of 49.5%. That is to say that, implementing a biological fishing closure (Scenario 3) would benefit the fishermen, the resource and the administration, and the contrary holds true for the implementation of Scenario 2 – reduction in fuel price. It should be interesting to note that Pernambuco has a quite narrow coast line, which represents 4.8% and 2.0% of the Northeast Region and Brazilian littoral extension, respectively, and there is an estimation that the number of fishermen correspond to 4.7% and 1.4%, respectively, and the number of boats to 5.5% and 1.7%, respectively.

The Scenario 4 (deactivation of larger boats), although the measure that clearly present further favourable impact on the resource, by increasing recruitment, biomass and parental stock, is always a socially undesirable measure because, in the short-run, have a meaningful unemployment feeling and is difficult to be accepted by those affected (boat owners and the corresponding crew), although a value in concept of retirement is always foreseen. Nevertheless, it is a measure that should be put into force if resource exploitation levels are over maximum sustainable yields, because if fleet reduction is done properly, it should result in an increase in net profit (rent) from the resources, as predicted by the basic theory of bioeconomics.

Ulrich *et al.* (2002) consider that effort allocation depends on stock sale price and abundance. During an analysis of the English Channel artisanal fishery these authors pointed out that an effort reduction of the French Western otter trawlers fleet leads to an increase of biomass and thus of the catch per unit of effort (CPUE). As the effort of the other fleets not subject to such a management measure in the English Channel remains constant, consequently their catch increase and also their gross revenue. Their revenue increase depends on their level of technical interaction with the otter trawler fleet. These authors believe that, in all cases, a decrease of a fleet fishing effort induces positive benefits to other fleets catching same stocks. It was not possible to observe such a trend among hand-liners and gill-netters in Pernambuco, mainly because of different target species, but it seems that as hand-liners catch a higher variety of species and among such diversity there are those that are gill-netters target species, such as lane snapper and blue runner, a reduction in hand-liners fishing effort will benefit the gillnet fleet rather than the contrary.

When decreasing the number of boats, mean individual fixed and variable costs remain constant, whereas total fleet cost decrease. On the other hand, decreasing the individual number of annual days at sea only decreases the mean and total variable costs (Ulrich *et al.*, 2002). On the economic side it is difficult to predict how a change in the short-run supply of fish will affect its price and thereby the level of effort of the individual fisherman and the rate of entry and exit of boats from the fishery. Also, the introduction of new methods of fishing may, which could turn to modify catchability, alter both the operation of fishermen and the growth process of the fish stock, but to study this is an expensive and laborious task.

The Scenario 5, whose objective is the protection of young fishes, means, in general terms, to increase selectivity aiming at catching, as much as possible, mature individuals of the exploited stock or population. Recently, the European Union submitted a proposal to the Council for amending the rules currently governing Mediterranean fisheries, with the objective of ensuring the sustainability of fisheries. Developed in concert with stakeholders, the proposal aims to introduce new technical and management measures adapted to the specific features of the Mediterranean Sea. To face up to the alarming situation of several Mediterranean fish stocks, the Commission’s proposal presents five prioritised range of measures that strengthen the need of protecting young fish, increasing selectivity, because catches of young fish and discards of non-marketable species are excessive, which are world-wide phenomenon. In a context of multispecies fisheries, however, with several species being caught simultaneously, as it is the case of the Mediterranean and Pernambuco State fisheries, it is hard to rely solely on fishing gear selectivity, since some, like nets, take in large and small species without distinction. The proposal, therefore, may encompass a set of measures that all focus on the same goal, such as letting the largest possible number of young fish reach maturity to replenish stocks, as follow:

- *Improving the selectivity of gears*. The measure regards short and medium terms modification of fishing gear, specially nets, making them more selective and should be regulated;
- *Reducing the size of certain gears*. The measure aims at limiting the fishing effort they produce;
- *Providing further protection for coastal zones*, which serve as privileged nurseries for young fish. Certain types of gears used in such zones are harmful to juvenile populations in two ways: first, they catch young fish; and second, they destroy coastal habitats, such as coral reefs and estuarine zones off Pernambuco coast, which are known to be main nurseries areas for young fishes;
- *Creating protected zones*, to protect spawning beds or sensitive habitats. The purpose is not systematically to prohibit fishing activities in such zones, but to establish restrictions in terms of the season and the gears used, either locally protected areas, regarding a fishing community exploited region, or located within or beyond territorial waters, which encompasses many fishing communities or fishing fleets; and
- *Establishing minimum landing sizes* for species whose stocks are threatened or in a poor state.

The spatial definition of protected coastal zones, such as nursery areas and juveniles habitats, seems to have gone effectively towards a stable production, profit and stocks levels, hence socially desirable due to the maintenance of all boats in both fisheries, as denoted in Figures V.12 and V.13. Off Pernambuco coastal zones and continental shelf, knowledge on coastal reef and pelagic fishes nursery grounds are scarce or inexistent at all, but as these areas and juveniles habitats are generally located in shallow regions and estuarine systems, an effective measure should be to prohibit fishing activities in shallower regions, specially non-selective fishing gears, within a certain distance of the coast, e.g. in depth less than 20 m, where currently still fishing both fleets. But, such a suggestion needs to properly assess scientific information to support governmental decision.

The simulation of a sixth scenario permitted to diagnose that joining management measures should be an interesting issue and strategy to be taken into consideration by the administration, whose results may clearly favour the implementation of socially desirable governmental fishing rules. Simulations are generally conducted under a constant activity pattern hypothesis, but changes in this pattern might be also introduced, and the attempt was to create a favourable economic, biological and technical condition. The results showed that the fishery and the stocks performance simulating the three management measures jointly – Scenario 2, reduction in the price of fuel; Scenario 3, biological fishing closure; and Scenario 5, reduction in the catch of juveniles by 10% – allowed positive benefits if compared with the application of each one measure, with the paramount importance upon which the government investment was the same as Scenario 2 (which has negative impact on the stocks), either in terms of subsidies – loosing taxes – or direct payment of salaries, having improved stocks rebuilding if compared with Scenarios 3 and 5 alone, the exception being the yellowtail snapper. The results showed that yellowtail snapper stock is more susceptible to fishing pressure, which could be related to the actual level of exploitation and spatial and temporal variability of stock size and abundance, because increasing effort due to increasing revenues could put such stock in risk of collapse.

Based on Anderson (1977) and on the assumption of the results obtained, the relationship between cost, revenue and effort for individual boats and the fishery as a whole of Pernambuco State coastal fishery, as well as the involvement that makes fisherman believes in continuing increasing profit, may be described by the total amount of effort for the fishery as a whole, and each boat shall make higher than normal profits when average revenues are greater than average costs. At this level, fishermen are motivated to increase effort, or other boats may enter the fishery, and the resultant increase in effort is lower catch per unit of effort. Each boat reacts to this lower return by decreasing effort to where return per unit of effort is again equal to the marginal cost. The lower return will cause profits per boat to fall even after the adjustment in its level of production. This increasing effort and the simultaneous reduction of effort per boat will continue as long as profits exist. The final equilibrium occurs when such an increase has moved down the supply, return per unit of effort will be lowered, and so in each boat return is equal to the marginal cost; the minimal average total cost. And so while each boat makes a normal return, there will be no excess profit to stimulate entry. As effort produced by each boat falls, total effort increase, because at the new equilibrium a larger number of boats, each producing a smaller amount of effort individually, exerts a greater amount in total. Each boat produces this effort at the minimum possible cost. Therefore, while the unregulated fishery may be economically inefficient in putting forth too much fishing effort, the amount it does use is produced at the lowest possible cost. This assumption, however, is valid because, in a straightforward manner, the fishery under consideration is a small part of the total market for fish and that its operation does not affect the price.

From the results analysed and on the biological and economic point of view, the local condition denotes that fisherman strategy to increase profit is always dangerous for the maintenance of the bioeconomic equilibrium that seems to effectively occurs in Pernambuco analysed fisheries. Thus, administrators and decision makers must face with the problem that any intervention must be carefully put into practice, because if erroneously implemented negative impact should occurs in the short run, and it is not clear what will be the resource response to other management measure afterward.

V.5 - CONCLUSIONS

- The MEFISTO model, with some adjustment, demonstrated to be appropriate to simulate management strategies for Pernambuco State coastal hand-line and gillnet fisheries. Although it became clear that the model, for the found reality, has some limitations regarding labour costs and owner share, which had to be previous calculated and the value entered into the model as an adaptation of the strategy found in the North-western Mediterranean, and that the available parameters did not fit the model requirement for a stochastic simulation, such aspects were not a limitation. On the other hand, it was possible to run the model and present the initial condition of the analysed fisheries and to proceed with different events to provide scientific and technical information for the local fishermen and boat owner and scientific community, and for the administration and decision makers;
- The analytical equations and the numerical procedures for the implementation of the model based on the conceptual bioeconomic model developed for Mediterranean-type

fisheries and numerical methods and relevant algorithms ancillary to bioeconomic fisheries modelling were neither reviewed nor conducted, because it was not the scope of the present chapter and thesis. Otherwise, all the required parameters were checked for their validity using the own model tools, aiming at providing a picture as much real as possible of the analysed fisheries;

- It was possible to figure out that, apparently, there is a biological and an economic equilibrium of the fisheries, as it was already pointed out in Chapter III (fishing biology) and Chapter IV (the economics of the fisheries), or the initial condition. Nevertheless, the results confirmed that any increase in fishing effort, translated in an increase in catchability or economic measures, such as subsidies, could drive stocks to an overexploitation condition, clearly threatening the snappers stocks, especially the yellowtail snapper;
- Although it may sound counter-intuitive, it can be assumed that a bioeconomic equilibrium for Pernambuco State hand-line and gillnet fisheries exist, because fishing is still active even with the demonstrated losses, whereupon in the long run an unsustainable condition would prevail, with the deactivation of boats, causing the undesirable situation of unemployment and lost of investment;
- Although is neither in the scope of the present work nor of MEFISTO model, that was the analysis of the fishing activity, the fact that most of boat owners being engaged in the commercialisation process of the fishery system, as middlemen or retailers, may explain how they can support fishing losses and maintain their boat fishing; and
- The conducted simulations were the first attempt to project management measures towards the future of the fishing activity and demonstrate that many technical, economic, biological or all together measures can be applied, with different implication for the fishermen / boat owners and the resource. The best management strategy seems to be joining the effects different conditions that would satisfy the claim of groups of interest in the activity, and would provide populations rebuilding, such as: (1) *economic subsidies*, at a level that permit to reduce boat owners costs; (2) *biological measures*, by the reduction of fishing effort by defining temporary fishing closure; and (3) *technical measures*, such as the creation of protected fishing areas, specially those known as nursery grounds.

FINAL CONSIDERATIONS

• *GENERAL DISCUSSION*

The decision process consist of a permanent confrontation between internal factors, represented for a set of conditioning linked to the structure of the production unit and its family, and external factors, represented for the local, regional, national and international socio-economic and political context. Experiences and information interaction may generate expectations and uncertainties that many times are difficult to manage. The planning process requires the understanding of actions in progress and the main difficulties to reach the objectives. These actions must be followed up by those evolved in the activity, preventing and correcting possible distortions, through the analyses of the operational, economic and financial performance of the fishermen organisation. This procedure will allow taking decisions for the convergence of objectives to fishery management and the sustainable development. As pointed out by Lleonart *et al.* (1999c), the evaluation of the biological and economic consequences of the various alternatives transition processes to bring about recovering a stock should be an interesting issue for the decision-makers.

Gulland (1971), analysing trends and extrapolation of catches for the world fisheries, mentioned that after an estimation of the potential yield of fisheries, at the corresponding period in the fisheries on particular stocks, when the limited potential from them was approached, crises often occurred. These crises have been limited in severity by their local effect and by the diversion of fishing to other areas and other stocks. An analogous crisis in the fisheries of the world as a whole could be much more severe because of the impossibility of such diversion. The world situation has been comparable to the expansion phase of a fishery on an individual stock; so long as the total resources have not been greatly affected, and many stocks remain unexploited and only slightly exploited, the probability of finding news stocks to exploit has remained high and the expansion has continued. If, however, the supply of new stocks begins to run short, then, as for the individual stocks, the failing catch per unit effort on old stock may no longer be balanced by diversion to new stocks. This may well result in a rapid slowing down in new fishing activities, as fishing ceases to be attractive. The result may be a quite sudden end to the period of expansion, and the beginning of a period when world’s catches change but little.

Management of a fishery should be mostly based on the historical evolution of the fish population involved. It does not make any sense to guide management by immovable criteria, such as for example, to consider fish population as a fixed engine generating biomass at a given rate (Beverton and Holt, 1957). Fish population dynamics is controlled by factors that can change with time, consequently changing recruitment, growth and natural mortality after the recruitment phase (Pereiro, 1995).

It is of great concern that the low availability of scientific information from the artisanal coastal fishery of Pernambuco State, North-eastern Brazil, is low and, as stressed by Freire and García-Allut (2000), may be considered equivalent to many new fisheries around the world and there is an urgent need to establish lines of actions for assessment purposes, for the incorporation of new source of knowledge, and an in-depth analysis of the mechanisms that regulate the population dynamics of the species of interest. Improvement of data collection, qualitatively and quantitatively, must be a jointly effort of administration, scientists and fishermen, because misreporting and data poor system may not reveal and reinforce measurement errors that, according to Ludwig and Walters (1981), may have two effects upon the assessment of stock and recruitment: (1) the parameters estimates may be inconsistent, as a result of hidden correlations in the regression equations; and (2) the amount of information available may be overestimated.

One overall followed principle, concerning the objective of the present thesis, is the utmost importance of the understanding that an optimum management system does not exist in the context of real fishery exploitations, that is, a system that maximises the objectives pursued through regulation at a minimum cost for all, but what seems reasonable is to seek for the development of an optimum management system for the context of each fishery under study (Franquesa, 1997). Another is the comprehension and belief of the importance modelling has for fisheries management and that, complying with this, the deficiency and uncertainty any model has to forecast the future must be envisaged, especially future recruitment.

As stressed in the Introduction, the conduction of a bioeconomic study is not straightforward, and the present one was based on the objective to apply the bioeconomic model MEFISTO (*ME*diterranean *FI*sheries *S*imulation *To*ols), developed in the scope of the North-western Mediterranean Sea fisheries, which allowed significant contributions for the understanding of the dynamics of the coastal fishery, and the identification of the main problems to be solve:

- The necessity to define and urgently implement regulations and management measures for the coastal fishery;
- The necessity to remove the pressure/effort on the traditional fishing stocks and to diversify the coastal fishing activity for other resources and/or fishing areas; and
- The necessity to invest in the coastal fishery.

The starting point was the basic idea that the integrated use of a bioeconomic model should afford significant contributions to the investigation and cooperation for the development of small-scale coastal fishery in developing regions, especially to assess and follow on the dynamics of fleets and fishing resources, aiming to propose and adjust management measures in accordance with local and current realities; the technical and economic multispecificity's in which the activity occur; and to propose strategies for the diversification of the activity.

With the approach of scientific method adopted here nothing can be proved, but a hypothesis can be rejected when it is shown with a high degree of probability to be false. When a rejected hypothesis is part of a more extensive model, one must accept the observed limitations of the applicability, or the involved part of the model must be broken down and advanced in another shape (Ursin, 1967). Thus, the identification of those main problems to define management strategies to local development, allowed the definition of the hypotheses that supported the present study:

- *The importance to apply and adequate bio-economic model for the management of the small-scale existing fishing activity*;
- *Most important commercial fish stocks are depleted, with low biomass levels, and there is a necessity to diversify the existing fishery*; and
- *The small-scale fishing activity must be a priority of governmental policies for the sustainable development of the fishery sector.*

Although the objective of the present study is the bioeconomic analysis of a specific coastal fishery, when deal with a natural resource that is under fishing pressure one must endeavour to be aware of the impact such activity plays on the surrounding system, if management and regulation measures is to be applied. The discussion, of course, will not deepen on such impacts, but the aim is to demonstrate the awareness one should have for the adequate resource allocation and management. Through the conduction of such a study the emphasis, thus, was to show that the resource has its time. The proposed study focused on the existing catch strategy, to establish a plan of catch adjustment, through the knowledge on the stock size and condition, which would make possible the establishment of biological, economic and technical measures, aiming at to make possible the participation of all the involved in the fishery. Therefore, as suggested by William and García (1986) before adopting any decision related to fishing regulation, on the basis of the utilised model, it must be evaluated the possible effects that a supposed close system do not happen, because according to Myers (1995), we are good at analysing problems when we recognise their existence, but we are sometimes less skilled at reaching out to new problems before they reach out to us.

It is well known that overexploitation usually leads to the economic collapse of a fishery rather than a reduction in biodiversity, because extinction of marine species is thought to be rare. It seems to be true if we consider the coastal biodiversity off Pernambuco State that, since long, no changes could be assessed on the composition of catches and total production, but fishing activity continues to be carried out in spite of fisheries production decline and low income taken, because as it is true throughout the world, also off Pernambuco there is too many boats chasing too few fishes.

According to Ludwig *et al.* (1993), there is a remarkable consistency of resource over-exploitation, often to the point of collapse or extinction, due to the following common features: (1) wealth or the prospect of wealth generates political and social power that is used to promote unlimited exploitation of the resources; (2) scientific understanding and consensus is hampered by the lack of control and replicates, so that each new problem involves learning about a new system; (3) the complexity of the underlying biological and physical systems preclude a reductionist approach to management, and optimum levels of exploitation must be determined by trial and errors; and (4) large levels of natural variability mask the effect of over-exploitation, because it is not detectable until it is severe and often irreversible.

In the specific case herein analysed it could be envisaged that management measures is far from being applied, thus the fisheries are neither managed nor mismanaged, although some conservationists measures have been successfully implemented. There are a series of laws and regulations but lack of sufficient staff and basic structure for the control of the regulations cannot be adequately enforced.

However, as stressed by Garizurieta (1997), it is well known that uncertainty related with fisheries informations and the dynamics of exploited fish populations, and the oceanographic factors that affect them, constitute an obstacle for an effective fishery management. The fishing impacts on the marine environmental may be profoundly affected by, and often screwed up with, effects of environmental, biological and human factors. Since the overall comprehension on such interactions still very limited and many causal nexus are and always will be difficult or impossible to prove scientifically, the management of exploited populations must be conservative and based on precautionary approaches. In other words, to be about reducing uncertainty and improving knowledge on the dynamics of exploited fish populations and on the ecosystems where they belong to, and to opt for fishery management secure alternatives.

In a multi-specific fishery, a single mechanism to preserve a particular stock must, involuntarily, facilitate the destruction of another one, being it the target stock or even the most susceptible to fishing pressure stock, and, for Lleonart *et al* (1999a), the solution to such a problem is to minimise fishing impacts in a controllable way. The challenge is that regulation systems are based, mainly, in the fishing mortality, but its effects on the resource and economic and social costs are extremely diverse. Although externalities must be of concern during a bioeconomic study, it could not be well identified, however it seems to occur at the levels of crowding and gears, specially in the gillnet fishery, whose higher fishing effort occur at shallow regions off Pernambuco continental shelf, may induced a higher risk to stocks sustainability due to change in the population structure.

The seasonal variation of the pattern distribution and the consequent level of relative abundance of some fish species commonly present a close association with the seasonal variation of environmental conditions. Environmental changes and fish abundance variations, which are difficult to explain just by the effect of fishing as time series become longer, cannot be analytically related, but it is important to be aware that it is unlikely that a marine system in a steady state can be found. Pereiro (1995) pointed out that fish abundance can decrease to levels similar to those known as “collapsed” or “failures” without heavy fishing pressure, and, reciprocally, it could be expected recoveries of fish stocks from very low levels of abundance due solely to natural factors, which means that fish stock would change in abundance over time, even though fishing mortality remains constant. Although fishing can reinforce natural changes, and, on some occasions, significantly affect natural trends, it would be very difficult to observe a fish stock affected by fishing mortality more than it is affected by natural mortality. For Tegner and Dayton (1999), with better tools, precaution and adaptive management, an approach based on maintaining healthy ecosystems provides realistic prospects for sustaining fisheries in variable environments, as well as protection of biodiversity.

It is remarkable to observe the strength of the conviction of groups exploiting public resources that their exploitation is an unalienable right, even if they are destroying other resources that take much longer to recover than the target resources. Considering the fact the most of these resources belong to society as a whole and are being managed by representatives of society, all the resources, consumptive and non-consumptive, should be managed to protect the most vulnerable component. Because this often means a reduced profit, such logical management is fought at both political and private levels. Finally, considering that there is a significant profit potential, there is no logical reason why society (either via the government, conservation groups, or even private citizens) is responsible for the burden of proof (Dayton *et al.*, 1995). But, it must be understood that to allow population to grow, harvesting must be cut down, thus revenue in the current period must fall.

A consistent fishery politics is a real necessity mostly in a developing country like Brazil, and the modelling and optimisation techniques discussed can be used to make it possible. For example, as stressed by Paiva (1986), simply seeking new well defined fishing stocks and/or to start fishing others hence under-exploited, hardly will compensate fall in production due to overfishing of the traditional fishing stocks, that support today fishery, because the potential of fishing production, as for each exploited stock, is dependent of fishing gear selectivity and fishing effort, and the increase in mortality fishing rates will always lead to the reduction of the exploited part of the stock which, consequently, alter the age class composition, and Dayton *et al.* (1995) suggested that proper management of any specie, including most large animals, must ensure that an adequate year class is available before the reproductive adults are harvested. Most fishermen still tend to regard scientists as opponents who are trying to limit their ability to earn a living, rather than partners in ensuring that their industry has a future, hints to a more productive relationship are beginning to emerge. Fishermen must become more involved in the scientific assessment of stocks.

A regulation program should be flexible enough to permit easy adjustment to fluctuating market and environmental factors. Notwithstanding the importance to regulate any given fishery, the proper goal must be to harvest the optimal amount of fish at the least possible cost. The institutional arrangements of the regulatory process must be flexible and designed to make resources released from the fishery available for other work in the economy. They should also motivate those who remain in the fishery to introduce improved technologies at the proper rate. The costs of instituting, operating, and enforcing the program must be justified by the potential benefits from regulation. Differing biological and economic conditions will dictate varying sets of regulations: which method should be chosen in a given case depends upon its relative capacity to solve the particular problem at hand.

The legislation that regulates labour relationship and social benefits are spread in many legal instruments, which generates difficulties for their application aiming at safeguarding boats fishing operation and the job of those actors engaged. Also, there is dissociation among many measures taken by governmental agencies, some restrained and others stimulating the same activity, revealing a lack of policy to define adequate legal and management measures. Many governmental, at national, state and municipal levels, and non-governmental agencies develop actions with no adequate co-ordination and management, leading to inefficiency, redundancy and conflicts, and even the recently State definition of resource property right has not been well applied due to lack of infrastructure to enforce control measures.

On the other hand, the problem in unregulated fisheries is that exploitation of the resource is limited only by the capacity of the fishers. Considering thus the artisanal fishery, it must be emphasised that the high dependency on the market may induce fishermen to exploit fishing resources above its natural reproduction capacity, because free market generate inexhaustibility and the management system must make fisheries sustainable and profitable, generate employment, and contribute to global food and social security. Defeo and Castilla (1998) highlighted the importance of constructing long-term databases in artisanal fisheries in order to improve stock assessment and to understand exogenous factors (e.g., market) influencing the dynamics of the stock and the fishery.

Otherwise, for Mackinson *et al.* (1997), many identical fishers try to benefit from exploitation of the resource, behaving at one of the three following aspects: either (1) succeeding in putting in place a co-operative arrangement, and thus achieving maximum economic rent; or, (2) failing to do so and end up at the bionomic/open access equilibrium, where economic rent is zero; or (3) again failing to co-operate, but continue to be able to increase fishing effort owing to the allocation of some form of subsidies. According to Seijo *et al.* (1998), the open access regime, although officially prohibited locally prevails because policing effort is extensive and ineffective, due to restricted means for State intervention, making that a non-enforceable rights becomes an empty right. This, combined with high uncertainty levels in stock magnitude, determines that a fisher may not benefit by postponing a catch with the expectation of catching a larger and probably more valuable fish later, since the fish is likely to be caught in the meantime by another fisher. The sustainable yield of a fishery, given certain temporal preferences of resource use, will be an attainable goal only when the number of fishers is limited by some kind of effort regulation and act in concert.

In the present study, the fact that the low productivity of the working force was due, partially, to the limitations and characteristics of the fishing stocks off these coastal areas was not analysed for its consequence but identified, which allowed to raise the assumption that it may be of great benefit for the local analysed stocks. Hence, for these stocks, the small-scale fishing seemed to be and still the most appropriate productive organisation. The industrialised process seems to be supported by the view that larger vessels clearly achieve higher earnings than the smaller one, trying to simplify the relation of earning capacity and gross tonnage. The understanding is that size is not significant, but efficiency. Many smaller vessels earn substantially more per gross tonnage than the larger one. Further data on average crew size would show that larger vessels have more GRT per crewmember and therefore earn per fisherman are often higher, but the results showed that higher expenses incurred by larger vessels lead to economic inefficiency and, in the long run, these vessels may disappear from the fishery if management measures would not be implemented.

It was observed, after the conducted analysis, that costs are very high and the small population size results in prices high enough to cover costs. Since boat owners all seem to meet their costs, there is no incentive to reduce effort and fish population size will remain low. Such an exploitation pattern seems to behave like an open access fishery system, and one of the reason that can explain such condition is that producers care only what their return to effort is, and are not concerned with the return to the fishery as a whole.

The observed fact that many fishermen eke out a scanty living may be attributable, then, to the open access nature of the fishery, combined with the fact that initial high returns may be followed by hesitant and dilatory adjustments in population and in entry and departure. Fishermen, either boat owner or true fisherman, may be a gambler waiting for the big catch that never comes, due to the limit size of the exploited stock and the existing applied effort. One crucial but reasonable point, is the fact aforementioned that such low income is the limiting factor that banned the increase in fishing effort, either not encouraging new entries or limiting re-investment to increase fishing effort through the increase of catchability (specifically the numbers of hooks, area of nets, etc.), what seemingly denote that these fleets had found an economic equilibrium point. Many scenarios can be constructed, but the key factor is the need to define a policy based on local reliable information and the world-wide perspective of the precautionary approach and that, as already stressed, government must not postpone to take management measure arguing that locally data poor collecting system and assessment is an stumbling block to take action.

It can be observed, from the supported literature and the results obtained that not all aspects of the Pernambuco coastal fishery are entirely unfavourable. Besides the relative biological and economic equilibrium found in the hand-line and gillnet fisheries, although extremely fragile, many programs, directly or indirectly co-ordinated by the responsible government agency are being conducted by research institutions, such as universities, and non-governmental organisations, with good results and well expected others. Potentialities are not encouraging, but sustainability and biological and economic improvement should be achieved, if fishery shall be well managed, bringing about society welfare.

This can be translated by a brief summary made by Crutchfield (1987) from the, according to him, two seminal studies that form the basis for most of the analytical work on fisheries economics (Gordon, 1954; and Scott, 1955b), which can be thus described:

- Fishing activity will expand or contract in response to profit or losses on the part of the fishermen;
- In the absence of regulation or controls on fishing activity, a bioeconomic equilibrium will be achieved where the marginal vessel just covers factor costs and the total catch is equal to the surplus production of the fish stock:
- At such an equilibrium, economic rents are dissipated since the marginal product of fishing effort is less than its social marginal cost; and
- Therefore, an economically efficient fishery would be operated as if it were owned by a sole owner; one who maximises the economic return to fishing activity.

It must be admitted that the perspective for the development of the fishing activity at Pernambuco State, North-eastern Brazil, must be based in the actions that can bring significant changes in the practices of management and the priorities of investigation. Such actions require the increase of activities destined to the scientific research and the control of the fishing operations, since the problem of lack of scientific information is specially worrying for the management of the activity and, in that case, prudence is the best way for decision makers and to struggle against uncertainties. Thus, the main actions, adapted from Anonymous (2001) and Mattos *et al.* (2001b), are:

- To strengthen institutional structure, with defined objectives and guaranteed funds, which will make possible the legislation enforcement at all the levels;

- To generate and to transfer new technologies and to train human resources in agreement with the local and regional peculiarities and demands;
- To consolidate functions of scientific advising, with methodological patterns for stock assessment (e.g. bioeconomic fishing analyses);
- To increase the applicability of management measures, with political support;
- Better control on fishing fleet growth capacity, with restrictions of subsidies that, in most of the cases, results hardly in the increase of fishing effort;
- To increase and encourage the participation of users, groups of users and fishing communities/societies in the management process;
- To create appropriate management of the fishing resources, in local and regional levels, which shall enable the development of models adapted to the peculiarities of each community;
- Maintenance and strengthening of social and economic characteristics and diversification of coastal fishing activities;
- Control measures at all levels of the productive chain; and
- Reduce environmental degradation in coastal areas and/or fishing areas, and the level of uncertainty in status and the economic risk associated.

Finally, it can be stressed that certainly much more work is needed before a bioeconomic study of the Pernambuco State, North-eastern Brazil, coastal fishery can be perfected, and there is no claim that either the specifics models that were used for the analysis of the collected data, considering all the mathematical approaches, or the estimated equations that are derived from them are the last word on the subject, but with some adjustment and careful analysis it was possible to obtain important results and informations for the regulation and management of such a fishery.

Although, from a biological and economic point of views it seems that the Pernambuco State coastal fishery has reached an equilibrium, the stock susceptibility and the institutional and productive fragility of the fishery system may indicate that a critical state is evident due to the heavy fishing pressure that the most important commercial fishing resources are submitted, leading to economic inefficiency, since it is not the result of planned actions. In agreement with Freire and García-Allut (2000), these problems are linked to the fact that the biological and socioeconomical paradigms in which the management policy is based are not adequate for this artisanal context, and with Ludwig *et al.* (1993), the resource problem are not really environmental problem, but human problems that we have created at many times and in many places, under a variety of political, social, and economic systems.

From the raised hypothesis we can conclude that the use of bioeconomic model to the assessment of the hand-line and the gillnet fisheries showed to be a very important tool for the administration, which may have informations based on scientific advise for the definition and implementation of management strategies for fisheries development; for the scientific community, which may improve knowledge on the population dynamics of the fishing stocks off Pernambuco and the dynamics of fishing fleets; and for the fishermen, which can join their empirical knowledge with the models outputs informations to improve their fishing strategies.

From the results obtained there is no evidence of commercial fish stocks depletion, inasmuch the target hand-liners and gill-netters species are considered, but that there is a necessity to diversify the existing fishery, because any increase in fishing effort would turn stock level to an over-exploitation condition, maybe with irreversible conditions for some of the stocks analysed. Such a biological and economic equilibrium should be maintained, nonetheless with the implementation of management conservation measure that encourage the reduction of the current level of effort, jointly with measures that can bring about fishermen claim, that is to say the jointly implementation of biological, economic and technical management measures.

According to Barros (2000), the greater the number of companies engaged in the coastal fishery, the greater the potential profitability of companies exploiting the oceanic resources. The externality produced by the coastal segment seems to be greater toward the oceanic because the effort of co-ordination is less than the one required for the oceanic fishing. Effort to increase productivity and profitability in these two segments means to establish different measures and mechanisms. Thus, for this author, notwithstanding a higher investment required by the oceanic fishery, this segment should generate greater return per job in Pernambuco, due to the overfishing of the coastal resources. Otherwise, the volume of the catches off Pernambuco continental shelf was not sufficient to make feasible the oceanic activity, due to coastal fishery stagnation, and any increase in fishing effort shall jeopardise coastal stock.

It became clear that the small-scale fishery activity must be a priority of governmental policies for the sustainable development of the fishery sector, showing to be *economic viable*, because with small investment in concept of subsidies together with management measures the sustainability of the coastal fishery can be reached; *desirable on the social point of view*, considering the amount of agents direct and indirectly engaged, and *ecologically adequate*, due to the low level of impact generated.

• *GENERAL CONCLUSIONS*

1. A description of Pernambuco State, North-eastern Brazil, coastal fishery was provided, which allowed the characterisation of the fishery system, the administrative and statistical features for data gathering, as well as the productive chain, and the visualisation of the fishing activity and the biological resource;
2. Biological and economic information were possible to collect through the official governmental institution and from two fishing communities, one located in Recife City, the capital of the State of Pernambuco, main base port of the gillnet fleet, and the other in Jaboatão dos Guararapes City, at the State southern region, main base port of the hand-line fleet;
3. Length-frequency distribution was used to estimate length-at-age of the studied species, and although not the best method, showed to be adequate for the analysed sample and to conduct a virtual population analysis (VPA), to rebuild the studied populations;
4. From the biological point of view, the mortality vectors indicated that the yellowtail snapper, mutton snapper, and females and males Caribbean sharpnose shark stocks are submitted to high levels of fishing effort, and the exception being the male stock of the Caribbean sharpnose shark, the two snappers' species and the female stock of shark are overexploited;
5. The VPA results denoted that snappers should have a stock-recruit density-independent pattern, because stocks recovering with decreasing fishing effort would probably occur. On the other hand, increase in the current level of effort would collapse the Caribbean sharpnose shark population, even for males, denoting the susceptibility of this species to fishing pressure and that there are density-dependent stock-recruit relationship;
6. The results obtained suggest that the studied stocks suffer from size-selective mortality, but a more detailed study on gear selectivity should be conducted to ascertain on such a way;
7. 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;

8. On the biological point of view the best regulation and management measures in the short-run for the studied yellowtail snapper, mutton snapper, and females and males Caribbean sharpnose shark stocks should be a reduction of 25% of the current fishing effort;
9. Nursery areas, specially for small coastal sharks, off Pernambuco waters 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;
10. The fishermen's decision considering the profits obtained from the fisheries are to re-invest in the activity;
11. Fishermen revenues is limited to the outcomes from the activity, trying to fish as much as possible aiming at increasing profitability;
12. The system of share is defined inside the fishery system economic structure, without outsider's interventions, even governmental, which strengthen relationship between those directly and indirectly involved;
13. Although not directly revealed and analysed by the collected data, it seems that credit is only available through small investors that sporadically outlay from bank investment going through extra, but risky, income on the fishing activity;
14. Low income is the limiting factor that impede the increase in fishing effort, either not encouraging new entries or limiting re-investment to increase fishing effort, and may suggest that the hand-line and gillnet fleets had established an economic equilibrium point;
15. The definition of the related biological and economic parameters permitted filled up each one of the three corresponding boxes of the MEFISTO model (the stock, the fisherman and the market boxes), and allowed the bioeconomic analysis of the hand-line and gillnet Pernambuco State coastal fisheries. All the required parameters were checked for their validity using the own model tools, aiming at providing a picture as much real as possible of the analysed fisheries;
16. The MEFISTO model, with some adjustment, demonstrated to be appropriate to simulate management strategies. Although it became clear that the model, for the found reality, has some limitations, such aspects were not an impediment to run the model and present the initial condition of the analysed fisheries and to proceed with different events to provide scientific and technical information for the local fishermen and boat owner, the scientific community, and for the administration and decision makers;

17. It was possible to figure out that, apparently, there is a biological and an economic equilibrium of the fisheries, from the initial condition. Nevertheless, collapse of the yellowtail snapper, mutton snapper, and females and males Caribbean sharpnose shark stocks would occur with increasing in fishing effort, translated in an increase in catchability or economic measures, such as subsidies;
18. A bioeconomic equilibrium for Pernambuco State hand-line and gillnet fisheries can be assumed, whereupon in the long run an unsustainable condition would prevail, with the deactivation of boats;
19. Albeit neither in the scope of the present work nor of MEFISTO model, which was the analysis of the fishing activity, the fact that most of the boat owner being engaged in the commercialisation process of the fishery system, as middlemen or retailers, may explain how they can support fishing losses and maintain their boat fishing;
20. The conducted simulations were the first attempt to project management measures towards the future and demonstrate that many technical, economic, biological or all together measures can be applied, with different implication for the fishermen / boat owners and the resource. The best management strategy seems to be the jointly application of different conditions that would satisfy the claim of groups of interest in the activity, such as boat owners and fishermen, and would provide populations rebuilding, such as: (1) *economic subsidies*, at a level that permit to reduce boat owner costs; (2) *biological measures*, by the reduction of fishing effort by defining temporary fenced season; and (3) *technical measures*, such as the creation of protected fishing areas, specially those known as nursery grounds;
21. The use of bioeconomic model to the assessment of the hand-line and the gillnet fisheries showed to be a very important tool for the administration, since informations based on scientific advise for the definition and implementation of management strategies for fisheries development are available; for the scientific community, which may improve knowledge on the population dynamics of the fishing stocks off Pernambuco and the dynamics of fishing fleets; and for the fishermen, which can join their empirical knowledge with the models outputs informations to improve their fishing strategies;
22. There is no evidence of commercial fish stocks depletion, inasmuch the target hand-liners and gill-netters species are considered, but that there is a necessity to diversify the existing fishery, because any increase in fishing effort would turn stock level to an over-exploitation level, maybe with irreversible conditions for some of the stocks analysed. Such a biological

and economic equilibrium should be maintained, nonetheless with the implementation of management conservation measure that encourage the reduction of the current level of effort, jointly with measures that can bring about fishermen claim; and

23. It became clear that the small-scale fishery activity must be a priority of governmental policies for the sustainable development of the fishery sector, showing to be economic viable, desirable on the social point of view and ecologically adequate.

• *FUTURE STUDIES AND PERSPECTIVES*

Further progress in bioeconomics is needed, in order that practical applications can be based on the confidence that the basic principles have been correctly formulated. Such evidence may be justified as the need for a shift in perspective among oceanographers towards assessing not just resource controls, but also predation and population dynamics as key features that structure marine ecosystems, and also, needless to say, the importance to conduct studies on the stock dynamic model and specific alternatives in accordance with the local peculiarities, making possible the optimisation of the biological and economic features of the fishery sector.

There is a need, thus, to attempt to gain an in-depth understanding of the process that determine the population dynamics of commercial populations species, and others that is not in the scope of the present study but is known to have utmost commercial importance for Pernambuco State coastal fishery, such as recruitment, spatial structure, density-dependence processes and spatial variability in growth, reproduction and mortality, that could preclude the development and establishment of regulations and management measures.

New studies are documenting trophic cascade in theoretically unlikely systems such as tropical forests and the open ocean. Together with increasing evidence of cascades, there is a deepening understanding of the conditions that promote and inhibit the transmission of predatory effects. These conditions include the relative productivity of ecosystems, presence of refuges and the potential for compensation. However, humans also alter trophic cascades. Analyses of the extirpation of large animals reveal loss of cascades, and the potential of conservation to restore not only predator populations but also the ecosystem-level effects that ramify from their presence (Pace *et al.*, 1999)

Future studies must consider a comparative analysis of the existing fisheries to assess the carrying capacity of the marine shelf ecosystems for harvestable species in the Northeast Region of Brazil, as proposed by Vasconcellos and Gasalla (2001) for the Southeast and South Regions Brazil, such as: (1) estimation of the primary production required to sustain fisheries catches; (2) to present a diagnosis of fisheries for the “fishing down the food web” phenomenon; and (3) the impact of fisheries on the structure of an exploited ecosystem. Those arguments and objectives were defined based on previous studies conducted by Pauly and Christensen (1995) and Pauly *et al.* (1998).

Such studies is justified because ecosystem principles and precautionary measures are to be effectively implemented, managers and decision makers have to take the possibility of ecosystem impacts of fishing down the food web into account when designing policies for the exploitation of marine resources (Vasconcellos and Gasalla, 2001). It is worthwhile, thus, to recognise and deepening in the understanding of the trophic level of the main group of species herein considered, supposing that such species play an utmost important role in the studied ecosystem. Such an approach may lead to the identification of sustainability indicators and the development and definition of economic indicators as an element of a much more comprehensive task, namely the development of indicators of sustainable development.

Modern governance needs broader and more active participation and involvement of fishers and coastal communities and development actors in decision-making, increased transparency, and systematic appraisal of management performance (Garcia and Staples, 2000). The perception of the importance of definition of sustainable and economic indicators is a important step regarding the need for socio-economic indicators in developing fishing nations, highly dependent of the artisanal fishery sub-sector. These indicators are expected to be used as tools for monitoring and evaluating sector performance, particularly with regard to fisheries management policies, instruments and measures (Bonzon, 2000).

Co-management system is being implemented quite often in many developed fishing nations, where responsibility for the exploitation of a given fishing resource are shared between fishers’ guilds, (fishers’ organisations supervised by the regional government) and fishery authorities. This change opened new opportunities for innovation and improvement in a management system following an adaptive process. According to Morales and Freire (2003) analysing goose barnacle fishery in Galicia, North-western Spain, the principal innovations are the increased management authority of the fishers’ organisations which had undergone organisational changes, and the introduction of information technology.

Considering the deficiency of scientific research in the Northeast Region of Brazil, another utmost study that should be appropriate to conducted and that could be envisaged after the present work is the spatial modelling of coastal commercial species. A well known methodology is the geostatistical model, which has, according to Maynou (1995), two basic interest: first, as a means of describing and mapping the spatial distribution of a species or ecological property; and second, as a means of optimising the evaluation of harvestable resources. Such methodology evaluated due to questionable assumption on the traditional estimation of abundance indices of commercial fish species by means of techniques derived from sampling theory. Geostatistical techniques allow to describe and model the spatial structure of a specie, by means of the computation of an experimental spatial dependence function and its fit by a theoretical model, and should help to accrue the knowledge on the population dynamics of commercial stock species off Pernambuco State continental shelf.

For instance, emphasising the importance of bioeconomic studies as stressed by means of a very important tool todevelop the small scale coastal fishery at Pernambuco, notwithstanding the paramount importance of others marine science research areas, priorities for future studies must be focused on the work promoted by FAO[2] and led by Seijo and colleagues (1998), quoting many others scientist, which may thus be synthesised:

- *Ecological and techonological interdependencies.* For the purpose of a more holistic approach to management research, fishery science should be directed to evaluating the ecological and technological interdependencies, as well as the influences of the physical environment. An *ecological interdependencies* is defined as ocurring when two stocks have a competitive or a predator-prey relationship, and also for intraspecific interactions. A technological interdependencies occurs when fleets with different fishing power and/or gear types, operate on different components of a single stock or on different target species, affecting their abundance in a dissimilar form;
- *The systems science approach in fisheries bioeconomics.* A critical step in the development of a management plan nis the elaboration of a mathematical model, and a systems simulation approach for fisheries modelling should be considered a very important tool, based on specific assumptions of any particular fishery regarding input variables, parameters and causal relationships between them;
- *Management.* Bioeconomic analysis must have as main objective the implementation of management measures for fisheries development, and should

support decisions for *state intervention criteria*, which should emphasise conservation and economic approaches, and equity approach in resource use; *management strategies*, such as property regimes and allocation of property rights, regulation of catch composition, regulation of the amount of catch, and extension programs and environmental education; and *multiple criteria optimisation approach for fisheries management*, taking into account that management of marine fisheries is significantly complicated by the fact that usually there are more than one set of criteria of relevance in evaluating fishery performance;

- *Spatial bioeconomic models.* Two alternative approach seem to be appropriate: (1) the assumption of spatial homogeneity (May be relax?) or heterogeneity of stock distribution that, for the latter, should consider fishing grounds variability in environmental conditions and related abundance, growth and mortality patterns, if divided into smaller areas must be analysed as independent units; and (2) the importance to develop a comprehensive approach, integrating effects of different environmental regimes on the spatial structure of the population, spatial heterogeneity of fishing effort, biological interactions, and the implications of economic factors and human attitudes; and
- *Risk and uncertinity: a precautionary approach.* Many fisheries experienced biological and economic overfishing as a result of risky management policies, so high uncertainty levels that characterise most of the fisheries and the corresponding caution in management need to be recognise. Hilborn and Peterman[55], quoted by Seijo and colleagues, identify seven sources of uncertainty in fisheries stock assessment: (1) estimates of fish abundance; (2) structure of the mathematical model of the fishery; (3) when estimating model parameters; (4) environmental conditions; (5) response of users to regulations; (6) future management objectives; and (7) in economical, political and social conditions.

Finally, it can be stressed the perspectives to conduct studies that identify the existence or non-existence of externalities and its correspondent levels, with could aid on a better decision-making process and implementation of adequate regulations and management measures.

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