THE FISHING ACTIVITY ON CORAL REEFS AND ADJACENT ECOSYSTEMS. A CASE STUDY OF THE NORTHEAST OF BRAZIL

presented by

Thierry Frédou

A thesis submitted for the degree of

Doctor of Science
in Oceanography

2004

Universidade Federal de Pernambuco
Centro de Tecnologia e Geociências
Departamento de Oceanografia

Université de la Méditerranée
Observatoire des Sciences de l'Univers
Centre d'Océanologie de Marseille
Diversité biologique et fonctionnement
des écosystèmes marins Cotiers
DIMAR UMR 6540

VIRTUS IMPAVIDA

UFPE
Pós-Graduação
Oceanografia

UNIVERSITE DE LA MEDITERRANEE AIX-MARSEILLE II

Dissertação aprovada pela banca examinadora:

Dr. Beatrice Padovani Ferreira

Prof. Mireille Harmelin-Vivien

Dr. Yves Letourneur

Dr. Sigrid Neumann Leitão

Dr. Enir Girondi Reis

Dissertação aprovada pela banca examinadora:

Dr. Beatrice Padovani Ferreira

Prof. Mireille Harmelin-Vivien

Dr. Yves Letourneur

Dr. Sigrid Neumann Leitão

Dr. Enir Girondi Reis

This thesis is dedicated to

My grandfather (in memoriam), my past

Flávia, my present

Marina, my future

Your love is the consolation in the sadness,
the serenity in the turbulence,
the repose in the exhaustion,
the hope in the despair
(Marion Garretty, 1917)

Table of content

List of figures

List of tables

Acknowledgements

- I am grateful to my supervisors Beatrice Padovani Ferreira, and Yves Letourneur for all support on science, on any kind of trouble I could experience and, for the friendship.
- To Mireille Harmelin-Vivien for the trust and the administrative support.
- I am indebted to *REVIZEE* Project, specially to all students and young researchers that helped with data collection and also thanks to Rosangela Lessa and Fabio Hazin coordinators of the sub area Population Dynamics and of 'Score nordeste' respectively.
- I am also grateful to *Recifes Costeiros* Project, to Mauro Maida who helped me giving all infrastructure essential to develop with my experimental data collection in Tamandaré (Pernambuco). I also thank Fabiana, Deborah, Bartô, and Maria Helena as well as all the other that passed by there for the fellowship. A special thanks for Danilo, who help me on maps.
- Thanks to Humber, which kindly helped me on R programming.
- The experimental diving was only possible with the support of so many friends. Many thanks to Amaro, Werick, Telinho, Alberto, and Amaral (in memoriam)
- Thanks to Rubens that help me to show the fishing points of Tamandaré bay.
- I thank the Coordination of the course *Pós-Graduação em Oceanografia Biológica* of Universidade Federal de Pernambuco, specially to Myrna whose support was always present.
- Many thanks to Sigrid Neumann-Leitão that always believed in me and gave me all the support I needed.
- My study and stay in Brazil were funded by a 2-year scholarship from '*Conselho de Aperfeiçoamento de Pessoal de Ensino Superior'* (CAPES) and '*Conselho Nacional de Pesquisa'* (CNPq - Brazil), for which I am most grateful
- My study was also supported by the department DIMAR 'Diversité biologique et fonctionnement des écosystèmes marins Côtiers'.
- The life in Tamandaré would not have been the same without Sergio 'Bili' Rezende. Thanks to have provided a place to live and a good friendship.

- Also, my life in Brazil would not always been so pleasant without that animated and warm support the Lucena's family gave to me. Special thanks to Susana, Jahilton, Katia, Marconi, Patricia and Max. Big kisses to João, Dudinha, Mariana, Carolina, Rachel and Fernandinho.
- Many thanks to my friends that helped me to keep going when I was down: (France) Jérome (jéjé), Gérald (Zé), Christophe (cri), Jérome (the kung-foo master), Sylvain (TG), Christelle 1 and 2 and Stephane; (Brazil) Clara and Fabio, Germana and Chico, Beatriz and Pipo, Romero and Luis, Tamara and Marcelo, Bernardo, Marcos, Luciano and Jiro.
- Many thanks to my parents, Christiane and Jean-Pierre, that always believed in me and were beside me. A special thought to my grandmother Yvonne and my aunt Lilou.
- This thesis is the conclusion of many within the university. I am specially grateful to Raphaël Plante.
- At least but not the last to Flávia that was essential to the completion to this work. This work is dedicated to you.

Abstract

THE FISHING ACTIVITY ON CORAL REEFS AND ADJACENT ECOSYSTEMS. A CASE STUDY OF THE NORTHEAST OF BRAZIL

Northeastern Brazilian coral reefs spread along about 3000 km of coastline. Many commercially valuable species inhabit, temporarily or permanently, the reefs and provide food and employment for millions. However, the lack of basic knowledge, as for example population structure of exploited stocks, catch level, stock assessment, fishing effect on biota etc, illustrate the need of an additional research regarding these ecosystems. The fishing pressure on such environment is rising, partly as result of the technological and demographic development within these regions. Various studies already showed that the fishing pressure is increasing and that many fish stocks are about to collapse or overexploited. This work, as part of the programme, funded by the Brazilian government, called REVIZEE (Assessment of the potential resources alive within the Economical Exclusive Zone of Brazil) that collected information on catch composition and biology of the main species within the EEZ, aimed to identify and assess the factors that influence the fishery dynamic on coral reef using statistical tools as well as mathematical modelling. The ultimate objective of this study consist in a contribution for the development of a management plan aiming at the sustainability of coral reef fishery in the Northeast of Brazil.

Within the reef fishery in Northeast Brazil, snappers were the main part of the artisanal catch and contributed most to the similarity between groups, outstanding the *Lutjanus chrysurus, L. synagris, L. analis, L. jocu* and in a lower extend, *L. vivanus*. Amongst the factors considered, the spatial effect (state as a factor) appeared to be the strongest attribute in isolating groups in Northeast Brazil. Considering the technological factors, 'trip duration' best discriminates the catch composition when compared to 'fleet category'. However, given some exceptions (mainly related to favourable strong winds), 'trip duration' categories are normally related to the fleet motion as motorised boats generally perform the longer trips.

For the five snappers considered, small fish were generally found near the coast in shallow waters and the larger fish were found off-shore in deeper waters. In terms of abundance, mean maximum relative abundance varied, as *L. synagris* was more abundant in shallow waters near the coast while *L. vivanus* mainly occurred in deeper waters on the continental shelf break and the slope. Gears caught similar size for all species and affected almost the entire range of their life history, however, fleets with different operation capacities affected stocks on different ways.

Traditional stock assessment models described the current status of *L. analis, L. chrysurus, L. jocu, L. synagris* and *L. vivanus* of Northeast Brazil. Length based models were not suitable for the studied species and may not be adequate for many other reef species. Although it may also be considered limited, due to the short time series, VPA (Virtual Population Analysis) based on age and true cohorts has shown to be the most appropriate, within the traditional methods applied for the assessment of the reef fish. In the overall, caution should be taken on the exploitation levels. The five species were found at fully or overexploited status and that statement was enhanced when more conservative reference points such as $F_{0.1}$ was considered. Models that incorporate technical interaction were also applied. It appeared that different fleets played distinctive roles on the life history of the snappers in Northeast Brazil.

Fishery independent information were used to get a picture of the fish biodiversity, where management attempts are set up, and to assess the relationship between catch-per-unit-of-effort (CPUE), through comparisons of abundance estimates obtained by underwater visual

censuses (UVC), with the inshore fishery survey. Fish composition varied accordingly to the habitat type. CPUE estimates varied from UVC indexes on the overall. However, sampling performed on ‘knolls’ for lutjanids were found similar. This may be explained by the fact that fish assemblage is restricted to a confined area where both survey methods present a similar operating range.

Thus, considering the results obtained through this work, the management plan in the Northeastern Brazil should encompass two actions: (1) effort reduction, i.e. of the fleet category that most influences the catch (motorised boats), and (2) implementation of areas that restrict fishing activities.

Resumo

A PESCA SOBRE OS RECIFES DE CORAL E OS ECOSISTEMAS ADJACENTES: ESTUDO DE CASO DO NORDESTE DO BRASIL

Recifes de coral da costa do Nordeste do Brasil ocupam aproximadamente 3000 km. Muitas espécies de alto valor comercial habitam temporariamente ou permanentemente nos recifes e fornecem sustento e emprego para milhares de pessoas. Porém, a falta de conhecimento básico como, por exemplo, a estrutura das populações dos estoques comercialmente explotados, o nível das capturas, a avaliação dos estoques, o efeitos da pesca sobre a biota, etc, demonstram a necessidade de mais esforço no que diz respeito ao conhecimento destes ecossistemas. Sabe-se que a pressão pesqueira sobre esse tipo de ambiente não para de crescer devido, em parte, ao desenvolvimento tecnológico e demográfico destas regiões. Vários estudos mostraram que a pressão da pesca vem aumentando e os estoques de peixes estão colapsados ou sobre-explorados. Esse trabalho, inserido dentro do programa financiado pelo governo Brasileiro chamado REVIZEE (Avaliação do Potencial dos Recursos Vivos da Zona Econômica Exclusiva) que coletou informações sobre a composição da captura e biologia das principais espécies da Zona Econômica Exclusiva, teve como objetivo identificar e avaliar os fatores que determinam a dinâmica das pescarias nos recifes de coral, utilizando-se de ferramentas estatísticas e de modelagem numérica. O objetivo final deste estudo consiste em uma contribuição para a elaboração de um plano de manejo visando a exploração sustentável da pesca no ambiente de recifes de coral do Nordeste do Brasil.

Dentro da pesca recifal da costa nordeste do Brasil, os lutjanideos foram parte importante na captura da pesca artesanal e contribuíram decisivamente para explicar a similaridade entre os grupos, destacando *Lutjanus chrysurus, L. synagris, L. analis, L. jocu* e, em uma menor proporção, *L. vivanus*. Dentre outros fatores considerados, o efeito espacial (estado como fator) foi o mais forte atributo responsável pelo isolamento de grupos. Considerando os fatores tecnológicos, ´duração da viagem´ melhor discriminou a composição da captura quando comparado com ´categoria da frota´. Entretanto, dadas algumas exceções (principalmente relacionadas com fortes ventos favoráveis), as categorias ´duração da viagem´ são normalmente relacionadas com a propulsão da frota, uma vez que barcos motorizados geralmente realizam viagens mais longas.

Para os cinco lutjanideos analisados, os menores peixes foram geralmente encontrados perto da costa em águas rasas e os maiores exemplares foram encontrados mais afastados da costa em águas mais profundas. Em termos de abundância, a abundância relativa máxima média variou, uma vez que *L. synagris* foi mais abundante em águas rasas perto da costa enquanto que *L. vivanus* ocorreu principalmente em águas mais profundas na plataforma continental e talude. As artes de pesca capturam indivíduos com tamanho similar para todas as espécies e afetam quase toda a faixa do ciclo de vida das mesmas, entretanto, frotas com distintas operações de pesca afetaram os estoques de maneira diferenciada.

Modelos de avaliação dos estoques tradicionais descreveram a situação atual do *L. analis, L. chrysurus, L. jocu, L. synagris* e *L. vivanus* da costa nordeste do Brasil. Modelos baseados em freqüência de comprimento não se mostraram adequados para as espécies sob estudo e podem não ser adequados para muitas outras espécies recifais. Embora isto possa ser considerado limitante, devido a curta série histórica, VPA (Análise de População Virtual) baseado em idade e coortes verdadeiras mostrou ser o método mais apropriado, considerando

as metodologias tradicionais aplicadas para a avaliação dos estoques dos peixes recifais. De uma maneira geral, os níveis de exploração devem ser avaliados com cautela. As cinco espécies foram classificadas como no limite máximo ou sobre-exploradas e essa conclusão foi ainda mais reforçada quando pontos de referência mais conservativos como o $F_{0.1}$ foi considerado. Modelos que incorporam interações técnicas também foram aplicados. Ficou evidente que diferentes frotas atuam distintivamente na história de vida dos lutjanideos do nordeste do Brasil.

Informações independentes da pesca foram utilizadas visando a obtenção de uma imagem da ictiofauna, onde medidas de manejo são implementadas e, para avaliar a relação entre a captura-por-unidade-de-esforço (CPUE), através de comparações com as estimativas de abundância obtidas através do censo visual (UVC), com a pesca experimental costeira. A ictiofauna variou de acordo com a complexidade do ambiente. As estimativas de CPUE variaram dos índices de UVC de uma maneira geral. Entretanto, para os lutjanideos, amostragens efetuadas em cabeços foram similar. Isto pode ser explicada pelo fato que a comunidade de peixes é restrita a área confinada onde ambos métodos experimentais apresentam uma faixa de operação similar.

Finalmente, considerando os resultados obtidos através deste estudo, um plano de manejo para a região nordeste do Brasil deve considerar duas ações: (1) redução do esforço, i.e. na categoria de frota que mais influencia a captura (barcos motorizados) e (2) implementação de áreas com restrições a atividade pesqueira.

Résumé

LES ACTIVITES DE PECHE SUR LES RECIFS CORALLIENS ET LES ECOSYSTEMES ADJACENTS. ETUDE DE CAS DU NORD EST DU BRESIL

Les récifs coralliens du Brésil se distribuent sur environ 3000 km de côte. Un grand nombre d'espèces de poissons commercialement importantes vivent de façon temporaire ou permanente autour des récifs, et fournissent nourriture et emplois à des millions de personnes. Pourtant, en écologie tropicale, tant fondamentale qu'appliquée, le manque de données de base (structure des peuplements et en particulier des populations à valeur commerciale, valeurs des captures, évaluation des stocks, effets de la pêche sur les écosystèmes, etc.) illustre le besoin de travaux supplémentaires dans ces milieux. Il est démontré que de nombre récifs coralliens de part le monde font l'objet d'une pression de pêche croissante. Dans plusieurs cas bien documentés, la pression de pêche est telle que les captures de poissons se sont effondrées ou ont, pour le moins, très sensiblement diminué ("surpêche"). Cette étude trouve sa place au sein du programme d'étude "REVIZEE" (Evaluation du potentiel des ressources vivantes de la Zone Economique Exclusive Brésilienne) financé par le gouvernement brésilien , qui a collecté un grand nombre de données sur les espèces pêchées comme composition des captures et biologie. L'objectif principal étant d'identifier et d'évaluer, à l'aide d'outils statistiques ainsi que de modèles mathématiques, les facteurs qui influencent la dynamique des pêches sur les récifs coralliens afin d'aboutir à l'élaboration d'un plan de gestion des pêcheries de récifs de corail du Nord-Est Brésilien.

Les Lutjanidae constituent le principal des captures de la pêche récifale de cette région. Elles ont contribué de manière importante à la similarité entre groupes de capture, principalement *Lutjanus chrysurus, L. synagris, L. analis, L. jocu* et dans une moindre proportion, *L. vivanus*. Parmi les facteurs pris en considération , l'effet spatial (les états géopolitiques étant considérés comme facteurs) parait être l'attribut prépondérant. Si l'on considère les facteurs techniques, la « durée du voyage » discrimine mieux les captures que la catégorie de flottille. Pourtant, malgré quelques exceptions (principalement dues aux vents et courants), la catégorie 'durée du voyage' est normalement liée au mode de propulsion des flottilles, comme par exemple les bateaux motorisés qui, en général, effectuent de plus longs parcours.

Pour les cinq espèces considérées, les individus de petite taille ont généralement été capturés prés de la côte dans des eaux peu profondes par opposition avec les poissons de grande taille qui ont été capturés en eaux plus profondes. En termes d'abondance, *L. synagris* a été plus abondant dans les eaux peu profondes alors que *L. vivanus* a été plus abondant dans les eaux profondes. Les engins de pêches ont capturé des tailles similaires et ont agit sur presque la totalité de leur cycle de vie, même si les flottilles, présentant des capacités opérationnelles différentes, influencent les stocks de manières différentes.

Les modèles halieutiques traditionnels ont décrit l'état actuel des stocks de *L. analis*, *L. chrysurus, L. jocu, L. synagris,* et *L. vivanus* de la région Nord-Est du Brésil. Les modèles basés sur la fréquence de taille n'ont pas été en mesure de fournir une réponse satisfaisante pour les espèces étudiées et ne donnerait probablement pas une réponse adéquate pour plusieurs autres espèces récifales. Quoique d'une portée pouvant être considérée comme limitée par le fait de la courte série temporelle, l'Analyse Virtuelle des Populations, basée sur l'âge et sur les cohortes réelles, s'est avérée la plus adéquate des méthodes traditionnelles appliquées à l'évaluation des stocks de poisson récifaux. Globalement, il apparaît que des

précautions devraient être prises afin de limiter le niveaux d'exploitation. Les cinq espèces de Lutjanidae ont été jugées complètement exploitées voire surpêchées. Ce qui apparait encore plus évident lorsque l'on prend en compte des points de références plus conservateurs, comme $F_{0.1}$. En outre, les modèles incorporant les interactions techniques ont monté que les divers types de flottilles ont joué un rôle distinct sur les cycles de vie des différentes espèces étudiées dans le Nord-Est du Brésil.

Des informations provenant de sources indépendantes des pêches ont été utilisées afin d'évaluer d'une part la biodiversité des assemblages de poissons récifaux, où des tentatives de gestion sont mis en œuvre, et d'autre part la relation entre les captures par unité d'effort (CPUE) à travers des comparaisons d'estimations d'abondance obtenues par des comptages visuels et des relevés de pêche de la région étudiée. L'assemblage de poissons a varié en fonction du type d'habitat. Les estimations de CPUE ont été, en général, différentes des comptages visuels. Malgré tout, les échantillonnages effectués sur certains sites comme les haut fonds de bord de plage par le biais des deux méthodes ont été semblables. Ceci peut s'expliquer par le fait que l'assemblage de poisson aurait été réduit à une zone confinée où les deux méthodes d'échantillonnage présentent une amplitude d'opération analogue.

Enfin, un plan de gestion pour la region nord-est du Brésil prenant en compte les résultas obtenus par cette étude devra considérer deux actions : (1) une reduction de l´effort de pêche, en locurence réduction de l´effort de la categorie qui influencie le plus les captures (les bateaux motorisés) et (2) l'implémentation de zones oú les activités de pêche sont restrictes.

Chapter I. General introduction

I.I. The reef environment Regional setting

The study of Brazilian reefs began in 1828 with an expedition of the naturalist Spix and Martius (1828). Darwin (1841; 1851) followed by other few visiting scientists that described restricted reef areas. However, the first complete description of the Brazilian coral reefs and their fauna was published by the biologist Jacques Laborel (1967) when he described the unusual characteristics of Brazilian coral reefs: the mushroom-like growth form, the strong endemism and the low diversity of the coral fauna (see for review Maida & Ferreira, 1997; Castro & Pires, 2001; Leão *et al.*, 2003). In the last two decades, an increased number of researchers worked on the field of Brazilian reefs. These studies consisted mainly of mapping the reef area (i.e. Maida & Ferreira, 1997), studies of the reef fauna and flora (i.e. Leão, 1986; Ferreira & Cava, 2001; Ferreira *et al.*, 2001), characterisation of reef environment and related sedimentary facies (i.e. Araujo, 1984), as well as conservation issues related to reef ecosystem (IBAMA/FUNATURA, 1991).

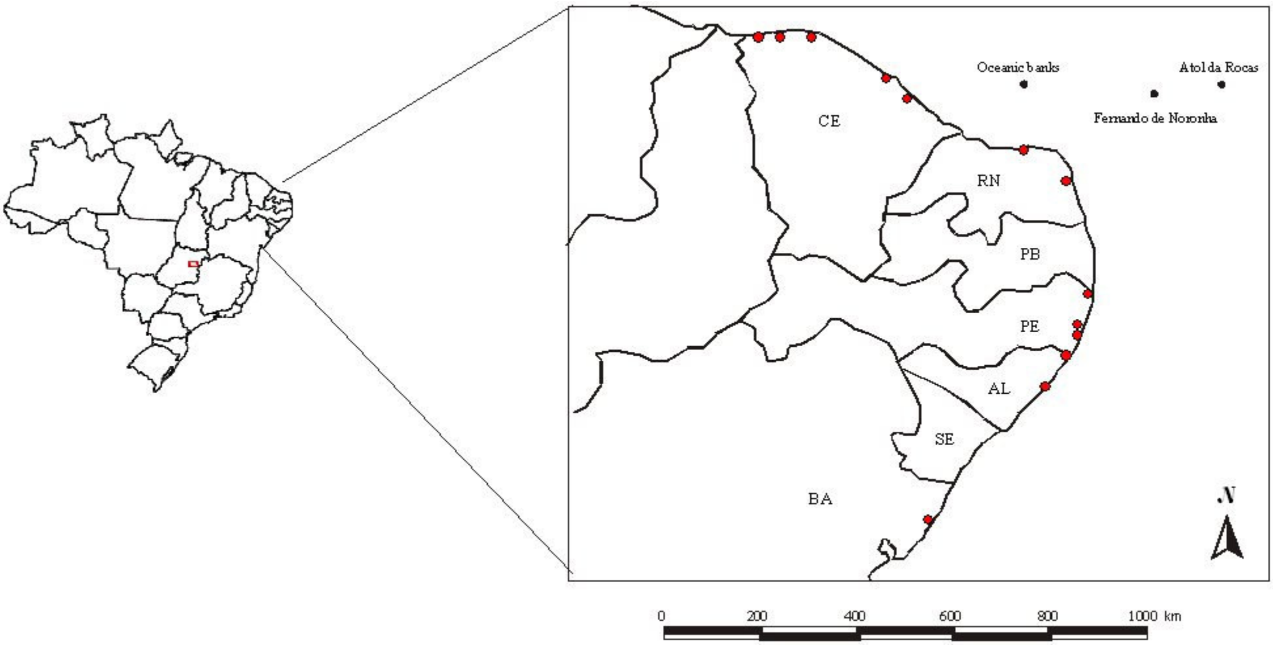


Fig. I.1: Northeast of Brazil. Red dot are sampled sites. States: (CE) Ceará, (RN) Rio Grande do Norte, (PB) Paraíba, (PE) Pernambuco, (AL) Alagoas, (SE) Sergipe, (BA) Bahia

Coral reef formations in Brazil extend for approximately 3000 km along the Northeastern coast (Maida & Ferreira, 1997) (Fig. I.1). There are different types of reefs: bank reefs, fringing reefs and one atoll. They are constituted by organic substrates built with coral, algae and mollusc skeletons. This region consists in a variety of habitats, including mangrove forests, fringing and platform reefs, and estuaries that act like inland extensions of the continental shelf. Where the shelf narrows in the central section of the Northeast Brazil Shelf region, the substrate consists almost entirely of carbonate sediments and is impacted by the South Equatorial Current. The Brazilian reef present two outstanding features: their structure and their coral composition. Reef structure called 'chapeirões' are commonly observed in Brazil. They consist of several mushroom-shaped coral colonies fused above, some extending 20m high and 50m in diameter. These formation may fuse and form reef banks which are found in the southern bound of reef range. Calcareous algae predominate along the northern part of the Brazilian coast (Laborel & Kempf, 1967; Maida & Ferreira, 1997; Leão *et al.*, 2003). Also unique to Brazilian reefs is their reef-building coral species composition. The diversity coral fauna (18 species) is low when compared to that of the Caribbean reefs, however, nearly half of it are endemic and some are relics of the ancient coral fauna of the Tethys sea (Leão *et al.*, 2003). Eighteen species of stony corals (scleractinians), four hydrocorals, four antipatharians, and eleven octocorals constitute the cnidarian fauna of Brazil so far identified. The most common forms of stony coral in the Brazilian reefs are the three species of the genus *Mussimilia*: *M. braziliensis, M. harttii* and *M. hispida*. Among the endemic species, *Favia gravida,* is the most common on the Northeastern reefs. Most of the frame building corals are massive. Encrusting forms are present along the edges of the reefs. Hydrocorals formed by the genus *Millepora,* present two major growth forms: branching and encrusting. Black corals form flat fan-shaped colonies (*Antipathes* sp.) or long branched colonies up to several meters long (*Cirripathes* sp.).

According to Leão (2003) Brazilian reefs are divided into four major sectors along the tropical coast: the northern, the northeastern, the eastern and the southern coasts. The area studied included southern part of the northern sector, the Northeastern and north part of the Eastern zone. It ranged from the State of Ceará to the north part of the state of Bahia including oceanic banks formed by the submarine mounts of Fernando de Noronha lined up east-west (Fig I.1). The only emerged peaks of the chain are the Atol das Rocas, the archipelago Fernando de Noronha, and further north the Rochedos de São Pedro e São Paulo (Fig I.1). Then, the area is divided in two parts: the northern realm (States of Ceará, Rio Grande do Norte, and oceanic banks) and the northeastern part (states of Paraíba, Pernambuco, Alagoas, Sergipe and the northern part of Bahia). The continental shelf varies from 45 to 60 km wide in Ceará and Rio Grande do Norte, then becomes relatively narrow in Pernambuco coasts (20 km), to wide again in the south of Bahia reaching 200 km. The shelf break is commonly found between 80 and 100 m depth (Laborel, 1967; Mabesoone & Coutinho, 1970; Maida & Ferreira, 1997; Leão *et al.*, 2003). The general atmospheric circulation pattern along the Northeast and East Brazilian coast is controlled by air masses from the South Atlantic high pressure cell and advances of polar air masses. Dominant winds are southeasterly and easterly trade winds. The Brazilian Current (BC) and the North Coastal Brazilian Current (NCBC) are the main surface currents on the Brazilian continental margin. They originate from the South Equatorial Current (SEC) at about 5° to 6° S and flow to the south (BC) with average velocity 50 to 70 cm^{-1}, and to the North and Northwest (NBC) with a velocity reaching 30 cm^{-1} (Stramma, 1991; da Silveira *et al.*, 1994). During the austral winter between the 10°S and 13°S (Sergipe and Northern Bahia) a reverse flow to the North may occur. North of 5°S the North Coastal Brazilian Current (NCBC) becomes stronger as a result of conjunction with the SEC. The range of Sea Surface Temperature (SST) along the northeastern Brazilian coast has a low variation from 30°C during summer and fall (October to August) to 28°C during winter (March to September).

The Northern region is a marginal realm where reefs are sparse. The coast is sandy and present reefs that grow as pinnacles in depth of 25 to 30 m. Oceanic Banks off this coast are the remnants of volcanic cone of the Mid-Atlantic ridge (Mabesoone & Coutinho, 1970) that rises steeply from great depths. These submarine mountain tops range between 40 and 300 m deep. The region is under the influence of the northern strong onshore winds, trade winds, and of the northern branch of the South Atlantic Equatorial Current. The water average temperature is 27°C in summer and 22°C in winter (Leão *et al.*, 2003).

Reefs abound on the inner shelf of the Northeastern region. The coral build-ups are generally patch of elongated bank reefs, but some attached banks are present as well (Leão *et al.*, 2003). The major current influencing the area is the Brazilian current which flows southward and in a lesser extend the North Brazilian Current flowing northward, also there are wind driven with varying speed and direction. The northeastern coast is dominated by the Southeastern and Eastern trade winds originated by two elements: the general atmospheric circulation pattern along the Northeast and East coast and air masses generated in the South Atlantic high pressure cell and polar air masses.

Although geological history of sandstone banks is poorly known, their formation is linked to the complex relative movements of the continental margin and the variations of the sea levels in the past (Mabesoone & Coutinho, 1970). As a general pattern, the northeastern continental shelf vertical profile can be divided into three zones: (i) the inner shelf, (ii) the outer shelf and (iii) the shelf break and the slope, another category may be add with oceanic banks, atoll and archipelago:

(i) The principal coastal feature consists of sandstone banks and superficial coral reef that are arranged in lines parallel to the coastline that can reach 10 km long by 60m width (Laborel & Kempf, 1967). Breaks along these lines occur at bays which usually contain small mangrove systems whenever river is present (Maida & Ferreira, 1997). From 10 to 20 m deep, a transitional zone, a mosaic of mud flats (due to river discharge) and areas made of sand and calcareous algae can be observed.

(ii) The outer shelf, from 20 to 80 m deep, presents a bottom rather smooth where calcareous algae, *Mesobeliaceas* spp and *Lithothamnium* spp, cover large part of the area (Kempf *et al.*, 1970). Some uneven areas with downs and high, called 'canais' occur on the external bound and run parallel to the shelf break (Kempf *et al.*, 1970).

(iii) The shelf break looks like a wall where the depth fall abruptly from 80 m to 500 m within 2 nautical miles, then the slope become more gradual with an inclination of 2° to 3° (Kempf *et al.*, 1970).

The East Brazil large marine ecosystem (LME) has a low productivity (<150 gC/m2/yr) (Stuhr, 1996). It has a more diverse food web than the large marine ecosystems to the North and to the South, but has lower production. Studies on primary productivity for this LME are scant. The Victoria Eddy along the eastern shelf edge (see Schmid *et al.*, 1995) creates an upwelling of nutrient-rich South Atlantic Central Water (see Gaeta *et al.*, 1999), leading to higher primary production rates. This LME is a transition zone in terms of the distribution patterns of the different taxonomic groups and the microplankton. It is influenced both by northern tropical warm waters and by southern colder upwellings (see Ekau, 1999).

I.II. Biogeography of Brazilian reef fishes

Although the reef ichthyofauna of the western Atlantic has been substantially studied, the reef fish of the Brazilian waters are still poorly known (Floeter *et al.*, 2001). Until the 1980's the Brazilian reef ichthyofauna was believed to be composed by Caribbean species (Moura *et al.*, 1999). Nowadays, various species were found endemic of the Western South Atlantic although very similar to their Caribbean counterparts (Floeter & Gasparini, 2000). The Brazilian reef fish fauna comprises around 320 species (Floeter & Gasparini, 2001). From these, 57 species were restricted to the southwestern Atlantic (Floeter & Gasparini, 2001).

Recently, two concurrent theories about the Brazilian endemism have been presented. The first idea is that a separate evolution of the northern and southern reef fishes population occurred as the Amazonian river represents a strong barrier through the discharge of a large amount of sediment and freshwater and that is probably the major reason of the Brazilian endemism (Rocha, 2003). An alternative proposition was that the Amazon area, because of its large influence and mainly due to the low salinity, has created an endemism area extending from the north of Brazil to the Ceará (Joyeux *et al.*, 2001). Therefore, the Amazonian river would not be an unbridgeable barrier for species (as various species from Caribbean islands do occur along the Brazilian coast).

There is a considerable homogeneity in the composition of the reef fauna within the Brazilian province (ranging from the Amazon delta to south Brazil), although there may be some differences between regions that present divergent salinity water temperature or reef type (Floeter & Gasparini, 2000). In the northeast of Brazil, main differences in diversity occur between continental environment and island (Floeter & Gasparini, 2000; Floeter *et al.*, 2001; Araújo & Feitosa, *in press*). Haemulids and lutjanids, well represented on the Brazilian reef formation (high number of species), are very little or absent on oceanic islands such as i.e. Fernando de Noronha (Floeter *et al.*, 2001).

I.III. Data collection

Most of the data for this study were collected as part of a national program called REVIZEE (Evaluation of the Potential of the Live Resources from Brazilian Exclusive Economic Zone), which was established in 1996. The program was set up in a multidisciplinary way and information on geology, physic oceanography, chemistry, and biology of species inhabiting the Brazilian waters was gathered. The fish and fishery sub-program gathered information along the Brazilian coast on exploited fish population in order to determine population dynamics and estimate biomass levels of economically important fish resources. Our data came from the area encompassing five Brazilian states (Ceará, Rio Grande do Norte, Pernambuco, Alagoas and Bahia, see Fig. I.1) during 5 years of sampling program. It was gathered information regarding the fishing tactics (fishing area, gear used, target groups, etc) and catch composition of fleet operating in the region. Fish were identified, measured and weighed. Biological material was collected for the development of age and growth studies as well as reproduction. This work already generated several M.Sc. thesis (Teixeira, 1998; Rezende, 1999; Diedhiou, 2000) and other scientific work (Diedhiou *et al.*, 2003; Rezende *et al.*, 2003; Ferreira *et al.*, 2004a; 2004b; 2004c; 2004d; Rezende & Ferreira, 2004). Another program 'Projeto Recifes Costeiros'[1] complemented the dataset available on the artisanal fishery in Pernambuco as well as on the local Tamandaré´s fish fauna through underwater visual censuses. Results from the data collection from the 'Projeto Recifes costeiros' gave support to the design of the REVIZEE program concerning reef fisheries in the Northeast of Brazil.

Fisheries statistics in Brazil have been collected by many public institutions (SUDEPE, 1967-1979; IBGE, 1980-1989; IBAMA, 1990-2001)[2]. From the 1990's, the program called ESTATPESCA run by the IBAMA was set up in order to collect fishery statistics from marine and estuarine ecosystem along the Brazilian coast. The information collected comprised each landing by vessel category, its production at species level, the gear category used, the cruise number and the fishing ground (Estatpesca, 2000). In the Northern Brazil (study area), 324 sampling sites were chosen for estimation of the total production (by the program 'Estatpesca') of the target species and control of technological characteristics of the Northeastern area.

I.IV. Species of genus *Lutjanus*

Generally demersal, the snappers are tropical and sub tropical species that are distributed on reefs down to depths about 450 m (Allen, 1985; Polovina & Ralston, 1987). Top predators, they consume a broad range of prey generally dominated by fish and macro invertebrate at the adult stage (Allen, 1985; Nagelkerken *et al.*, 2000).

Lutjanids are daily and nocturnally active, but in contrast to diurnally active only species they do not seem to feed during daytime (Polovina & Ralston, 1987; Nagelkerken *et al.*, 2000). Juveniles migrate out of the mangrove and patch reefs to the adjacent seagrass beds to feed on invertebrates. Commonly, adults that shelter on the coral reef by day migrate to the adjacent seagrass beds at night to feed. The selection of the feeding site appears to be determined by the presence and abundance of their preferred food items (i. e. Tanaidacea, Decapoda, and small fishes) (Allen, 1985; Duarte & Garcia, 1999; Nagelkerken *et al.*, 2000).

Lutjanids present two types of reproduction pattern: continental species spawn during the extended summer period whereas island population present an all-year round spawning

---

[1] Projeto Recifes Costeiros: Program that aims to preserve coral reefs, beaches and mangroves along the protected area 'APA Costa dos Corais' through a sustainable management of the area. The protected area covers over 413 thousands Ha along a coastline 130 km long between the states of Pernambuco and Alagoas. Management actions taken are socio-political, scientific and educational.

[2] Brazilian fisheries statistic: Superintendência do Desenvolvimento da Pesca (SUDEPE), 1967-1979; Instituto Brasileiro de Geografia e Estatística (IBGE), 1980-1989; Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis IBAMA, 1990-2001.

season (Grimes, 1987). They produce eggs with pelagic dispersion (Grimes, 1987). Commonly long lived species, i.e. over 50 years for *L. campechanus* (Wilson & Nieland, 2001), they generally show low growth and natural mortality rates (Manickchanddass, 1987; Manooch, 1987; Polovina & Ralston, 1987; Davis & West, 1992; Milton *et al.*, 1995; Rocha-Olivares, 1998; Hodd & Johnson, 1999; Cappo *et al.*, 2000; Hood & Johnson, 2000; Luckhurst *et al.*, 2000; Newman *et al.*, 2000; Burton, 2001; Newman, 2001; Patterson III *et al.*, 2001; Wilson & Nieland, 2001; Burton, 2002)

Our study focused on five species of *Lutjanus*, which inhabit from coastal to deep demersal waters. The main species caught by the artisanal fishery in Northeast of Brazil were studied: the mutton snapper *L. analis* (Cuvier, 1828), the yellowtail snapper *L. chrysurus* (Bloch, 1791), the dog snapper *L. jocu* (Bloch and Schneider, 1801), the lane snapper *L. synagris* (Linnaeus, 1758) and the silk snapper *L. vivanus* (Cuvier, 1828) (Fig. I.2).

*Lutjanus analis o*ccurs in continental shelf areas as well as clear waters around islands (Cervigón *et al.*, 1992). Large adults are usually found among rocks and coral while juveniles occur over sandy, vegetated (usually *Thalassia*) bottoms and mangrove systems (Cervigón *et al.*, 1992). They form small aggregations, which disband during the night (Allen, 1985) and feed both day and night on fishes, shrimps, crabs, cephalopods, and gastropods (Allen, 1985). It has been reported individuals reaching 30 years old (Rezende *et al.*, 2003).

L. chrysurus inhabits coastal waters, mostly around coral reefs. They are usually seen well above the bottom, frequently in aggregations. Young individuals are usually found over weed beds. Adults feed on a combination of plankton and

benthic animals including fishes, crustaceans, worms, gastropods and cephalopods. Juveniles feed primarily on plankton (Lieske & Myers, 1994). Spawning occurs throughout the year, with peaks at different times in different areas (Smith, 1997; Diedhiou, 2000). In the northern Brazil, 18-year-old fishes were reported (Diedhiou *et al.*, 2003).

Adults of *L. jocu* are common around rocky or coral reefs. Young individuals are found in estuaries and occasionally enters rivers. They feed mainly on fishes and benthic invertebrates, including shrimps, crabs, gastropods and cephalopods (Allen, 1985). Individuals that aged 25 year old were reported in the northeastern Brazil (Ferreira *et al.*, 2004c; Rezende & Ferreira, 2004).

L. synagris inhabits shallow coastal waters and is found over all types of bottom, but mainly around coral reefs and on vegetated sandy areas, in turbid as well as clear water (Lieske & Myers, 1994). *L. synagris* often forms aggregations, specially during the breeding season. They feed at night on small fishes, bottom-living crabs, shrimps, worms, gastropods and cephalopods. Nineteen-year-old individuals were reported in the western Atlantic (Luckhurst *et al.*, 2000) and up to 22-year-old individuals in Brazil (Ferreira *et al.*, 2004d).

L. vivanus is common near the edge of the continental and island shelves; also found in deeper waters (below 200 m); usually ascending to shallow water at night. It feeds mainly on fishes, shrimps, crabs, gastropods, cephalopods, tunicates and some pelagic items including urochordates (Polovina & Ralston, 1987). *L. vivanus* is a restricted spawner in the continental part while its insular counterpart spawn all year round (Polovina & Ralston, 1987).

I.V. Reef fishery in Brazil. The case of snappers

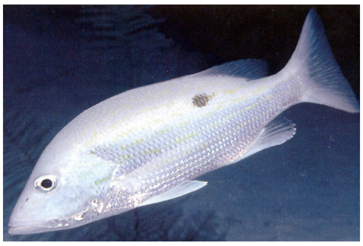
The Northeast coast is one of the country's most densely populated coastal regions, with the State of Pernambuco standing out as the epicentre of this concentration (Moraes, 1999). To supply food and economic resources the Brazilian reef fishes are intensively exploited by artisanal fisheries that concentrate on the reef formations distributed along the continental shelf up to the continental slope and over oceanic banks (Ferreira *et al.*, 1998; Ferreira & Maida, 2001).

According to Ferreira *et al.* (2000), fisheries in Brazilian reefs may be divided into two types. First, the activity of recreational and artisanal scale fishers occurs nearby the coast in shallow waters and reefs formations. Fishing point may be reached by swimming or using rowing or sailing canoes. Second, the medium scale commercial fisheries that operates by the coastal part of the shelf, using sailing or motorised boats that reach deeper waters as far as the shelf break. Only motorised boats, that may operate also on the banks far from the coast, have storing capacity (Ferreira & Maida, 2001).

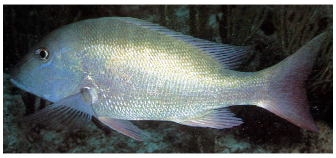
Along the Northeastern coast, snappers represent one of the main resources for the artisanal fishery in terms of abundance and fishers income (Santos, 2001). Lutjanids' catches in the Northeast Brazil ranged between 11341 tonnes during the 60's, that represented 34% of the catch in this decade, and 77422 tonnes during the 80's, 43% of the catch (Fig. I.3). During the 60´s and 70´s, the most targeted species in Northeast Brazil was the red snapper, *Lutjanus purpureus* (Poey 1866), and in minor proportions, *L. analis*. From 1978 with the collapse of the red snapper fishery, others species as *L. jocu*, *L. chrysurus*, and more recently, *L. synagris*, constitute the major part of the lutjanids catch in Northeast Brazil (65%) (Fig. I.3) (SUDEPE, 1967-1979; IBGE, 1980-1989; IBAMA, 190-2001). Amongst the four main states of the Northeast of Brazil, Ceará was responsible for the highest catches of species of the genus *Lutjanus* with catches up to 8200 tonnes per year. However, from 1986, the Lutjanids' catches have shown a decreasing trend since catches in the state of Ceará declined sharply.

The decreasing trend in landings of the *Lutjanus* species in Pernambuco was also observed since 1968. This trend was directly related to the collapse of the main species *L. purpureus* that reached its maximum in 1981 when 6800 tonnes were landed. By this time, *L. purpureus* was responsible for 70% of the total of snappers landed in northeastern Brazil and almost all catches were from Ceará fishing activities (6700 tonnes). *L. purpureus´*s catches in Pernambuco showed a decline since 1968 and, by 1988, this species was nearly absent. In the last two years (2000 and 2001), *L. purpureus* only represented 18% of the total catches of *Lutjanus* species (1100 tonnes in average). Conversely, the relative contribution of other species of *Lutjanus* in the total catch was increasing, specially in Bahia, that steadily increased its Lutjanids catches since 1968.

Although *L. purpureus* is of a great value for the Northern Brazil fishery it is, currently, exclusively targeted by the industrial sector, because of their aggregating property and also due to over-fishing. Nowadays, *L. purpureus* is not only caught within the northeastern shelf although it can be landed in ports of the region (mainly in Fortaleza – Ceará). Therefore this species was not included into our analyses.



Lutjanus synagris



Lutjanus analis

Lutjanus chrysurus

Lutjanus jocu

Lutjanus vivanus

Lutjanus purpureus

Fig. I.2: Lutjanus species considered in the study (source all species 'Projeto Recifes Costeiros' except *L. chrysurus, L. vivanus* and *L. purpureus* www.fishbase.org)

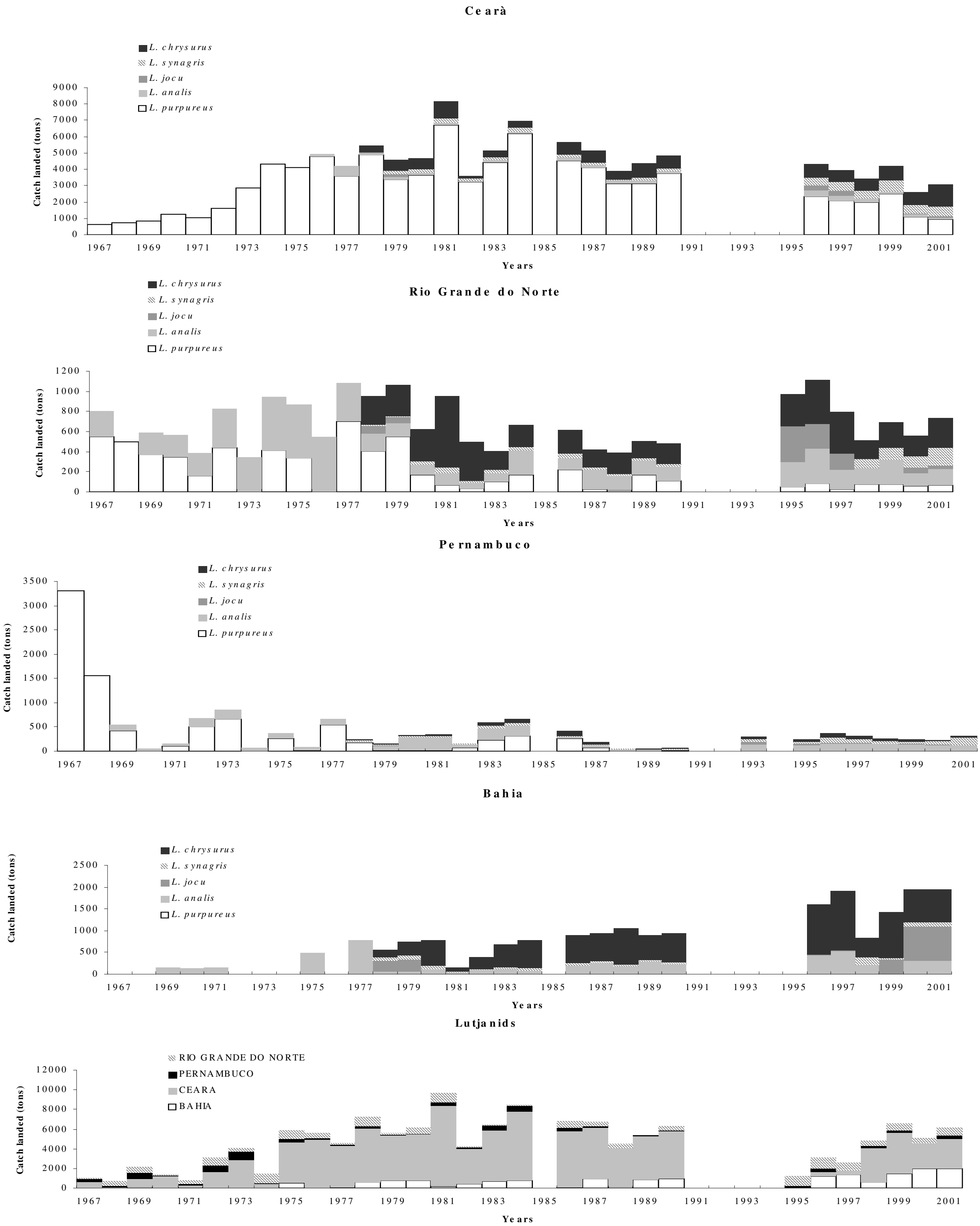


Fig. I.3 Lutjanids' catch time series from 1967 to 2001. From North to South catch times series of Ceará, Rio Grande do Norte, Pernambuco, Bahia.

I.VI. General objectives of the thesis

Tropical snappers are widely distributed throughout the tropical seas of the world (Allen, 1985). In Brazil, snappers are of particular commercial interest mainly for the artisanal fishery. The exploitation, in terms of catch levels, is carried out with relatively high exploitation rates from many decades. However, no stock assessment for the elaboration of a management plan for a sustainable exploitation has been carried out in Brazil for such resource. The program REVIZEE represented the first attempt to run a comprehensive stock assessment including the multifleet and multispecies characteristics of the fishery.

This study aims to assess the current status of the artisanal fishery of the Northeast Brazil through the exploitation of its main resource, the Lutjanidae family, and to help improving future sampling programs for stock assessment and management in the northeastern Brazilian framework.

I.VII. Specific objectives and description of the chapters

This study, set up within a multigear and multispecific framework, has the main objective to evaluate the factors which drive the dynamics of the reef fishery in Northeast Brazil, using statistical analysis and modelling tools. The final goal of this study is to provide suggestions for a management plan for the reef fishery in the Northeast Brazil.

The specific objectives of the study are:

1. Identify, describe and quantify the factors that influence the reef fishery in Northeast Brazil using uni- and multivariate approaches; (Chapter 2)
2. Evaluate the relationship between the species distribution of snappers in the water column and the fishery distribution. The Lutjanidae family will be chosen as its gather the main species related to the reef environment in the Northeast Brazil. (Chapter 3)
3. Evaluate the stocks of *Lutjanus* spp. based on traditional approaches used in fishery science (Chapter 4);
4. Once the factors that influence the fishery, the multispecific nature of the reef fishery and the competition among fishers with different gear/fleets are identified, models including technological interactions will be applied in order to estimate the exploitation rates, biomass and productivity of fish stocks most important in the reef community (Chapter 5);

5. Validate the estimates of biomass derived from the indirect models (Chapters 4 and 5) with direct estimates of population abundance/biomass based on Visual Census Techniques (Chapter 6);
6. Suggest management measures for the reef fishery in Northeast Brazil (general discussion – Chapter 7).

Chapter II. Dynamics of reef fishery in the Northeast Brazil: a univariate and multivariate approach

II.I. Introduction

One of the main purposes of a fishery management plan is the adaptation of the catch to the potential of the exploitable resources (Hilborn & Walters, 1992). In multispecific fishery, a common situation on coral reefs, regulations based on unispecific assessment have already shown their limitations (Polunin & Roberts, 1996). Fisheries science has recognised that fish species do not exist in isolation from one to another and that they are not harvested independently (Dann, 1987; Magnusson, 1995; Jennings *et al.*, 2001). Technical interactions arise when gear (or rather the fleet in a artisanal multigear fishery) comes into contact with stocks of different species resulting in a mixed catch. Technical interaction may also arise when co-existing fleets exploit the same resource (Lucena *et al.*, 2002).

The reef ecosystem present a great number of species packed on small spatial dimension (Longhurst & Pauly, 1987). The fishery dynamics of reef communities and fishing impacts are better described when considered their multidimensional aspects (multispecific, multigear, multifleet, spatial and temporal variations). In the case of exploited fishes, the identification and the quantification of factors influencing the dynamics of the fishing activities and the structure of this community appear to be necessary in a management framework. This strategy would help to foreseen the effects and hence to qualify and quantify the variables that influence the fishery dynamics.

The study of the fleet dynamics and their fishing strategy, through the analysis of the diversity of their catch composition, is an important part in fishery ecology (Hilborn, 1985). Such research's line is particularly useful in the case of multispecific and multigear fishery (Murawski *et al.*, 1983; Biseau & Gondeaux, 1988). In fisheries that do not provide sufficient and/or accurate, reliable commercial fishery data, analysis based on catch composition provides an objective and quantitative alternative means of classification (He *et al.*, 1997). In this study the data quality was not homogeneous within the entire dataset. Many landings presented missing data either on the biological aspect or on the abiotic aspect. Therefore such robust methods were recommendable. Several studies have already looked at the characterisation of the fleet dynamics using multivariate methods (Pauly, 1980b; He *et al.*, 1997; Pitcher *et al.*, 1998; Preikshot & Pauly, 1998; Pelletier & Ferraris, 2000). These techniques are useful to obtain an integrated picture of the structure of the system, the factors that characterise the fishing activity and also the comprehension of the adaptive fisher's techniques to the biological and ecological characteristics of the target species. Furthermore, a multivariate approach would improve the definition of a new typology of fishing activity in order to best define technological categories for fishing statistics.

Many community data sets show some *a priori* defined structure. In the Northeast Brazilian fishery, a vessel may carry more than one gear and a vessel with similar technological characteristics may reach different grounds. The qualification and quantification of the factors that influence the catch are essential for the development of a management plan.

This chapter aims to identify, describe and quantify the factors that influence the reef fishery in Northeast Brazil using, in a first step, an univariate approach completed by a multivariate approach. In this context, the homogeneity of the Brazilian reef fishery, in terms of spatial distribution (variation between states and/or distance to the coast) and technological interactions was examined looking at the catch composition by state, by gear (when only one gear was used), by vessel and by the 'trip duration' categories. It should be noted that the concept of state was not only geopolitical unit but also a geomorphological and socio-cultural unit.

II.II. Material and methods

II.II.1. Data

Data have been collected for five years (from 1996 to 2000) within the REVIZEE framework (Chapter I), a local program that aimed to gather information on the Brazilian marine ecosystem within the Exclusive Economic zone (EEZ), in 10 landing sites of the artisanal reef fishery along 5 states of the Northeastern coast of Brazil: Ceará (CE), Rio Grande do Norte (RN), Pernambuco (PE), Alagoas, (AL), Bahia (BA) (Fig. I.1). The study was based on interviews obtained during landings where information on the fishery (date, name of the vessel, landing site, fishing grounds, depth, time at sea and moon phase), vessel category (vessel type, gear, motion power and number of fishers) and landings (catches identified at species level, size of individuals and sometimes weight) were recorded. From vessels that exploited reef fishes (hereafter, 'reef fishes' means a species that may occur on reefs but is not necessarily restricted to reef), one hundred eighty seven species were reported. Species considered as 'rare' were excluded from the study. The selective criterion included the species that represent more than 1% of the total catch (in number of individuals) or species present in the catch of more than 5% of the vessel sampled. In addition, care was taken to not exclude species that would be important in some state and inexistent in others. Abundance by state was analysed but no further species were reintegrated in the analysis. The dataset became 1667 landings and 60400 individuals in 37 species (Table II.1)

Table II.1: Main species caught by the artisanal reef fishery along the Northeast Brazil. Note that 'Main species' means that the list is based on the reduced dataset.

Familly	Species	Species code	Relative abundance (%) (nb)	Occurrence %
Balistidae	*Balistes vetula*	Bal vet	0.7	6.8
Carangidae	*Carangoides bartholomaei*	Car bar	2.4	11.2
	Carangoides crysos	Car cry	2.9	15.1
	Caranx latus	Car lat	3.7	20.5
	Elagatis bipinnulatus	Ela bip	1.1	6.7
	Seriola dumerili	Ser dum	2.4	24.2
	Seriola rivoliana	Ser riv	0.2	4.3
Clupeidae	*Opisthonema oglinum*	Opi ogl	5.4	5.4
Corphaenidae	*Coryphaena hippurus*	Cor hip	2.2	26.0
Haemulidae	*Haemulon aurolineatum*	Hae aur	1.8	3.1
	Haemulon melanurum	Hae mel	0.8	4.9
	Haemulon plumieri	Hae plu	2.5	12.5
Holocentridae	*Holocentrus adscensionis*	Hol ads	1.5	8.6
Lutjanidae	*Lutjanus analis*	Lut ana	6.3	43.5
	Lutjanus apodus	Lut apo	0.4	5.4
	Lutjanus chrysurus	Lut chr	16.2	40.4
	Lutjanus cyanopterus	Lut cya	0.1	3.4
	Lutjanus jocu	Lut joc	4.2	37.8
	Lutjanus synagris	Lut syn	7.5	29.0
	Lutjanus vivanus	Lut viv	3.1	10.8
	Rhomboplites aurorubens	Rho aur	1.6	7.5
Malacanthidae	*Malacanthus plumieri*	Mal plu	0.8	7.6
Mullidae	*Pseudupeneus maculatus*	Pse mac	4.1	2.9
Rachycentridae	*Rachycentron canadum*	Rac can	0.2	4.9
Scombridae	*Acanthocybium solandri*	Aca sol	0.6	10.9
	Euthynnus alletteratus	Eut all	0.6	5.3
	Scomberomorus brasiliensis	Sco bra	2.2	13.2
	Scomberomorus cavalla	Sco cav	3.9	27.8
	Scomberomorus regalis	Sco reg	0.3	5.0
	Thunnus albacares	Thu alb	0.3	5.3
	Thunnus atlanticus	Thu atl	1.0	10.3
	Thunnus obesus	Thu obe	0.5	5.8
Serranidae	*Cephalopholis fulva*	Cep ful	2.4	15.0
	Epinephelus adscensionis	Epi ads	0.2	3.6
	Mycteroperca bonaci	Myc bon	1.3	19.0
Sparidae	*Calamus penna*	Cal pen	0.2	4.5
Sphyraenidae	*Sphyraena barracuda*	Sph bar	0.5	8.1

II.II.2. Methods

Clarke and Warwick (1994) defined a framework for the study of changes in community structure. Fish assemblage analysis may pass by 3 stages: representation of the assemblage, discrimination of site or conditions and links between abiotic factors and species assemblage. In a fishery point of view, the analysis of the catch aims at determining species that drive the fishing dynamic, discriminating fishing techniques or fishing conditions and identifying what factor may influence the catch composition.

Within this framework, statistical tools used in ecological studies are grouped into two categories: the univariate and the multivariate methods.

The univariate techniques condense the full set of species counts for a sample into a single coefficient, for example an index of the diversity or an indicator species coefficient. For diversity indexes, traditional statistical methods, such as analysis of variance (ANOVA) or regression techniques, may be applied.

Most of multivariate techniques work on the principle of similarity coefficients calculated between every pair of sample. These, then, may facilitate either a classification of samples or descriptors into groups (clustering) or an ordination plot in which samples or descriptors are mapped according to their similarity (distances between pair of items reflect their relative dissimilarity). One may choose amongst various (dis)similarity coefficients, also called ‘metrics of community structure’, present in the literature (Rice, 2000). Then, representing communities may be done by dendrograms, and multidimensional scaling (MDS) plots. The clustering techniques link samples in groups on the basis of (dis)similarity definition. The MDS method distribute spatially (usually in two or three dimensions) samples in such way that the rank order of distances agrees with the rank order of the similarities (Clarke, 1993; Legendre & Legendre, 1998). The discrimination of groups of sites or conditions may be tested by analysis of similarities techniques (ANOSIM) and species contributing for such similarity within each group and/or dissimilarity between groups may be identified. Ultimately, having treated biological information independently, any associated abiotic factors matched to the same set of samples can be examined for their own structure and its relation to the biotic pattern.

II.II.2.1. Factor and data matrices

In the Northeast Brazil, 4 factors were thought to be relevant as descriptor of fishing tactics: ‘state’, ‘vessel category’, ‘gear’, and ‘trip duration’. The ‘trip duration’ category is usually related to the vessel characteristics (propulsion, storing and catch preservation capacity) and hence the fishing grounds that could be reached. Motorised vessels typically effectuate longer trips and are able to reach fishing grounds further away from the coast. However, this cannot be generalised, as sailing boats may reach deeper water when driven by favourable winds. Thus, in order to identify what is the best descriptor between vessel category and trip duration, two ordination analysis that consider two sets of factor were tested: (1) state, vessel and gear, (2) state, trip duration, and gear.

Considering the 'trip duration' as category, each sampled vessel were discriminated by state and by 4 categories (Table II.2). Each state is identified by a two letters code: Ceará (CE), Rio Grande do Norte (RN), Pernambuco (PE), Alagoas (AL) and Bahia (BA). For example, sample grouped as CEA is designated for landings recorded in Ceará that presented a trip duration less than two days. CEB is the code related to landings recorded in Ceará that presented a trip duration between two and five days, etc. Fleet categories were designated as 'paquete' (PQT), 'jangada' (JAN), 'sailing boats' (BOV), 'motorised boats' (BOM) and 'mixed propulsion boats' (BOT) (Table II.3). Finally, the three main gears categories considered were line, gill net and trap

Table II.2: Trip duration category and equivalent fishing ground type.

Category	*Trip duration*	*mean Depth (m)*	*Fishing typology*
A	< 2 days	33	Fishing activity during the same day/fishing crepuscular time and in the following morning at rising time
B	2 – 5 days	61	Fishing along the shelf to the shelf break including canals
C	5 – 9 days	81	Fishing along the shelf break and the slope
D	>9 days	81	Fishing from the shelf break to the oceanic banks

Table II.3Fleet category description.

Fleet type	*Code*	*Depth range (m)* 25% - median - 75%	*Description*
Paquete	PQT	8 - 12 - 24	Sail, wood-made, flat shell without keel nor cabine Size<6m, no storing capacity
Jangada	JAN	14 - 30 - 42	Sail, wood-made, flat shell without keel nor cabine storing capacity (isotherm box)
Bote à vela	BOV	43 - 73.5 - 96	Sail, cabine, storing capacity size<15m storing capacity, ice
Bote motorizado	BOM	41 - 52.5 - 93	Motorised, cabine, storing capacity size<15m storing capacity, ice
Bote	BOT	82 - 93 - 115	Sail and motor facilities, cabine, storing capacity size<15m storing capacity, ice

II.II.2.2. Characterisation of fishing types

Both cluster analysis and multidimensional scaling were used. Both techniques were found ‘complementary’ to each other when viewed in combination, specially when the stress value of an MDS plot reaches high values (considered high at 0.2). The stress value represents the ‘adequacy’ of a MDS representation. Clarke (1993) found that stress values lower than 0.2 were acceptable. Due to the high number of sampled vessels, samples were averaged over groups constituted by state x (trip duration or vessel) x gear used. This showed a remarkably simple pattern analogous to an ‘additive model’ for main effects in standard univariate analyses (Clarke & Gorley, 2001). Hierarchical complete linkage cluster and Multidimensional scaling (MDS) analyses were used to discriminate landings (averaged by grouping factors) sampled along the Northeastern coast of Brazil. This characterisation was carried out by considering the pre-defined grouping factors (gears, state, and trip duration or vessel category) that were considered relevant in defining the artisanal northeastern reef fishery.

Clustering analysis aims to reduce the number of studied objects (individuals) by grouping them in homogeneous classes. The entire following analysis was based on non-metric properties combining cluster and MDS and since the precise similarity value will not have any direct significance, the complete linkage was chosen as the best appropriated linkage option. The similarity matrix was calculated using a coefficient less sensitive to missing data. In this case, the distance coefficient of Bray–Curtis was chosen. Similarity was computed as S=1-D, where D is the Bray-Curtis distance.

Multidimensional scaling (MDS) can be considered to be an alternative to factor analysis. In general, the goal of the analysis is to detect meaningful underlying dimensions that allow the researcher to explain observed similarities or dissimilarities (distances) between the investigated objects. In factor analysis, the similarities between objects (e.g. variables) are expressed in the correlation matrix (or variance/covariance matrix). With MDS, one may analyse any kind of similarity or dissimilarity matrix, in addition to correlation. MDS do not require either normality of distribution or linearity between variable. A stress coefficient indicates the fit of the graphic representation similar to R^2 in regression analyses. Each MDS representation plot here had stress values lower than 0.15. As the cluster analysis, the MDS were also carried out considering the state, vessel category, and gear or trip duration as factors. Groupings from the cluster analysis were superimposed on the MDS ordination in order to appraise the adequacy and the mutual consistency of both representations.

Analyses were based on species frequency data only as information on weight was only available for the main species caught.

In a first step, cluster and MDS plot were based on an averaged data matrix. Matrix 1 was based on the average of the frequency number by species caught during each trip within each category states x vessel x gear. For instance, the frequencies of number of each species were averaged for the category motorised boat (BOM) that used traps as a gear and operated in the state of Pernambuco and so on for all combinations between vessel types, gears and state. Matrix 2 was based on the average of the frequency number by species caught by boat within each category states x Trip duration x gear. In addition to the above technique, a two-way Analysis of similarity test (2 way ANOSIM) was used to test the significance of observed differences between groups (Clarke & Warwick, 1994). Differences according to the crossed factors 'state', 'vessel' or 'trip duration' (defined *a priori*) were tested. The gear factor was not tested as it was the least relevant for the discrimination of groups as identified through cluster and MDS analysis (but see results section).

The null hypothesis - '*no state effect allowing for the fact there may be time at sea effect*' and the opposite hypothesis '*no trip duration effect allowing for the fact there may be a state effect*' - were tested.

Differences according to the crossed factors 'state' and 'vessel' were also tested. The null hypothesis - '*no state effect allowing for the fact there may be vessel effect*' and the opposite hypothesis '*no vessel effect allowing for the fact there may be a state effect*' - were tested.

The ANOSIM analysis aimed to test statistically the groups defined with cluster and MDS analysis. The analysis was, however, based on the original matrix (landings sampled) instead of an averaged catch.

II.II.2.3. Study of the fleet dynamics through their catch composition

The Shannon index of diversity (H') (Margalef, 1958), which combines information on species richness (number of species) and how individuals are distributed among species (evenness), was calculated considering the identified clusters from MDS and ANOSIM which was thought to be relevant in defining typologies for the reef fisheries in Northeast Brazil.

The similarity of percentage analysis (SIMPER) (Clarke & Warwick, 1994; Clarke & Gorley, 2001) was used to examine the percentage contribution that each species is responsible to the dissimilarity between two groups and thus identifies those species which discriminate between groups. The Indicator species analysis (ISA) (Dufrêne & Legendre, 1997), was also performed to detect and describe the value of those species that characterise typologies. This method produces an 'Indicator Value' (IV) for each species within each group. It varies from 0 (non indicator species) to 100 (perfect indication species exclusive of the group). The 'indicator value' (IV) of a species for a partition of sites is the largest value of (IV) observed over all clusters. The significance of the maximum IV of each species was assessed by a Monte Carlo procedure, the null hypothesis being: 'Indicator value is no larger than would be expected by chance' (i.e. that the species has no indicator value). Indicator values superior to 20% were highlighted in order to visualise the 'core conservation area' of these species (McGeoch & Chown, 1998).

II.II.2.4. Linking abiotic factors to catch composition

The relationship between abiotic factors and the catch composition was examined using BVSTEP procedure (Clarke & Gorley, 2001). As an alternative to the canonical correspondence analysis, Clarke and Ainsworth (1993) proposed a method called BIO-ENV for empirically linking environmental variables to biotic matrix. BVSTEP can be compared to stepwise regression concept, using forward or backward selection (Clarke & Warwick, 1994). The routine calculates a measure of agreement between two (dis)similarity matrices. This was done by rank correlating the matching element with Spearman's rank correlation coefficient ρ. Given the exponential escalation in the number of combinations of abiotic variables that BIO-ENV has to search through, a stepwise search through the possibilities was undertaken with the BVSTEP routine. The abiotic dissimilarity matrix included the following abiotic attributes: vessels, gear, depth, number of fishers, moon light (in proportion of light), period of the year (trimester), and effort as number of fishers per days spent at sea. Normalised Euclidean distance was used. The Spearman's rank correlation (ρ) between the abiotic and biota similarity matrices was tested using a permutation procedure under the null hypothesis that there is no relation whatsoever between the two matrices.

II.II.2.5. Role of snappers exploitation in the Northeast Brazil reef fishery

From a management point of view, it is relevant to have the best knowledge of the species that really matter in the reef fishery dynamic, such as snappers in the studied area. A generalisation of the BIO-ENV routine called BIO-BIO (the abiotic matrix is replaced by the biotic matrix) allowed the determination of the small subset of species whose similarity matrix best matches the entire set of species (Clarke & Ainsworth, 1993; Clarke & Warwick, 1994). This analysis aims to find the smallest possible subset of species, which combined, 'explain' most of the pattern in the full data set. Clarke and Ainsworth (1993) found that the best subset would be defined when the similarity matrix obtained from the smallest set of species reached a correlation with the similarity matrix obtain from the full set about $\rho>0.95$, as it was found that when ρ reach this level no distinction could be found between two ordinations (note that ρ would be 1 if the full set of species was considered).

Within the determined subset, each species, particularly the snappers, contribution was looked at.

II.III. Results

The catch composition of the reef fisheries in Northeastern Brazil is composed by 187 species distributed among 14 families. However, the Lutjanidae family dominated the catch (from 1996-2000) when considered the percentage in number of fish (28.7%).

II.III.1. Determination of groups

Considering the matrix 1 (see methods), the cluster (Fig. II.1) and MDS representation (Fig. II.2) the state factor followed by the vessel category appeared to be the main factors driving the catch composition (species number and number of individuals for every species). The cluster analysis separated 10 groups at 40% of similarity (threshold arbitrarily chosen to get few clusters in numbers and well defined (Romesburg, 1984; Legendre & Legendre, 1998). In a first approach, Pernambuco, Alagoas and Rio Grande do Norte landings presented specific catch composition while Bahia and Ceará catches could not be clearly separated. Within each state cluster, the factor 'vessel' segregated better the averaged landings than the gear factor. The two way ANOSIM test corroborated these results. The global test indicated that there is a difference between groups (state effect combined to the vessel effect) (p>0.001). Also, in the overall the pairewise test showed significant differences in the catch composition between states allowing for the fact that there is a 'vessel' effect as well as between vessel taking into account the state effect (Table II.4).

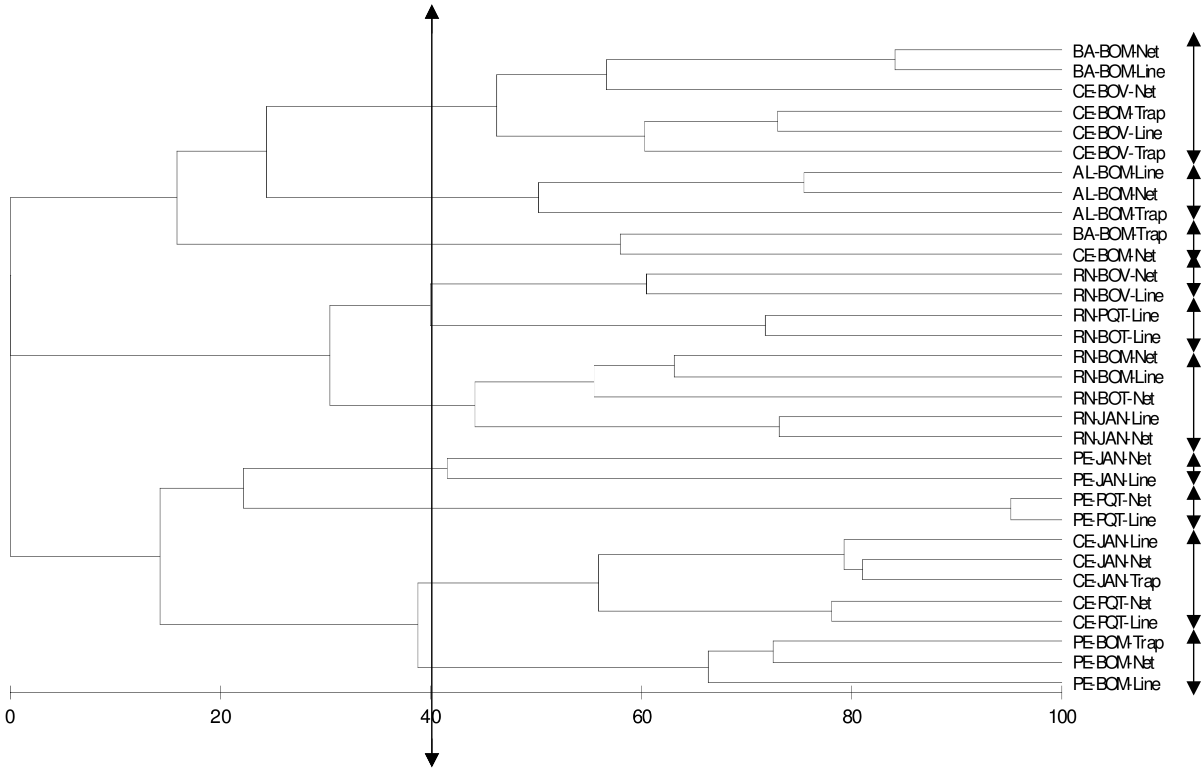


Fig. II.1 Dendrogram for hierarchical clustering (using complete linking) of catch groups State-fleet-gear based on the Bray-Curtis similarity matrix. The 10 groups separated at 40% similarity threshold.

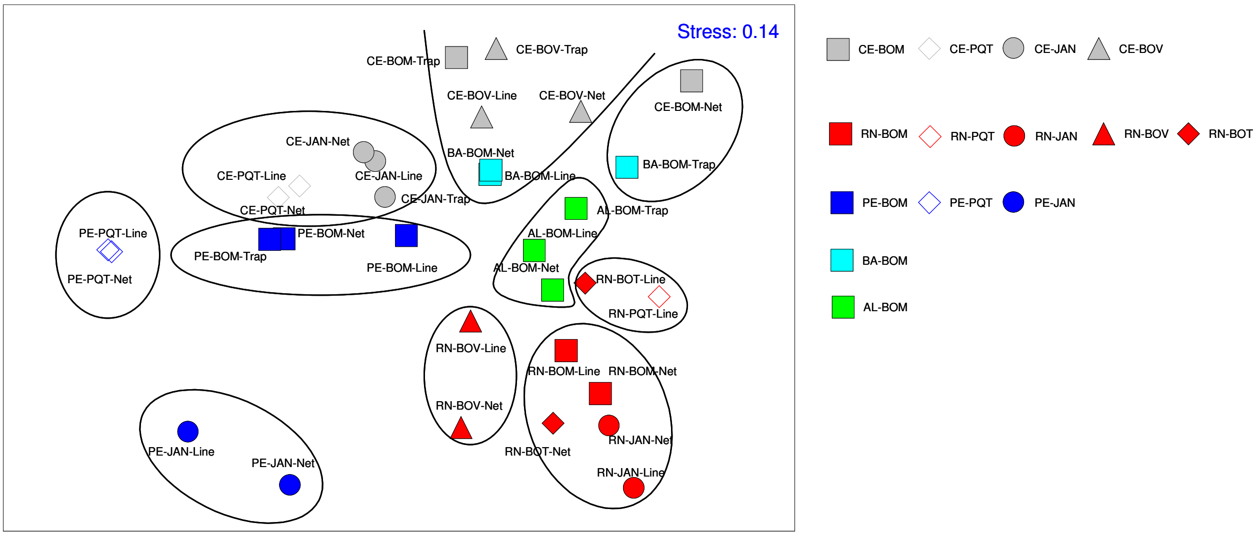


Fig. II.2: 2-dimensional MDS plot of the catch groups State-Fleet-gear based on Bray-Curtis similarity with superimposed clusters from Fig. II.1 at level of 40% similarity.

Table II.4 Results of two-way crossed ANOSIM testing differences of catch composition between states and fleet categories.

Between states groups:

Global Test
Sample statistic (Global R): 0.186
Significance level of sample statistic: 0.001

Pairwise Tests

Groups	Statistic R	Significance Level
PE,RN	-0.004	0.537
PE,BA	0.181	0.001
PE,CE	0.241	0.004
PE,AL	0.087	0.001
RN,BA	0.253	0.001
RN,CE	0.382	0.001
RN,AL	0.221	0.001
BA,CE	0.087	0.253
BA,AL	0.134	0.001
CE,AL	0.652	0.001

Between Fleet groups:

Global Test
Sample statistic (Global R): 0.151
Significance level of sample statistic: 0.001

Pairwise Tests

Groups	Statistic R	Significance Level
BOM, BOV	0.056	0.018
BOM, BOT	0.003	0.331
BOM, JAN	0.277	0.001
BOM, PQT	0.372	0.001
BOV, BOT	0.022	0.116
BOV, JAN	0.074	0.111
BOV, PQT	0.293	0.001
BOT, JAN	-0.339	0.978
BOT, PQT	0.442	0.003
JAN, PQT	0.071	0.017

The analysis based on the matrix 2 defined the groups State x trip duration (trip duration category formed sub-groups within each state). Cluster (Fig. II.3) and MDS plot (Fig. II.4) were based on averaged landings by states, trip duration and gear type. The factor 'state' and 'trip duration' appeared as the main elements driving the catch composition. The states of Pernambuco and Ceará were split into three groups, Bahia formed one group and Alagoas and Rio Grande do Norte were rather similar. In the overall, the sub-groups were defined according to the trip duration category. An ANOSIM test confirmed the differences according to the crossed factors 'state' and 'trip duration'. Both null hypothesis - 'no state effect allowing for the fact there may be gear effect' and symmetrically 'no trip duration effect allowing for the fact there may be a state effect' - were rejected at $p<0.005$ (Table II.5). Thus, from then on, the univariate and multivariate analysis were based using the trip duration category and state as relevant and best defining the typologies of the reef fishery in Northeast Brazil.

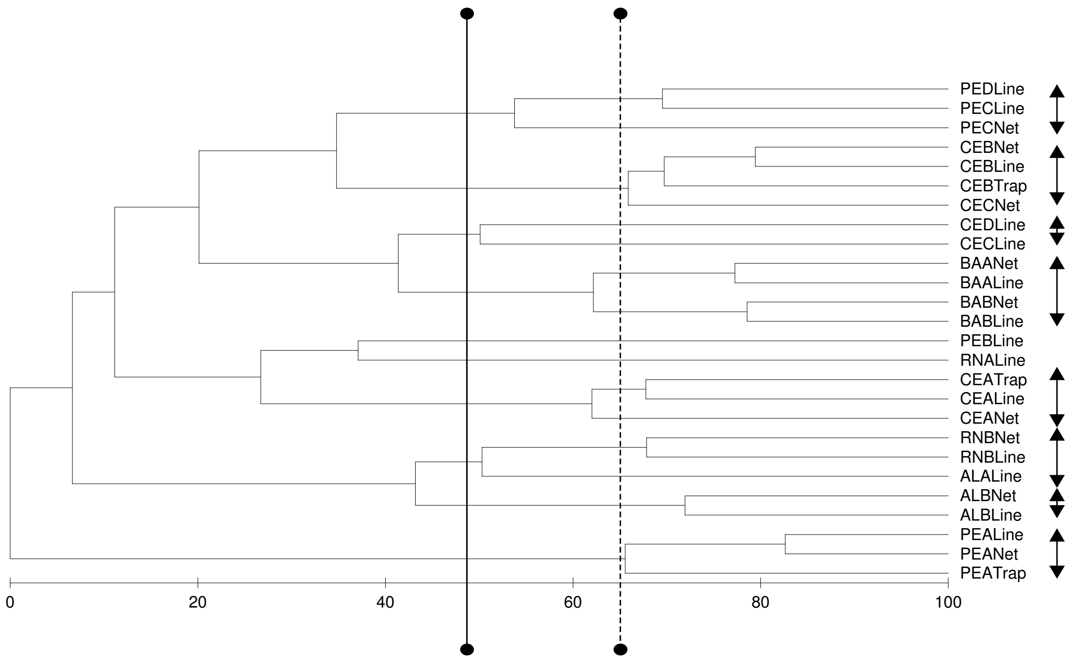


Fig. II.3: Dendrogram for hierarchical clustering (using complete linkage) of catch groups State-trip duration-gear) based on the Bray-Curtis similarity matrix. 50% and 65% similarity threshold (plain and dotted line respectively) shows that state and trip duration are the grouping factors.

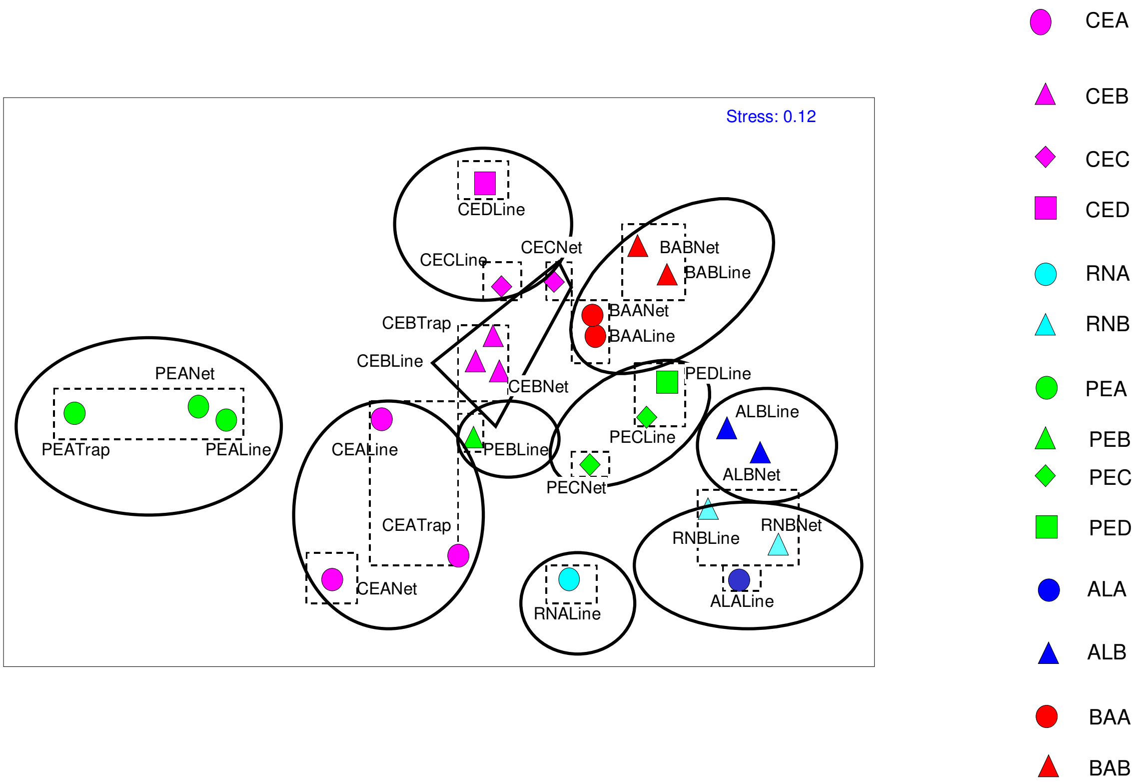


Fig. II.4: 2-dimensional MDS plot of the catch groups State-trip duration-gear based on Bray-Curtis similarity with superimposed clusters from Fig. II.3 at similarity level of 50% (continuous line) and 65% (dashed line)

Table II.5: results of two-way crossed ANOSIM testing differences of catch composition between states and trip duration categories.

Between states groups:

Global Test

Sample statistic (Global R): 0.403

Significance level of sample statistic: 0.001

Pairwise Tests

Groups	Statistic	R Significance Level
PE, RN	0.295	0.001
PE, BA	0.437	0.001
PE, CE	0.412	0.001
PE, AL	0.353	0.001
RN, BA	0.295	0.001
RN, CE	0.525	0.001
RN, AL	0.281	0.001
BA, CE	0.416	0.001
BA, AL	0.248	0.001
CE, AL	0.552	0.001

Between trip duration groups:

Global Test

Sample statistic (Global R): 0,27

Significance level of sample statistic: 0.001

Pairwise Tests

Groups	Statistic	R Signif Lev
B, A	0.249	0.0(
B, C	0.216	0.0(
B, D	0.307	0.0(
A, C	0.329	0.0(
A, D	0.447	0.0(
C, D	0.175	0.04

II.III.2. Diversity pattern of exploited fish species

The southern part of the studied area (Bahia and Alagoas) showed the highest diversity (H' index >2) while Rio Grande do Norte had the lowest diversity (H'<1) (Fig. II.5). In another hand, the category trip duration 'B' showed the highest index of diversity except for Pernambuco and, the trip duration category 'A' reported the lowest diversity. The categories trips duration 'C' and 'D' presented similar range of diversity index within state.

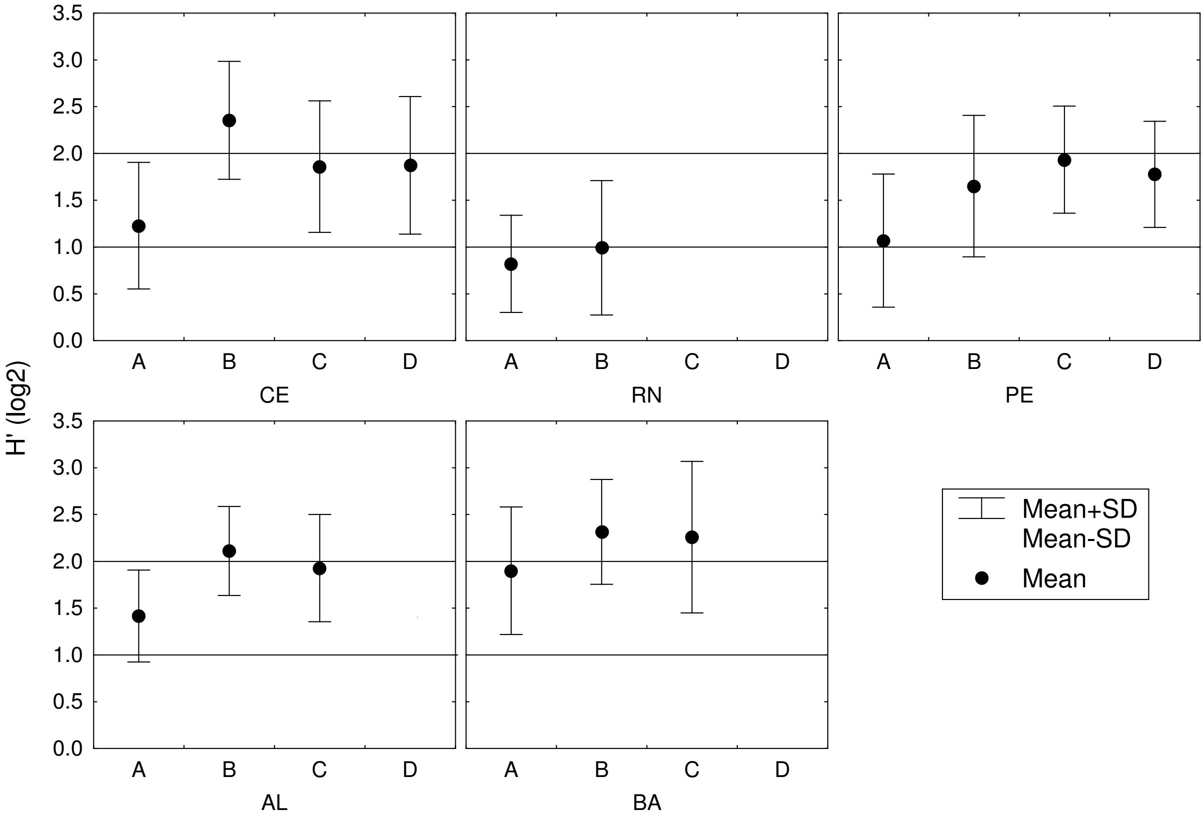


Fig. II.5: Diversity (H') and standard deviation intervals for catch landed by state and trip duration. (CE) Ceará, (RN) Rio Grande do Norte, (PE) Pernambuco, (AL) Alagoas, (BA) Bahia.

II.III.3. Typology of groups

The reef fishery in Northeast Brazil was characterised, on the overall, by 4 lutjanids species: *Lutjanus analis*, *L. chrysurus*, *L. synagris*, and *L. jocu* (Table II.6). *Coryphaena* *hippurus* and *Scomberomorus cavalla* presented also an important role for the typification of groups. Few species were found important in a particular group such as *Pseudopeneus maculatus* with 21% contribution for PEA (state of Pernambuco, trip duration category A) which was typified by one more species, *L. synagris* (62%). *L. synagris* also contributed sensibly for CEA (State of Ceará trip duration A) and for RNA (state of Rio Grande do Norte trip duration A). Important contribution were found for *L. analis* in Pernambuco (trip duration B, C and D) and in Alagoas (category A) (see Table II.6 for the complete description).

The indicator species analysis (ISA) differs from species associations analysis in that it determines which species are indicative to a particular group. Good indicator species will be found mostly in a single group of a typology and be present at most sites belonging to that group. Indicator species that were significant at $p<0.01$ were shown with * mark on the Table II.7. Largest indicator values (IV>20%, in bold in Table II.7) were found in the Ceará (A, B and D trip duration categories), Pernambuco (A) and Bahia (B). Few species characterised the fishing area as *Opisthonema oglinum* for CEA, *Holocentrotus adscensionis*, *Haemulon melanurum* and *Malacanthus plumieri* for CEB, *Lutjanus chrysurus, Rachycentron canadum, Acanthocybium solandri* for CED, *Pseudopeneus maculates, Lutjanus synagris*, *Haemulon aurolineatum* for PEA and *Caranx latus* for BAB. Some species presented low but significant IV as they were 'rare' species but restricted to a sector and therefore not considered to be here by chance.

Table II.6: Percentage occurrence of fish in each category, from SIMPER analysis. Those species, which contributed >5% to the Bray-Curtis similarity of each group are shown. (see Table II.1 for species codes)

	Cearà				Rio Grande		Pernambuco				Alagoas			Bahia	
Species	**A**	**B**	**C**	**D**	**A**	**B**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**A**	**B**
Lut ana			5.2		19.3	73.7		29.6	42.1	34.2	40.6	12.8	27.5	11.6	18.1
Lut chr		19.9	26.3	42.8	18.1			23.5	16.3	13.1		7.6	10.4	33.8	19.3
Lut syn	56.0	11.7	15.6	11.4	47.6		61.3	8.5						9.0	
Lut joc		7.2	10.0	8.7		15.5		9.5	17.0	25.7	40.1	21.9	30.9	12.9	12.0
Sco cav		6.4	12.5							7.6		6.1	8.2		7.5
Cor hip				7.3					10.0	11.3		21.1	14.8		
Ser dum												16.5			9.7
Car lat														8.0	13.8
Pse mac							21.4								
Myc bon			11.0	7.3											
Sco bra	17.2														
Opi ogl	17.2														
Car bar								7.0			9.7				
Hae plu		13.2													
Cep ful		6.8												5.2	
Hol asc		10.5													
Lut viv															
Car cry								8.0							
Aca sol				7.7											
Rho aur															
Mal plu		5.6													

Table II.7: Indicator values IV (% of perfect indication).Column header 'MaxGrp' is the group identifier for the group with the highest indicator value. Species which present a significant IV are marked by *.

		Cearà				Rio Grande do Norte		Pernambuco				Alagoas			Bahia	
Species	***MaxGrp***	***A***	***B***	***C***	***D***	***A***	***B***	***A***	***B***	***C***	***D***	***A***	***B***	***C***	***A***	***B***
Pse mac*	PEA							39	1							
Hol asc*	CEB		33	5												
Hae mel*	CEB		33	2												
Opi ogl*	CEA	31		3												
Car lat*	BAB			2	6				1		2	1			8	28
Lut chr*	CED		4	5	26	1			3	4	3			1	8	12
Mal plu*	CEB		26	5											2	
Aca sol*	CED			1	25				1	6	3		2	1		1
Lut syn*	PEA	12	5	6	8	7		23	3						2	1
Rac can*	CED	1	2	6	23											
Hae aur*	PEA	1						20								
Ser dum*	BAB				3		1		1	1		1	9		2	18
Hae plu*	CEB		17			3		4	5							
Thu obe*	BAB														6	17
Lut ana*	PEC		1	1		3	9	1	10	15	9	3	2	3	2	10
Sco cav*	BAB	1	4	8	4					1	4		2	3	1	15
Car bar*	PEB							4	15			2	1		1	
Sco bra*	CEA	15	1					3	5							
Myc bon*	CEC		1	15	12		1		1	3	1	1		3		1
Cep ful*	CEB		13	3		1		1	2						7	1
Car cry	BAB				1				9			1	1		2	11
Ela bip*	BAB									1	5				1	10
Lut joc	PED		4	7	5		2		2	7	9	2	4	7	3	8
Thu atl*	BAB												6	2	4	9
Cor hip	CED		2	2	8		1		1	8	8		7	6	1	3
Lut apo*	PEB							1	8						1	5
Bal vet	CEC		4	7	5										2	
Cal pen	CEB	1	7	3											1	
Epi ads*	BAA														7	3
Rho aur	BAB				3					1					5	6
Lut cya	BAB								1	2	1					6
Lut viv	BAB			1	4	3	1			2	4				1	4
Sph bar	CED	3		2	4							2		2	1	4
Eut all	CEB	3	4		1				2						1	
Ser riv	BAB					2				1			2			4
Thu alb	BAB								1				1	1		4
Sco reg	BAB									1	1	2	1	1	1	3

II.III.3.1. Relationship between catch composition pattern and the fishing typologies.

Each best factor combination issued from the BVSTEP procedure, that showed a higher Spearman's rank correlation, was identified for each state (Table II.8). Each correlation was found significantly different from zero, although no strong match of the catch pattern with abiotic factors were identified. An important part of the catch variation could not be explained by the abiotic factors used in the analysis. It appears that the depth, on the northern coast (Ceará), and trip duration on the southern coast (Bahia, Alagoas) maximised the correlation coefficient. The dry season (trimester 1 and 4) as well as the crew size were also important for the south states. It should be noted that Bahia presented the lowest correlation coefficient and the largest set of abiotic variables required.

Table II.8: Best combination of variables, giving the largest rank correlation ρ between biotic and abiotic similarity matrices, taken at each state along the Northeast coast. CE: Ceará; RN: Rio Grande do Norte; PE: Pernambuco; AL: Alagoas; BA: Bahia.

States	*Best combination of abiotic variable*	*Spearman rank correlation (ρw)*	*Permutation test significance level*
CE	Depth	0.435	<0.001
RN	Depth, Trimester 2	0.377	<0.001
PE	Trip duration	0.497	<0.001
AL	Trip duration, Trismester 1 and 4, crew size	0.25	<0.001
BA	Trip duration, Trap, Moonligth, Trimester 1 and 4, Crew size, Depth	0.168	<0.001

II.III.4. Determination of the 'best' subset of species that characterised the catch composition

From all the species combination possible, it was observed that 13 species were the main responsible for the characterisation of the typologies in the reef fishery in Northeast Brazil (ρ=0.952). In other words, only 13 species were required to maximise the correlation between biotic and abiotic matrices. The family of Lutjanidae was the most important family with 5 species (*Lutjanus chrysurus*, *L. synagris, L. analis, L. jocu, L. vivanus*) that showed a hierarchical structure: the best combination at one level is always a subset of the best combination at the next level (Table II.9). Species of the families Carangidae (*Carangoides crysos, C. latus, Seriola dumerili*), Coryphaenidae (*Coryphaena hippurus*), Haemulidae (*Haemulon plumieri*), Scombridae (*Scomberomorus cavalla, S. brasiliensis*), and Serranidae (*Cephalopholis fulvus*) were also relevant (Table II.9).

Table II.9: Main combinations of the 13 species (variables) determined as the subset that best represents the catch variation. The bold type indicates overall optimum. K represents the number of species combined used to calculate the matching coefficient between biotic and abiotic matrices.

k	Best variable combinations (ρ_w)
1	Lut chr **0.476**; Lut joc 0.449; Lut ana 0.434; Car lat 0.284; Ser dum 0.276; Sco cav 0.246; Cor hip 0.243; Lut syn 0.213; Cep ful 0.183; Hae plu 0.18; Car cry 0.147; Lut viv 0.133; Sco bra 0.116
2	Lut chr + Lut ana **0.613**; Lut chr + Lut syn 0.585; ...
3	Lut chr + Lut ana + Lut syn **0.731**; Lut chr + Lut syn + Lut joc 0.690; ...
4	Lut chr + Lut ana + Lut syn + Lut joc **0.799**; Lut chr + Lut ana + Lut syn + Ser dum 0.767; ....
5	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav **0.832**; Lut chr + Lut ana + Lut syn + Lut joc + Cep ful 0.825; ...
6	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu **0.857**; Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Ser dum 0.856; ...
7	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum **0.880**; ...
8	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip **0.889**; ....
9	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip + Cep ful **0.913**; …
10	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip + Cep ful + Car lat **0.926**; ...
11	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip + Cep ful + Car lat + Sco bra **0.935**; ...
12	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip + Cep ful + Car lat + Sco bra + Lut viv **0.944**; ....
13	Lut chr + Lut ana + Lut syn + Lut joc+ Sco cav + Hae plu + Ser dum + Cor hip + Cep ful + Car lat +Sco bra+Lut viv+Car cry **0.952**

II.IV. Discussion

The study of fishery dynamics and their impacts on the reef fish communities needs to look at the multispecific structure within the technological categories in space and its evolution over time. In the case of exploited marine species, identification of factors (determination of fishing typology) that influence the dynamic of the fishing activities and the structure of this community appears to be necessary, specially in multispecific and multigear tropical fisheries, by providing a synthetic representation of fishing operations as a necessary step in understanding the dynamics of mixed fisheries (Pelletier & Ferraris, 2000).

In this study, univariate and multivariate techniques were used, aiming at the identification of an integrated picture of the structure of the reef system of Northeast Brazil. Amongst the factors considered (gear, vessel category, state and trip duration category), the spatial effect (state as a factor) appeared to be the strongest attribute in separating groups in Northeast Brazil. The fishery dynamic of each state was found to be influenced by a complex combination of technological and environmental factors that drives the landing composition in each state.

Considering the technological factors, ‘trip duration’ best discriminated the catch composition when compared to ‘fleet category’. Although ‘trip duration’ categories are normally related to the fleet motion (rowing, wind motioned and motor) as motorised boats generally effectuate the longer trips, there are some exceptions reported in the Northeast Brazilian reef fishery. For example, wind motioned boats may reach as far as the shelf break favoured by strong winds in states of Rio Grande do Norte and Ceará. For this reason, trip duration was the factor that best determines the distance from the coastline, the variety and the uniqueness of the fishing grounds reached and hence the catch composition (more coastal or deeper water group of species). Although it was expected that the gear factor would separate groups of catches, the factor ‘gear’ appears to be the less representative for discriminating the catch landed. The reason for this may be that the Northeastern Brazilian fishery is typically multigear and multispecies fishery. For most fleet categories, boats may carry, during a single trip, more than one type of gear.

The complexity of the significant factors appears to be the main feature (influencing the catch composition) and is related to the fishing grounds, i.e. the distance from the shore, the fleet depth operation, and also probably their variety and their diversity. Pelletier and Ferraris (2000) state that the analysis of the Senegalese artisanal fishery dynamics could be improved if fishing locations were precisely defined. Same considerations could apply here. The trip duration was found an important factor influencing the fishery dynamics as it is commonly related to the distance from the shore and that alternative factors as information on depth are not always available.

The maximum of diversity reached at the intermediate ‘trip duration’ category depend on the habitat availability (Longhurst & Pauly, 1987; Levinton, 2001) and the ecological range of the species caught may explain the pattern found (shallow and deep species mixing at intermediate range, chapter 3).

Although in some instance the diversity may be partially influenced by the biogeography of reef assemblage (Floeter *et al.*, 2001; Joyeux *et al.*, 2001; Araújo & Feitosa, *in press*), it is interesting to note that the state with the wider continental shelf (as Rio Grande do Norte) presented lower diversity than the states with narrower continental shelf (as Alagoas and Bahia). This could be explained by the fact that fishing trips in Rio Grande do Norte do not occur much in deeper waters. Conversely, fishermen from Bahia can easily reach deeper fishing grounds thus resulting in higher index of diversity. The state of Ceará, however, showed intermediate values of diversity index which could be explained by the fact that, although with a wide continental shelf, the state of Ceará has external factors as winds and currents which drives the boat to reach deeper fishing grounds within a shorter period of time.

Snappers were the main part of the artisanal catch and contributed most to the similarity between groups. The subset that best defined the catch variability was primarily represented by snappers as *Lutjanus chrysurus, L. synagris, L. analis, L. jocu* and, to a lower extend, *L. vivanus*.

Several criteria may characterise the reef fishery of the Northeastern Brazil as for instance life history and ecology of species caught, technical characteristics, geographical characteristics (i.e. geomorphology of the shelf) (see Chapter 1) and local culture. Fishing patterns observed respond to simultaneous interaction of these attributes. Each vessel has a catchability and efficiency, which is specific to its design and to its operation range in relation to the species caught. Moreover, similar fleet may have a distinct impact consistent with the fishing area. Changes in the catch composition will incorporate technological effect through spatial and/or temporal changes.

The heterogeneity of the northeastern reef fishery described here may have consequences on an eventual choice of a model for management issues. Multispecies fishery models may be defined within two main categories, the one which account for biological interactions and models of technological interactions. Incorporating biological interaction into multispecies models present several difficulties as pointed out by Pikitch (1988). Interactions arising from technical scheme are more realistically identified and can be applied in stock assessment and management (Brugge & Holden, 1991; Gulland, 1991; Lucena *et al.*, 2002). Technical interactions in the reef fishery rely on competing fleet exploiting the same resources and on the mixed catch resulting from multiple target species (Hilborn & Walters, 1992). Fleets can exploit different stages in the life cycle of the fish stock, in simultaneous or sequential harvesting and also can involve different geographical areas. Such cases are very common in tropical fisheries that are typically multifleet and multispecies. Because technical-interactions models are rather straightforward (by opposition to biological interaction models) and are essentially derived from single-species models (Brugge & Holden, 1991), the impacts of fishing pressure on reef species and ecosystem should be investigated considering such factor (see Chapter 5).

Managers should be aware that implementation of a common harvest strategy may not be applicable for the entire zone. Every state presented proper dynamics and individual management policies should be preferred. As discussed by Hilborn and Walters (1992) if one assumes as a premise that there is a spatially structured system, a grand opportunity could arise in setting up a range of alternative management policies for the various replicates. The alternative policies can be used in a quicker way (smaller system) and in a safe way, providing a buffer against risks of overexploiting some areas. In the case of the Northeast Brazil, artisanal reef fishery stock assessment modelling and consequently harvest strategies should take in consideration that the region is not homogeneous (i.e. different fleet composition, species interactions, geomorphological characteristics). In order to refine such perception, the spatial effect from survey, in addition to more detailed information about commercial fishing activity, should be gathered.

This analysis also helped to reduce the species complexity to few ones. Within this subset, lutjanids appear to be the main group as they represented most of the catch and were found to be driving the fishery dynamics. Lutjanids are also very appreciated by the local market and are fish of a high commercial value. Thus, further attention should be paid on the ecology and on the impact of fishing on such group. Reef fishery science argues that, due to the high complexity of the system, single species assessment may not be adequate. An alternative may be on the half way between, considering models that take into account data aggregated into major species groups (Ralston & Polovina, 1982). In the present case, lutjanids should be the group of species used.

Main conclusions and thesis outlook

In this chapter, the overall picture of the reef fishery in Northeast Brazil was looked at based on univariate and multivariate techniques. These techniques were useful in obtaining an integrated picture of the structure of the system. It also helped to characterise the fishing activity in the area.

Within the reef fishery in Northeast Brazil, snappers were the main part of the artisanal catch and contributed most to the similarity between groups, outstanding the *Lutjanus chrysurus, L. synagris, L. analis, L. jocu* and in a lower extend, *L. vivanus*. Amongst the factors considered, the spatial effect (state as a factor) appeared to be the strongest attribute in isolating groups in Northeast Brazil. The factor ‘gear’ appears to be the less representative for discriminating the catches, as the Northeastern Brazilian fishery is typically a multigear fishery. For most fleet categories, boats may carry in a single trip more than one type of gear. Considering the technological factors, ‘trip duration’ best discriminates the catch composition when compared to ‘fleet category’. However, given some exceptions (mainly related to favourable strong winds), ‘trip duration’ categories are normally related to the fleet motion as motorised boats generally effectuate the longer trips. Fleet categories will be further considered in this study within the stock assessment (Chapter 6), not only because they were efficient in defining typologies in the Northeast reef fishery but also, for practical reasons, considering future management measures to be suggested for the main species exploited by the reef fishery in the region.

In order to better understand how the fleet dynamic is related to the species dynamic, the distribution of snappers (primary group of species driving the fishery) and their relationship with the fishery dynamic was studied in Chapter 3. Such information will consider the relationship between the species distribution and the dynamics of the fleets (gear used, fleet category and operating area).

Chapter III. Bathymetric trends of Northeastern Brazilian snappers (Pisces, Lutjanidae): Implications for the reef fishery dynamic

III.I. Introduction

The abundance of marine species fluctuates in space and time. Such fluctuations may be due to physical (currents, temperature, etc.), or biological processes (as growth and mortality) as well as behavioural processes (migration, habitat use) (Jennings *et al.*, 2001). Numerous studies have been conducted on spatial and/or temporal distribution of reef fish communities, as size dependent processes have long been recognised as important for the community structure and resources (Sale, 1980; Gobert, 1994)

In the case of reef fishes, it is rather common to observe size distribution according to depth (MacPherson & Duarte, 1991; Hilborn & Walters, 1992). A common pattern observed for species is the increase of the number of large specimens with increasing depth (Roberts, 1996). This pattern has been attributed to two main natural processes: ontogenetic migrations from coastal reefs to the external part of the shelf or depth related growth and mortality rates. While ontogenetic migration may be related to availability of suitable prey for juvenile fish or predation avoidance (Roberts, 1996), differential growth and mortality may be related to environmental factors. Temperature variation according to the depth gradient leads to variation in basal metabolism rates and therefore may alter the growth rate (Longhurst & Pauly, 1987). Determining the natural pattern of distribution is specially important for species that are targeted by fisheries, as the effects of fishing in a population may also be extended to population parameters.

Fishes are an important component of reef environment as they influence the structure of the communities through predation, competition, and territoriality processes (Sale, 1980). The complexity of the interaction on the reef ecosystem turns the study on fishing effect rather difficult (Jennings & Polunin, 1995b; Polunin & Roberts, 1996). In Brazil, various species are exploited by fishers mostly using hook and line, gill nets and traps. Reef fisheries, which operate mainly in the northeastern, have an important role in the socio-economic life of the region (Ferreira & Maida, 2001). However, very little is known on the fisheries dynamics operating in this area and their effects on reef fish communities. This chapter focused on five species of *Lutjanus*, which inhabit coastal to deep demersal waters. The main species caught by the artisanal fishery in Northeast of Brazil were considered: the mutton snapper *L. analis*, the yellowtail snapper *L. chrysurus,* the dog snapper *L. jocu,* the lane snapper *L. synagris and* the silk snapper *L. vivanus.* The distribution and relative abundance of these species along a depth gradient, across the Northeast Brazil continental shelf and upper slope, were described and analysed. The effects of the reef fishery on distribution, size of fish and CPUE (catch-per-unit-of-effort) of snappers considering the relationship between the species distribution and the dynamics of the fleets (gear used, fleet category and operating area) were also discussed.

III.II. Material and methods

III.II.1. Data collection

Data were collected from August 1996 to March 2000 (REVIZEE program). Species were identified and measured at the landing site. The landings sites were chosen within each state according to their contribution in the local artisanal fishery. Sites were localised over the five states, Ceará, Rio Grande do Norte, Pernambuco, Alagoas and Bahia (see Chapter I, Fig.I.1). In addition, some data were collected from research vessels that operated on the banks and oceanic islands (Atol das Rocas and Arquipélago de São Pedro e São Paulo) off the Rio Grande do Norte coast.

Fishermen were interviewed and information regarding the operation within the fishery and catch were collected. Within the REVIZEE framework, more than 69 000 records of fishes supplied by 2400 trips were gathered. For this study, nearly 23 000 fishes, which had information on depth, were considered amongst the 5 species of *Lutjanus* (Table III.1).

Table III.1: Lutjanids sampled with information on depth by states and research surveys.

Species	*Ceará*	*Rio Grande do Norte*	*Pernambuco*	*Alagoas*	*Bahia*	*Research*	**Total**
L. analis	392	178	977	103	1320	556	3526
L. chrysurus	2578	400	1092	93	5618	176	9957
L. jocu	750	79	394	142	989	167	2521
L. synagris	2271	534	1770	13	489	59	5136
L. vivanus	130	252	183	42	1090	22	1719
Total	6121	1443	4416	393	9506	980	22859

Information on specific landings and effort (number of boats) by fleet category were collected for the studied period by the program 'ESTATPESCA' held by the Brazilian Environmental Agency for official statistics (IBAMA, *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renovaveis*). The total number of boats (averaged along the months) that were in activity during the studied period were about 17000 boats. The reef fishery can be distributed into five categories of fleets classified as following, from the most rudimental to the most technically advanced fleet: 'Paquete' (PQT), 'Jangada' (JAN), 'Bote a vela' (BOV), 'Bote' (BOT), 'Bote motorizado' (BOM) (see Table II.3 for details).

III.II.2. Data analysis

The relationship between depth and fish size was assessed by correlation and regression analyses. The correlation analysis was used to test the statistical significance of the relationship for each species. The correlation between depth and size was determined for all species using non-parametric Spearman's rank correlation coefficient. One of the advantages of the non-parametric correlation is that the resulting coefficient is not influenced by outliers that are often present in biological data. Also, normality in depth and fish size data is not required to perform the analysis. The regression analysis was performed using the Kendall's robust line-fit method (1990) described in Sokal and Rohlf (1995). Since slopes from all pairs of observations required to be computed and stored, the vast amount of calculation needed drove us to use only a random sample of paired observations. As for non-parametric correlation, the non-parametric regression does not require normality of data, the slope of the regression curve is not affected by outliers, and it allows the independent variable being either of the Model I or Model II type (Model I regression assumes that (1) the independent variable X is controlled by the observer, (2) there is no observation error, (3) process error are normally distributed with a mean=0 and (4) samples along the regression line have a common variance which is the variance of the error term, Model II assumes that both variables Y and X are measured with error, and it gives a regression line lying between the Y on X and the X on Y regressions. The model II regression estimates a slope between two variables that are meaningful only when measurement error is the sole cause of statistical error.). Kendall's rank correlation was used in order to test whether the slope (β) for each species was different from zero.

Catches were analysed by gear, which were arranged amongst the following categories: line, net and trap. Minimum, maximum and average values of fish size were analysed by gear in order to describe the gear effects on the life history of the species. For each species, catches were also analysed by sampled year and fleet category. Catch-per-unit-effort (CPUE) was used as an index of relative abundance. The catch was defined in two different ways: (1) by using total weight (Kg) caught by species and (2) by using number of individuals caught.

Furthermore, in order to standardise the effort between gears, the time (days) spent at sea for each trip was chosen as the best estimate. In spite of the roughness of the unit of effort, catch and effort for each species were positively correlated (Spearman's correlation $r = 0.5$, $p < 0.001$). The CPUE analysis was carried out species specific considering the following depth strata: < 20m (inner shelf), 20 to 80m (outer shelf), and >80m (slope) (Mabesoone & Coutinho, 1970). The outer shelf zone was not detailed for size distribution analysis as information on effort was too much scarce. The Kruskall -Wallis non-parametric test was used to test the differences of the CPUE index between depth strata. We also looked at CPUE *versus* depth strata relationship using Spearman's rank correlation analysis.

III.III. Results

III.III.1. Catch composition of *Lutjanus* species by year, gear, depth and fleet

All five species showed a positive and significant correlation between the fork length and the depth (Table III.2).

Considering all gears pooled together, the fish size caught ranged for snappers from 7.5 to 103 cm FL. Mean fork length by species showed a decreasing trend from 1997 to 1999 (non significant for *L. jocu*) except for *L. chrysurus* that showed a significant increasing trend in the mean size (Fig. III.1).

Table III.2: Spearman's rank correlation coefficients (r) and slope (β) between depth and fish size. **Note**: *** is p<0.001, n is the number of specimen measured for each species, n1 is the total number of two point slopes, n2 is the number of slope randomly sampled used to estimate β (median of the β's of each two points slope). See robust line-fit for method (Sokal and Rohlf, 1995).

Species	*r*	*n*	*β*	*n1*	*n2*
L. analis	0.40***	3526	0.217***	6214575	7515
L. chrysurus	0.29***	9957	0.071***	49565946	7354
L. jocu	0.18***	2521	0.089***	3176460	7540
L. synagris	0.35***	5136	0.138***	13186680	7723
L. vivanus	0.13***	1719	0.023***	1476621	6993

Line fishery caught snappers from 7.5 to 99 cm FL, while nets caught individuals from 13 to 85 cm FL and traps caught individuals from 16 to 103 cm FL (Fig. III.2). Analysing the catch composition by species, every gear (note: the term gear is used as a generic term that represents the entire category, e.g. 'Net' represents all nets used in the fishery that encompass every selectivity characteristics) affected roughly the entire size range of the snapper populations (Fig. III.2). The fork length of snappers caught by all the three gears significantly increased according to depth (ANOVA, F=1296.2, df=2, p<0.001) (Table III.3). The operating depth range was higher for line but shallower for net and traps (Table III.4a). Paired gear groups were tested using the Mann-Whitney U procedure. Line depth operation was significantly different from net and trap (p<0.001), where no difference could be distinguished between net and traps. Lines, nets and traps caught individuals of similar size for all species. Fishers using hook and line operated preferentially along the outer shelf. Net users occurred preferentially in the shallow water (inner shelf) and the outer shelf and, traps were set up preferentially within the 20-80 m (Table III.4b). Largest specimens of each species were caught at deeper limits of the species range.

When analysed by fleet category, on the overall, BOM affected roughly the entire fish size range. The PQT fleet always caught smaller individuals, while JAN, BOT, and BOT oscillated within the intermediate size range (Fig. III.3). The PQT and BOV or BOT were restricted to, respectively, inner and outer shelf and, outer shelf and slope (Table III.5). The fleets JAN and BOM fished along the entire depth range (Table III.5). Similar pattern was observed for median operating depth and proportion of fleet (Table III.6). As a general pattern, small individuals were exclusive to shallow waters and larger ones to deeper waters; an intermediate zone presented a mixed sized fishes (Fig. III.4).

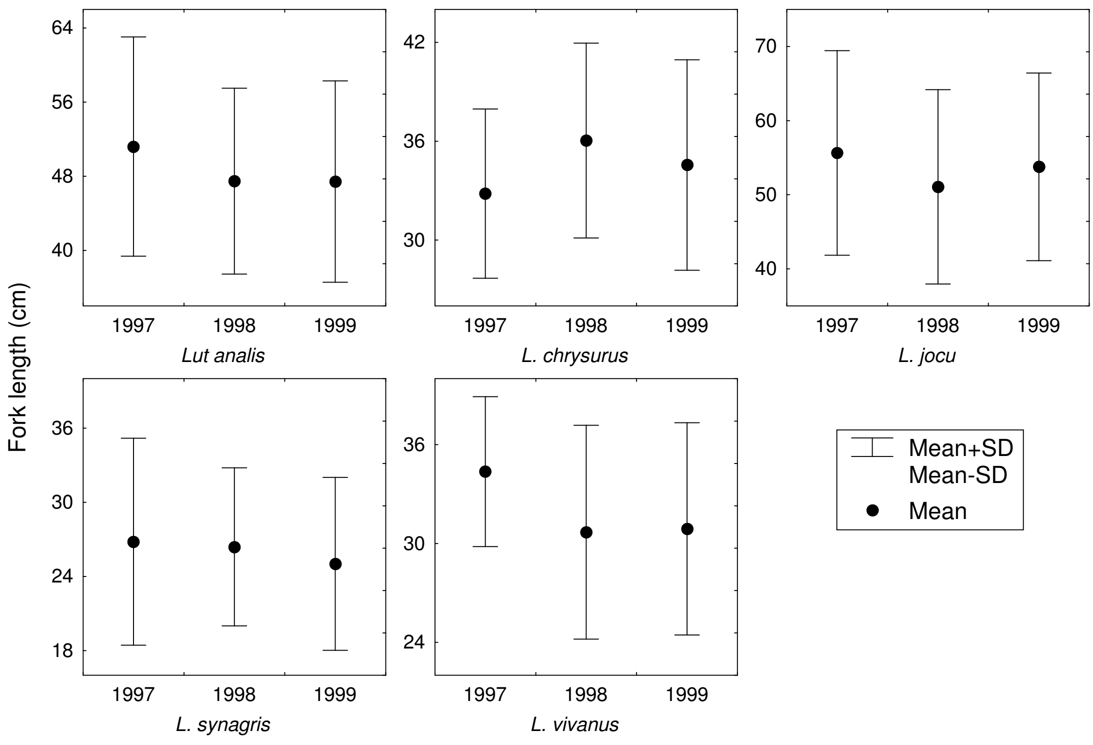


Fig. III.1: Mean size (cm FL) ± standard deviation of each species exploited along the Northeastern coast during the studied period (complete sampled years).

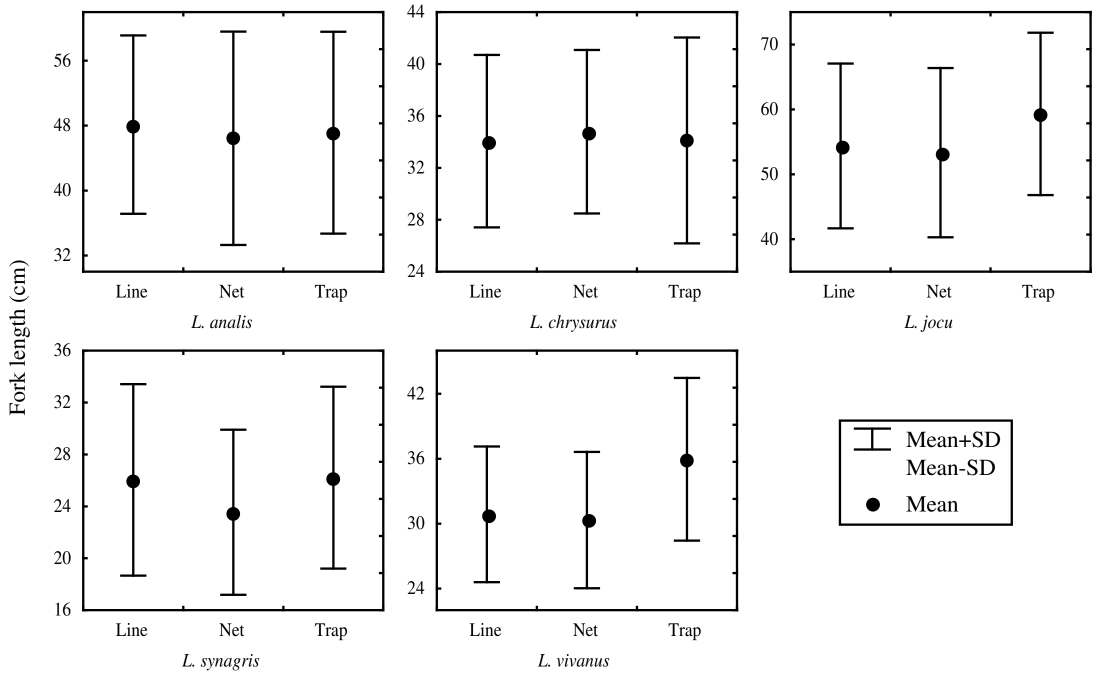


Fig. III.2: Mean size (cm; FL) ± standard deviation of the five main snapper species caught by the three main gear categories (Line, Net and Trap).

Table III.3: Mean fork length (cm) ±SD of the five snappers (*L. analis, L. chrysurus, L. jocu, L. synagris, L. vivanus*) by gear and depth layer.

Depth (m)	*Line*	*Net*	*Trap*	*All*
<20	23.4 (7.3)	22.1 (6.5)	27.3 (10.1)	23.1 (7.2)
20-80	36.9 (11.9)	35.6 (11.9)	35.5 (14)	36.6 (12)
>80	39.8 (12.3)	37.8 (11.7)	38.2 (13.7)	39.3 (12.3)

Table III.4: (a) Median and quartiles of depth (m) of operation for each gear, and (b) proportion (%) of gear used by depth layers.

(a)

Gear	*Quartile 25%*	*Median*	*Quartile 75%*
Line	27	43.5	63
Net	12.6	34	52.5
Trap	27	36	44.3

(b)

Depth (m)	*Line*	*Net*	*Trap*	*All*
0-20	25.1	40.3	24.6	28.1
20-80	53.2	45.6	60.0	51.9
>80	21.8	14.1	15.4	19.9
Total	100	100	100	100

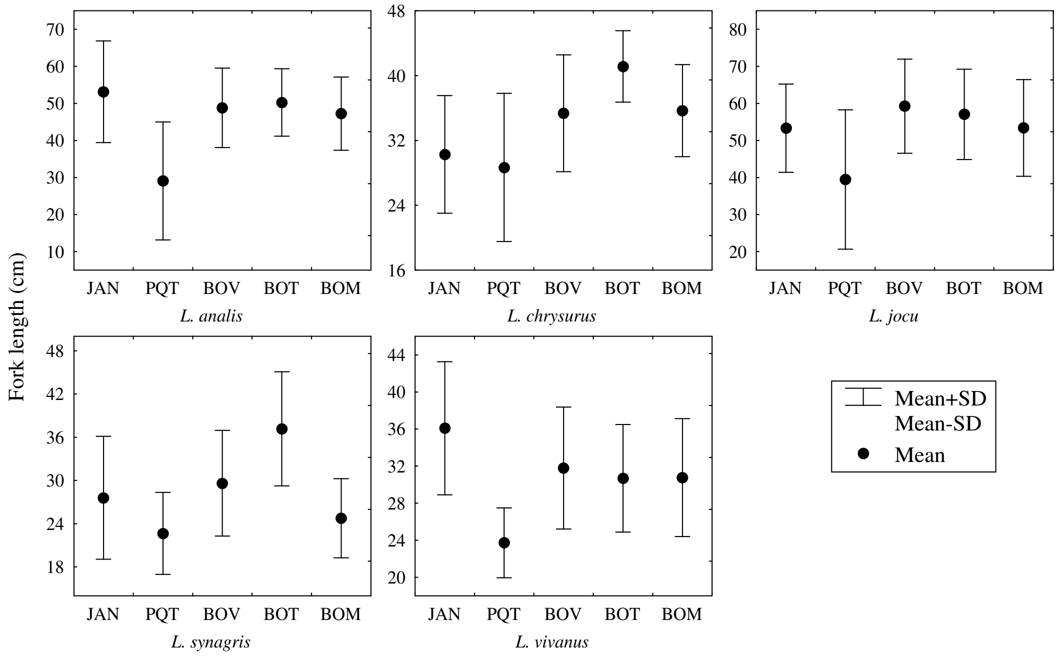


Fig. III.3: Mean and range size (cm FL) of the five main snapper species caught by the five main fleet categories 'motorised boat' (BOM), 'jangada' (JAN), 'paquete' (PQT), 'mixed powered boat' (BOT), 'sailing boat' (BOV).

Table III.5: Mean fork length (cm) ±SD of the five snappers by fleet category and depth layer.

Depth layer	*JAN*	*PQT*	*BOV*	*BOT*	*BOM*
<20	12.7 (4.28)	13.3 (5.34)			18.1 (0.79)
20-80	41.3 (12.14)	31.2 (8.8)	61.4 (12.44)	63.5 (4.01)	46.3 (12.33)
>80	96.1 (10.24)		111.7 (21.18)	117.3 (16.07)	106.2 (20.97)

Table III.6: (a) Median and quartiles of depth (m) of operation for each fleet category and (b) proportion (%) of fleet by depth layers.

(a)

Fleet	*Quartile 25%*	*Median*	*Quartile 75%*
BOM	42	52.5	97.5
JAN	31	37.5	48
PQT	10.5	19	20
BOT	93	127.5	127.5
BOV	60	75	108

(b)

Depth (m)	*JAN*	*PQT*	*BOV*	*BOT*	*BOM*	*All*
<20	13.1	69.5			1.5	9.0
20-80	82.0	30.5	54.4	12.6	68.5	67.7
>80	4.9		45.6	87.4	30.0	23.2
Total	100	100	100	100	100	100

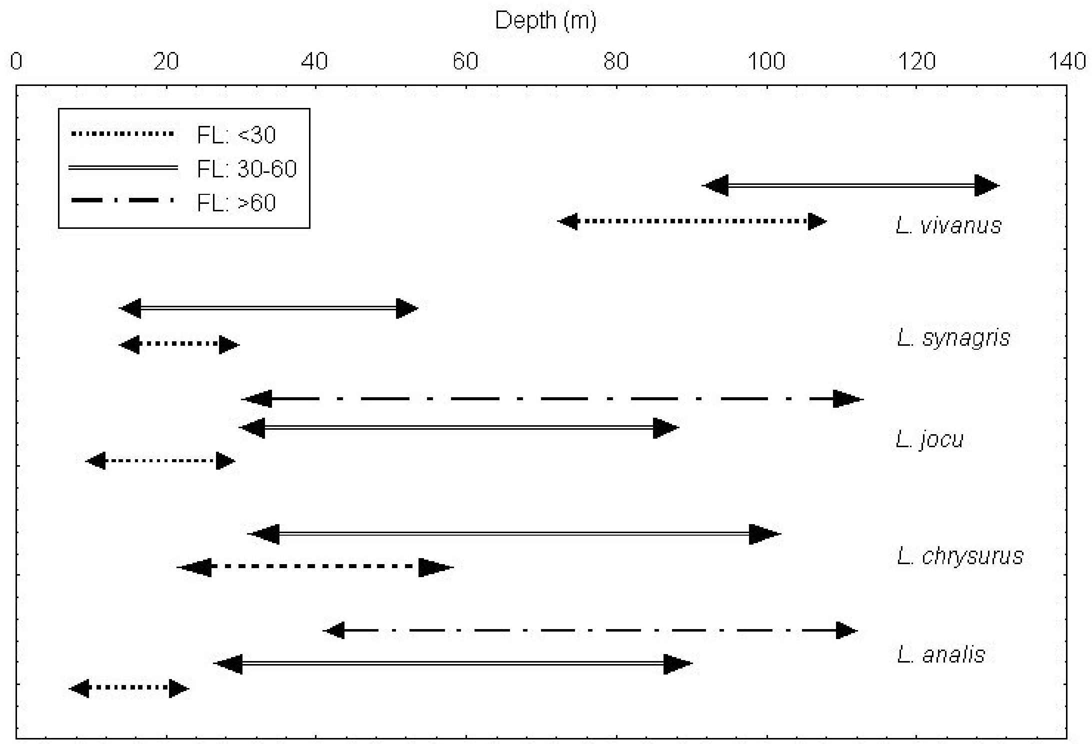


Fig. III.4: Size distribution (cm) of the five *Lutjanus* species (FL= fork length) according to the depth in the studied area.

III.III.2. Catch per unit of effort (CPUE) *versus* depth relationship

Although snappers have a wide range of distribution, differences between species were detected. The maximum relative abundance (numerical and biomass CPUE) of the *Lutjanus* species varied according to depth. *L. synagris* and *L. vivanus* were more abundant at the extremes of the snappers distribution range: shallower and deeper waters respectively. The three other species (*L. analis*, *L. chrysurus*, and *L. jocu*) showed a smoother distribution with a maximum abundance reported in the 20 - 80m depth strata, the outer shelf part (Table III.7a and 7b). The relationship between the numerical CPUE (individuals caught per day at sea) and the depth was negatively correlated for *L. synagris, L. jocu, L. chrysurus,* and *L. analis*. *L. vivanus* presented a non-significant positive relationship (Table III.8a), while the relationship between the depth and the CPUE in kg per day at sea was negative for *L. synagris*, positive for *L. analis* and *L. vivanus*, and non significant for *L. chrysurus* and *L. jocu* (Table III.8b).

Table III.7: (a) Mean CPUE (kg/time at sea) by species and depth strata, and (b) Mean CPUE (Number of individuals/time at sea) by species and depth strata.

(a)

Depth	*All*	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*
<20	6.0	1.6	3.5	1.2	**6.5**	--
20-80	**10.8**	**2.1**	**8.5**	**2.1**	5.3	2.8
>80	6.9	1.2	8.0	1.1	1.7	**3.9**

(b)

Depth	*All*	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*
<20	1.7	1.0	0.5	0.3	**1.8**	--
20-80	**12.6**	**9.6**	**4.8**	**5.2**	1.4	1.4
>80	8.6	4.6	5.1	3.6	0.5	**2.2**

Table III.8: Spearman's rank correlation coefficients, probability and sample size (n) of the relationship between depth and CPUE (bold and underlined coefficients are significant at 5%), and (a) numerical CPUE, (b) biomass CPUE. (Note that n varies from Table III.1 according to the available information about effort, also n varies from 6a to 6b according to available information on individual weight / or size)

(a)

Species	*r*	*p-level*	*n*
All	**-0.06**	0.029	1227
L. analis	**-0.19**	<0.001	597
L. chrysurus	**-0.16**	<0.001	567
L. jocu	**-0.27**	<0.001	518
L. synagris	**-0.27**	<0.001	614
L. vivanus	0.13	0.153	132

(b)

Species	*r*	*p-level*	*n*
All	**0.45**	<0.001	1224
L. analis	**0.09**	0.025	594
L. chrysurus	0.03	0.467	567
L. jocu	-0.05	0.284	518
L. synagris	**-0.12**	0.003	614
L. vivanus	**0.21**	0.018	132

Fleets mostly operated between 20 and 80 m (51% of the total number of trips) (Table III.9), where the maximum of lutjanids abundance index is reported, affecting mainly the adults of *L. analis* and *L. jocu* (> 30 cm FL) and, both juveniles (< 23 cm FL) and adults of *L. chrysurus* (Fig. III.4). Within, the outer shelf (20-80 m), depth stratum 20-40 m concentrated 20% of trips, which influenced young adults (> 30 cm) of *L. jocu*, and both juveniles and young adults of *L. synagris* and *L. chrysurus*, in return the depth stratum 40-80 m concentrated 31.3% of the trips.

Table III.9: Effort allocation in number of trips by depth layer by fleet category. Total N: 1667 trips (note that N is the number of landings with available information on vessel category)

Depth	*PQT*	*JAN*	*BOV*	*BOT*	*BOM*	**Total**
0-20	13.5	11.7	0.1	0.1	1.8	27.2
20-80	2.3	15.7	1.8	0.3	31.3	51.3
>80	--	0.7	1.5	1.4	17.9	21.6
Total	15.8	28.1	3.4	1.8	51.0	100

III.III.3. Fleet interactions and catch composition *of Lutjanus* species by fleet

Motorised boats 'Botes Motorizados' (BOM) and wind motioned 'jangadas' (JAN) were the most important fleet categories captures lutjanids with respectively 51% and 28% of the total number of trips during the studied period along the northeastern coast (Table III.9). Motorised boats operated mostly from 20 m towards offshore (over 80 m deep) whilst JAN fished from the coast up to 80m deep. Sailing boats (BOV) and mixed boats (BOT) represented 5% of the total number of trips with an operation range mostly above 80 m. PQT represented 15% of the total number of trips and operated mainly from the coast up to 20 m deep.

The snappers' catch composition (Fig. III.5) shows that motorised boats (BOM) was the main category that fished on the five studied species as they operated along the entire depth gradient (Table III.9). However, *L. synagris*, that inhabits shallower waters, was less affected by motorised boats but it was the main target of the wind propelled 'paquetes' (PQT) and 'jangadas' (JAN). Conversely, *L. vivanus,* which inhabits deeper waters, was targeted almost exclusively by boats (Bom and BOV). The remaining species were mainly caught by motorised boats although 'jangadas' (JAN) had a significant role in the exploitation. As fishing activity was greater at shallow (<20 m) and intermediate depth (20 to 80 m), where rudimental fleet and more advanced technologically fleets overlap, fishery in Northeast of Brazil affects mainly species that inhabits preferably this depth layer (*L. analis*, *L. jocu* and *L. chrysurus*).

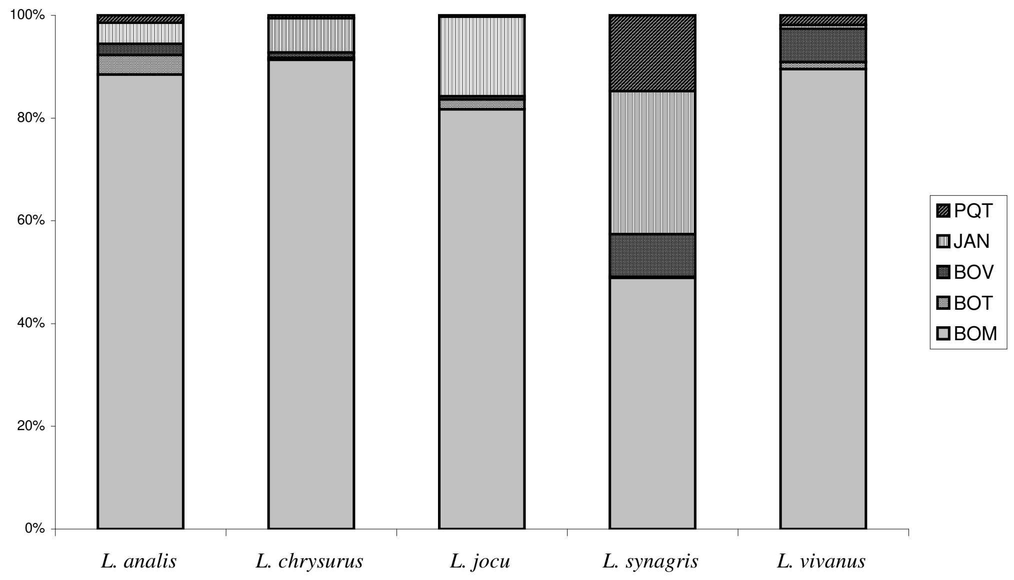


Fig. III.5: Proportion of the main fleet categories that exploit the five lutjanids species studied.

The 'jangadas' (JAN) fleet category was the most numerous fleet in activity along the northeastern coast, from Ceará to Alagoas (53% of total operating boats) (Table III.10), followed by the motorised boats category (BOM) with 22.4% of the total fleet. However, although motorised boats were less numerous, their fishing power was greater than 'jangada's' ones and, landings of motorised boats (BOM) and 'jangadas' (JAN) equally represented 27% of the *Lutjanus* catches recorded by the Brazilian official statistics during the period from 1997 to 2001 (ESTATPESCA). Motorised boats (BOM) and sailing boats (BOV) showed the greater yield considering the biomass, CPUE and the numerical CPUE. BOM yielded 13.7 and BOV 9.6 kg / days spent at sea whilst JAN yielded 6.1 kg/ days (Table III.11a and III.11b).

Trip duration (days spent at sea) was different amongst fleet categories and states (Table III.12). While small fleets, 'paquete' (PQT) and 'jangada' (JAN), spent at sea no more than two days, more sophisticated fleets trip duration (BOM, BOV) could reach 12 days at sea. However, differences between states were recorded. 'Jangadas' (JAN) from Ceará and Rio Grande do Norte spent, in average, 2 days at sea whilst, in Pernambuco, trip was restricted to a day. Motorised boats (BOM) time at sea ranged from 1 - 2 days in Bahia to 4 - 5 days in Pernambuco, Alagoas and Rio Grande do Norte. In Ceará trips of Motorised boats (BOM) may last up to 12 days .

Table III.10: Boats in activity, registered by the national fishery statistic program (ESTATPESCA) by state along the Northeastern coast during the studied period. Note that the BOT category is not reported by the program.

Fleet	*Ceará*	*Rio Grande do Norte*	*Pernambuco*	*Alagoas*	*Bahia*	**Total**
PQT	11.2%	4%	--	--	0.8%	16%
JAN	10.6%	12.6%	10.9%	11.8%	6.8%	52.7%
BOV	2.7%	4.8%	--	1%	0.3%	8.9%
BOM	5%	6.1%	5%	3%	3.3%	22.4%
Total	29.5%	27.5%	15.9%	15.8%	11.2%	100%

Table III.11: Relative abundance, catch per unit of effort ((a) numerical CPUE in number of fish per day, (b) biomass CPUE, in kg.day-1), by fleet category for the five lutjanids species.

(a)

Fleet	All	L. analis	L. chrysurus	L. jocu	L. synagris	L. vivanus
PQT	5.2	1.4	4.1	1.1	5.7	–
JAN	6.4	1.3	3.8	1.8	4.4	1.7
BOV	7.3	0.9	7.6	1.7	2.1	2.4
BOT	4.1	0.9	–	0.9	–	–
BOM	11.9	2.2	11.3	1.9	8	3.3

(b)

Fleet	All	L. analis	L. chrysurus	L. jocu	L. synagris	L. vivanus
PQT	1.8	1.7	1.6	1.1	1.5	–
JAN	6.1	7.0	1.6	4.6	1.3	1.4
BOV	9.6	2.4	5.5	6.3	1.6	1.9
BOT	4.8	2.2	–	3.5	–	–
BOM	13.7	8.9	6.8	4.8	2.0	1.7

Table III.12: Averaged time spent at sea (days/trips) by state and fleet category.

State	*Fleet*	*time at sea*
Ceará	PQT	1.3
	JAN	2.2
	BOV	11
	BOM	12.7
Rio Grande do Norte	PQT	1.8
	JAN	2.3
	BOV	1.8
	BOT	2.9
	BOM	3
Pernambuco	PQT	1
	JAN	1
	BOM	4.5
Alagoas	BOM	4
Bahia	BOM	1.7

III.IV. Discussion

Patterns of the relationship between body size and abundance in natural assemblage have been documented for a number of animal taxa (Gaston *et al.*, 1993). Also, in a fishery context, an increase of the number of large specimen with increasing depth is commonly observed (see review in Roberts, 1996). Our results indicated that significant body size *versus* depth relationship has been observed for each species. Bathymetric distribution according to demersal fish size has been already reported (Lukens, 1981; MacPherson & Duarte, 1991). The relationships, examined in our study, showed a general trend going towards a greater size with increasing depth and at the same time towards smaller size in shallower waters, a result also reported in various studies (Rooker, 1995; Machias *et al.*, 1998; Rex & Etter, 1998). However, the depth- body size relationship is weaker at intermediate depths due to a spatial overlap. Indeed, when small individuals are exclusive to shallow waters and only large ones are caught in deep waters, mixed catch of medium and large fishes is reported at intermediate depths. This movement may be related to feeding and reproductive habits (Uiblein, 1991; MacPherson, 1998; St-John, 1999; Grutter, 2000; Carrasson & Matallanas, 2001).

Oliveira (2000) reported that, in the Northeastern Brazilian waters, maximum relative abundance (CPUE) of teleosts on the external part of the shelf and the slope was observed within the depth strata of 100 – 150 m. In this study, the maximum abundance of four *Lutjanus* species (*L. vivanus* did not present a significant pattern) was negatively correlated with the increasing depth, when numerical CPUE was considered but the relation changed when biomass CPUE was considered. Individuals were caught in greater number in shallow waters but as most of them were small sized fishes, the relationship between CPUE index, considering weight, and depth showed a mixed pattern. Several hypothesis have been offered to describe this pattern, including differential mortality or growth with depth or migration to deeper water with increasing size (Roberts, 1996). Ecological characteristics of shallow and deep waters may be responsible for such distribution. Shallow waters feature shelters for younger fish, as they, generally, have a higher productivity and are inhabited by small preys that are also targeted by young, small sized fish. The maximum length reported for the *Lutjanus* species (*L. analis*: 94 cm FL, *L. chrysurus*: 87 cm FL, *L. jocu*: 128 cm FL, *L. synagris*: 60 cm FL, *L. vivanus*: 83 cm FL) (Allen, 1985) is similar to the maximum length registered for the Northeast Brazilian catches. For all species, young individuals were also caught. Hence, the three main operating fishing gears (traps, lines and gill nets) affect almost the entire range of the life history of the *Lutjanus* species. However, gears caught fishes of similar size for all species. Different category of fleet were discriminated by depth of operation although no great differences were found in mean size caught.

In a multispecific perspective, the fleet/gear comes into contact with stocks of different species, and a mixed catch result due to the exploitation of technologically interdependent species (Anderson, 1986). In such a context, the technological interactions is not only related to the selection of part of the stock but also with the selection of the species caught. Considering the species' distribution and the multispecific nature of the reef fishery in Northeast Brazil, fleet operation may vary from shallow to deep waters depending, amongst others factors (environmental conditions, motorised or wind motioned boats, shelf width, trade winds, etc), on the availability of a typical coastal species (as *L. synagris*) or a typical deeper-water species (as *L. vivanus*). Considering such stratified distribution, fleets with different operation capacities will affect stocks on different ways.

These differences may not be necessarily related to gear (a boat in tropical fishery may carry more than one gear) but also to the fleet power, which is related to fleet category, and also to the state, due to its environmental characteristics. Fishing grounds, i.e. shallow or deep waters, will be reached according to fleet power. Factors as engine power, 'size' of the crew, carrying capacity, presence or absence of ice are related to the distance to the shore and hence, the time at sea. Additionally, environmental conditions such as wind, rain, currents, or the continental shelf width may influence the access to shallow or deep fishing grounds.

Our results highlighted that technological interactions will affect the catch composition and therefore the fishing impact on snappers. All fleets categories mostly operated within the 20-80 m depth zone, what consequently affected mostly *L. analis*, *L. jocu* and *L. chrysurus.* Motorised boats (BOM) affected mainly *L. vivanus* because of its deeper waters fleet operation. 'Jangada' (JAN) and 'paquete' (PQT) had as their main target *L. synagris* since they operate in shallower waters.

Also, climatic, oceanographic or geographic characteristics as winds, currents or geomorphology of the shelf may influence the fleet operation and catch composition. For example, wind motioned boats, PQT, JAN, BOV, in Ceará had a greater operating range, and therefore affect a greater number of species, due to the dominant winds that allow the vessel to reach deeper waters.

Fleets are likely to exploit different stages of the life cycle of a fish community while operating in different geographical areas, in simultaneous or sequential harvesting (Charles & Reed, 1985). Fisheries of the same fish community are linked through their exploitation. To maintain the sustainability of the stock and to guarantee the continuance of the resource, the optimal fleet mix and catch allocation should be carefully considered (Kulbicki *et al.*, 2000; Labrosse *et al.*, 2000; Letourneur *et al.*, 2000; Lucena *et al.*, 2002).

The multifleet and multispecies nature of the northeastern Brazilian fisheries has various consequences in terms of resources management and ecological issues. In the study area, few marine protected areas (MPA) have been created along the coast as a part of a new management alternative of reef ecosystems (Ferreira, 2000). Some marine protected areas have been set parallel nearby the coast, mainly because of logistical reasons, i.e. zone easily accessible and that can be watched from the shore. This setting would only preserve part of the life cycle of some species, excluding other parts of life cycle and, possibly, other species. Due to the within and between fish species spatial structure, the MPA design will have consequences on its efficiency (Kramer & Chapman, 1999). In small reserves near the shore, snappers' home range will exceed the MPA limits. Considering the reef fishery in Northeast Brazil, the MPA might be most efficient if set in direction to the off-shore in an attempt to protect the entire range of fish distribution and consequently the entire life cycle of the species. This could also offer some protection of various kind of habitats used by different stage of the life-cycle of each species.

Although one is aware that a dataset originated from commercial fisheries may only partially represent the fish community because of gear selectivity and fishing tactics, one may consider that variations in the effort and/or gear fishing power represent the actual trend in the fish distribution (fishers go where the fish is). More attention should be given on technological interactions and multispecies aspects of the reef fishery in Northeast Brazil as stock assessment models for the management of single species fished by one type of gear (or fleet) may be inadequate to apply to the northeastern Brazilian fisheries and to predict changes at the assemblage level (Pikitch, 1988; Hilborn & Walters, 1992). The inter- and intra-specific bathymetric distribution and the multifleet character of the Northeastern Brazilian reef fishery demonstrate that considering only one category of a fleet will likely bias our assessment on the real impact of fishing activities.

Main conclusions and thesis outlook

In this chapter, the bathymetric trends of Northeastern Brazilian snappers were described and its relation with the reef fishery dynamic were considered. For all species, small fish are generally found near the coast in shallow waters and the larger fish are found off-shore in deeper waters. In terms of abundance, mean maximum relative abundance varied, for each species, from the shallow water layers with *L. synagris* to the deep water layers with *L. vivanus*. Gears catch fishes of similar size for all species and affect almost the entire range of their life history. Fleets with different operation capacities will affect stocks on different ways and this is mainly related to the fleet power, which is related to fleet category. All fleets categories mostly operated within the 20-80 m depth zone, what consequently affected mostly *L. analis*, *L. jocu* and *L. chrysurus.* Motorised boats affected mainly *L. vivanus* because of its deeper waters fleet operation. JAN and PQT had as their main target *L. synagris* since they operate in shallower waters.

For the next chapter, the status of the *Lutjanus* species will be assessed and it will be evaluated the applicability of traditional methods (as yield per recruit model and length based methods). These methods are widely applied for the assessment and management of tropical fishery. Fishing mortality and stock size are parameters to be estimated for each of the studied species.

Chapter IV. Stock Assessment of snappers using traditional approaches

IV.I. Introduction

The basic purpose of fish stock assessment is to provide managers advice on the optimum exploitation of the aquatic living resources to guarantee a sustainable production over time (Sparre & Venema, 1998). Broadly, fisheries management is concerned with the utilisation of the fish as a resource for the best benefit to society, i.e. profitability of the fishing industry and maintaining the livelihoods of the fishermen (Pascoe *et al.*, 1997).

Due to the poor knowledge of the resource dynamics and the often limited range of data available, the management of fish stocks in developing countries is often based on fragile foundations. The knowledge of the status of fish stocks is poor or even inexistent, and this lack of suitable information can hamper stock assessment and fisheries management (Reis, 1992).

Stock assessment is typically carried out with the finest of information available. This 'best' information is often identified as representing the most likely values for the parameters of the population under study (Restrepo *et al.*, 1990). Powerful analytical techniques permit reconstruction of the population dynamics of exploited fish stocks and provide estimates of mortality rates and population abundance based on interpretation of commercial catch statistical data (Megrey, 1989). One of the first theories concerning the exploitation of fish stocks come from Baranov (1918). It provided the theoretical basis for Derzhavin (1922) who was perhaps the first to conceive the idea of applying data describing the age structure of a population to catch statistics in order to calculate the contribution of each year's cohort to each year's total catch.

From time to time, however, new models are being elaborated, or extensions and augmentations of older methods are being developed. There are several methods based on catch-at-age data. According to Hilborn and Walters (1992), these models can be divided in two classes: (a) Virtual Population Analysis (VPA) or cohort analysis which calculates stock size based on catches with no underlying statistical assumptions (b) 'Statistical catch-at-age Methods' which rely on formal statistical models.

VPA (Gulland, 1965; Murphy, 1965) and cohort analysis (Pope, 1972) has been widely applied to commercial fish stock assessment. It consists of a 'backwards solution' where historical abundance of a cohort are estimated on the basis of subsequent catches.

The 'Statistical catch-at-age Methods', reviewed by Megrey (1989) 'provide more formal methods for estimating the current abundance of cohorts still being fished. They are an extremely powerful and elegant synthesis of VPA, catch curves, selection curves, and stock and recruitment' (Hilborn & Walters, 1992). Data requirements vary from only catch by age and year up to information concerning effort Paloheimo's (1980), Fournier and Archibald's (1982) and Dupont's (1983) models, total catch by year Fournier and Archibald's (1982) model and catch estimate error. As for the classical VPA extension, new statistical methods have been developed in recent years to improve population estimates.

Although age-structured models are considered the best choice for most of fisheries biologists, determining age by reading check marks in hard parts of the fish is neither an easy task nor a cheap one, specially in tropical fisheries. Jones (1984) first developed an adaptation of the age cohort analysis to length-based method, the length-cohort analysis. The length-frequency analysis was used traditionally to validate of age determination methods. These techniques are growing in importance and new approaches have been developed in order to use length distributions for stock assessment (Fournier *et al.*, 1990).

Length cohort analysis was developed for species that cannot be aged. It is applied in the situation when only length composition data for the total fishery are available for one year (or the average length composition for a sequence of years). It is assumed that the picture presented by all length classes caught during one year reflects that of a single cohort during its entire life (Sparre & Venema, 1998).

The most suitable assessment method to apply is still a difficult question to answer. The researcher needs to carefully consider what data are available, what errors the data might be subjected to what fishery-specific events might be relevant to the population dynamics of the exploited stock. Mathematical models are then selected in order to extract the most of information from data (Megrey, 1989). Also, fisheries biologists are always concerned to the fact that estimates of management-related quantities obtained from quantitative fisheries assessment methods are subject of errors of all different sources. These errors are related to the poor knowledge of the resource dynamics or to the poor and/or small quantity of the data.

In this chapter, I analyse the use of traditional methods to assess the current status of 5 target species (*Lutjanus analis, L. chrysurus, L. jocu, L. synagris* and *L. vivanus*) caught in Northeast Brazil. The limitations of each model are also discussed.

IV.II. Material and methods

The determination of the current status of the stock of five reef fish species regarded as target for the small scale fishery in North-eastern Brazil (*L. analis, L. jocu, L. chrysurus, L. synagris* and *L. vivanus*) included estimates of the fishery mortality and exploitation rates using different methods and the determination of reference points as ‘Fmax’ frequently used for the management of fish stock.

Routine visits to the landing sites of the commercial fishery were undertaken in 5 states and interviews with skippers and managers were carried out between 1996 to 2000. Information regarding the operation within the fishery and catch were collected in a monthly basis. The fork lengths (FL) of commercially landed fish were measured to the nearest centimetre (see Chapter 3 for details on the number of individuals sampled by species).

Port samples were obtained and annual sampled numbers-at-length were converted to annual total catches numbers-at-length using information on landing statistics by year and by state taken from the official Brazilian statistics supplied by IBAMA (*Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renovaveis*).

The stocks were evaluated considering the Northeast region as a unit, polling together information referred to Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE) and North Bahia (BA). There was no sampling program for the states of Paraíba and Sergipe within the scope of the REVIZEE Program as landings for these states are not as important as for the others states. However, the total catch of Sergipe and Paraíba was added to the total catch of the Northeast region and the length composition for these states was here considered as similar to the composition of the adjacent state.

The Brazilian Current (BC) and the North Coastal Brazilian Current (NCBC) are the main surface currents on the Brazilian continental margin (Stramma, 1991; da Silveira *et al.*, 1994; Sadovy, 1996). They originate from the South Equatorial Current at about 5° to 6° S and flow to the south (BC), and to the north and northwest (NBC). The bifurcation of these current causes the North-eastern Brazil to be divided into two areas: the northern realm (States of Ceará, Rio Grande do Norte, and oceanic banks) and the northeastern part (states of Paraíba, Pernambuco, Alagoas, Sergipe and the northern part of Bahia) (see Chapter 1 - Introduction). Considering that the studied species have pelagic eggs and larvae, one would think that the reef fish in Northeastern Brazil might be comprised of, at least, two different units of stock. In terms of stock assessment, such statement would imply a separated analysis considering separately the two areas. However, there is no clear evidence that supports this hypothesis. Preliminary genetic studies could not discriminate different stock along the Northeastern coast. It is supposed that fish spawned along the North coast of the Northeast Brazil may mix with fish spawned in the south coast of the region. Therefore stock assessment was carried out considering one unique stock.

The catch-at-size models require data on numbers-at-size by year and an assumption about natural mortality. The total number-at-size was used as input for the use of the Length cohorts Analysis (Jones, 1984) and consequently, the predictive model of Thompson and Bell (1934). The age-based VPA (Gulland, 1965) was also used and the total catch-at-size was converted into the total catch-at-age using age-length-keys (ALKs) constructed from the direct age reading, separately by species (Rezende *et al.*, 2003).

For the 5 species either the length-cohort analysis and the VPA was used and the detailed method is described below.

The model of Beverton and Holt (1957) was used to *L. vivanus* since, for this species, there is no estimative of total catch and this approach can be used when only the total number of individuals sampled is available.

IV.II.1. Growth parameters and natural mortality

IV.II.1.1. Growth parameters

For four of the five target species considered in the analysis (*L. analis*, *L. jocu*, *L. chrysurus*, *L. synagris*), a three set of growth parameters (Table IV.1), obtained according to the model of von Bertalanffy (1938), were considered as input for the application of the length cohort analysis: growth parameters derived directly by the otoliths readings (Rezende *et al.*, 2003), growth parameters obtained by back-calculated length-at-age (Rezende *et al.*, 2003) and growth parameters determined empirically according to the method of Jones (1984). The growth parameters are necessary as input for the length cohort analysis and hence the predictive model of Thompson and Bell based on length.

IV.II.1.1.1 Growth parameters based on direct readings of the otoliths

Total length (FL) in cm, was recorded and the pair of the otoliths *sagittae* removed. Analysis of fish age was based on examination of transverse sections of sagittal otoliths. Alternate opaque and hyalines zones were counted through stereomicroscopic. Fish were considered to be 1 year-old after the formation of the first zone and a further year was added for each subsequent zone (Ferreira *et al.*, 2004a; 2004b; 2004c; 2004d). Such pattern was validated by marginal increment analysis (Rezende & Ferreira, *in press*). The otoliths were analysed: the four species showed and annual pattern however only *L. chrysurus* showed a very strong pattern. These results were supported by several studies already published (see for review, Rezende & Ferreira, *in press*). Further study on direct validation techniques using tetracycline marking are currently being developed (Rezende & Ferreira, *pers. com.*).

For the otoliths direct readings, two different readers assigned ages for the fish, with no previous information on the fish length. If two readings agreed then that age was adopted as definitive. The otolith was considered ineligible and discarded if there was no good visibility (for more details, see Rezende *et al.*, 2003).

It was derived theoretical growth parameters by fitting the direct lengths-at-age to the von Bertalanffy (1938) growth equation:

$$L_t = L_\infty (1 - \exp^{-k(t-t_0)})$$

where L_t is the length at age t, L_∞ is the asymptotic length, k is the growth coefficient and t_o is the age when length would theoretically be zero.

Table IV.1: Growth parameters obtained according to three methods: direct reading of the otoliths, back-calculated lengths-at-age and growth parameters obtained according to Jones (1990)[1]

Species	Method	Parameters (L_∞ in cm FL, t0 in year, k in $year^{-1}$)	L max (cm, CF)	Number of observations
L. jocu			105	196
	Direct reading[2]	L_∞=77.8 k=0.107 t0=-3.8		
	Back-calculated length-at-age[2]	L_∞=71.2 k=0.11 t0=-4.3		
	Jones	L_∞=105 k=0.35		
L. analis			85	257
	Direct reading[2]	L_∞=60.6 k=0.16 t0=-0.13		
	Back-calculated length-at-age[2]	L_∞=84.5 k=0.05 t0=-1.8		
	Jones	L_∞=85 k=0.48		
L. chrysurus			90	582
	Direct reading[2]	L_∞=71.9 k=0.04 t0=-6.4		
	Back-calculated length-at-age[2]	L_∞=49.5 k=0.107 t0=-2.5		
	Jones	L_∞=90 k=0.096		
L. synagris			65	421
	Direct reading[2]	L_∞=62.3 k=0.038 t0=-6.5		
	Back-calculated length-at-age[2]	L_∞=46.8 k=0.036 t0=-6.5		
	Jones	L_∞=65 k=0.73		
L. vivanus	Back-calculated length-at-age[2]	L_∞=60 k=0.051 t0=-2.3	75	421

[1] Growth parameters compatible to the ones reported in literature for fish species of the family Lutjanidae (Acosta & Appeldoorn, 1992; Newman & Williams, 1996; Rocha-Olivares, 1998; Santa Maria & Chavez, 1999; Newman *et al.*, 2000; Burton, 2001; Burton, 2002; Newman & Dunk, 2002). [2] (Rezende *et al.*, 2003)

IV.II.1.1.2 Growth parameters based on back-calculated lengths-at-age

Back-calculation lengths-at-age was the second source of data for the determination of the growth parameters. This technique is widely used to obtain growth curves, to estimate length-at-age of individuals that are rarely observed, to compare growth differences amongst populations or sexes of the same species and even to illustrate gear selectivity (Francis, 1990). The purpose of back-calculation is to estimate body lengths from scale or otoliths measurements. The details of the estimation of the back-calculated lengths-at-age are described in Rezende and Ferreira (2003). For the analysis of *Lutjanus vivanus*, due to the lack of juveniles in our samples, it was only used the growth parameters derived from back-calculated lengths-at-age.

It was derived theoretical growth parameters by fitting the back-calculated lengths-at-age to the von Bertalanffy (1938) growth equation.

IV.II.1.1.3 Growth parameters based on the method of Jones (1984)

An empirical relationship based on a procedure suggested by Jones (1984) is also applied for the determination of the growth parameters. It is based on choosing a value of L_∞ equal or 'little greater' (Jones, 1990) than the maximum individual sampled. Afterwards it is chosen a value of K 'compatible' to the estimated L_∞ using the method of Ford and Walford described below:

$k=\ln[(L_\infty - L_t)/(L_\infty - L_{t+1})]$

In this case, the animal grows from L_t to L_{t+1} within one year. This may hamper the use of this method since the length interval for *Lutjanus* species to grow within one year greatly varies and, growth parameters obtained based on this approach is questionable.

IV.II.1.2. Natural mortality (M)

Methods for calculating natural mortality are based on empirical relationships between M and other biological and environmental parameters, but because they are less demanding on specific data, they are unlikely to produce good estimates for a particular stock (Gulland, 1989). In that case, a good knowledge of the life history of the species and of the fisheries in question helps the choice of a suitable estimate, and should be considered of maximum importance (Reis, 1992). For Lutjanids species, M reported in literature varies from 0.104 to 0.49 (Newman & Williams, 1996; Newman *et al.*, 2000; Burton, 2001; Newman, 2001; Burton, 2002; Newman & Dunk, 2002). However, most of the estimates for *Lutjanus* species rely up to the value of 0.23.

A number of traditional empirical models estimates the natural mortality (M) considering the water temperature and growth parameters or the age at first maturity (Rikhter & Evanov, 1976; Pauly, 1980a). Recently Ault *et al.* (1998) developed a method, which allows application of a convenient and consistent method to normalise the annual instantaneous natural mortality rate M to life span. This method has been applied for coral reef fish stocks. Initially it is assumed that St_λ, the fraction of the initial cohort numbers surviving from recruitment t_r to the maximum age, can be expressed as:

$$S(t_\lambda) = e^{-M(t_\lambda - tr)}$$

Where t_λ is the maximum age registered.

Then, the authors assume an unexploited equilibrium, by setting the probability of survivorship of recruits to the maximum age to be 5% (i.e. $S(t_\lambda) = 0.05$), and letting t_r be equal to 0. The equation above was rearranged in order to provide and estimate of M as following:

$$M=-\ln(St_\lambda)/t_\lambda$$

It was also calculated M based on the method described by Rikter & Evanoff (Rikhter & Evanov, 1976) and Pauly (1980a). Depending on the species and method applied, M varied from 0.1 to 0.3. This range will be used for the sensitivity test, which investigates the effects of different values of natural mortality on the estimates of stock size and fishery mortality.

IV.II.2. Length at first capture (L_{50})

The length at first capture was obtained based on the catch curve. When using a linearised catch curve to estimate mortality it is usually necessary to discard the left hand side of the curve because juvenile fish are not fully exploited. A conceptually simple way to estimate how many fish are missing at each age is to extrapolate on the straight line from which the total mortality coefficient Z is estimated, in order to find the number of juveniles there ‘ ought to be’. The differences between the ‘ expected numbers´ of individuals that ought to be and the actual numbers of individuals caught should give the ogive resulting from the combined effect of recruitment and mesh selection, and the L_{50} is obtained (Sparre & Venema, 1998).

IV.II.3. Stock assessment models

IV.II.3.1. Length-cohort analysis and VPA

The length cohort analysis and VPA uses commercial catch data to calculate stock sizes and mortality rates of age based or length-based cohorts. It does not by itself indicate how many individuals can be caught to meet a given objective, nor does it predict the future. If explains the past (Jennings *et al.*, 2001). This method uses backwards algorithms, which are, based on catches, used for the estimation of the stock size. VPA calculates the size of the stock based on past catches and the number of individuals alive in each cohort for each past year. The relationship is simple and, the number of individuals alive in the beginning of next year will be equal to the number of individuals alive of the current year minus the annual catches and the rate removed by the natural mortality of the referred year (Sparre & Venema, 1998). The output of such methods is the fishing mortality and the number of individuals alive for each year for the whole period.

However, in a tropical fishery it is often available information concerning the catch-at-age for a short period (1 year or 2). In this situation, it could be used the VPA with pseudo-cohort. There is also a method proposed by Jones (1984) (Length Cohort Analysis) which converts lengths to age based on the growth parameters of von Bertalanffy (L_∞, k, t_0), in case of the absence of information on catch-at-age. The methods based on pseudo-cohort is based on the assumption of a constant parameter system, i.e. when we are working with data from one year assuming that these resemble those of a cohort during its entire life, which means that recruitment and total mortality (Z = F+M) remains constant every year. It is evident that this assumption of constant parameter system is rarely fulfilled in real life. However, 'it often happens that only by making such assumptions we are able to carry out an analysis of available data, and it is better to do a crude analysis than none at all' (Sparre & Venema, 1998).

However, it is also possible to follow the fate of a single age group, or cohort, over successive time intervals. This is applied in this study as the VPA for real cohorts.

Hence, for this study, the current status of the 5 species of *Lutjanus* is assessed exploring three possibilities of methods as described in the scenarios below:

Scenario 1 The length cohort analysis based on the model proposed by Jones (1984). The input data necessary for the application of the model are: the total caught number-at-size, terminal E (F/Z) (determined interactively), an assumption of Natural Mortality M and three set of growth parameters (L_∞, k, t_0). The set of growth parameters used as input were based on three scenarios: Scenario 1a - growth parameters based on direct readings of the otoliths; Scenario 1b - growth parameters based on back-calculated lengths-at-age and Scenario 1c - growth parameter based on the method proposed by Jones (1984) with L_∞ based on maximum size and compatible k.

<u>Scenario 2</u> Age-based Virtual Population analysis (VPA) (Gulland, 1965) using pseudo cohorts, assuming equilibrium conditions where nor the effort neither the catchability has changed over the whole studied period. The input data for this model is the total caught numbers-at-age (average length composition for 1996-2000) and an assumption of natural mortality.

<u>Scenario 3</u> Age-based VPA using the real cohorts during the studied period (1996-2000). The input data for this model is the total caught numbers-at-age by year and an assumption of natural mortality.

For each of the scenarios used for the assessment of the *Lutjanus* species, it was investigated the effects of different values of natural mortality on the estimates of stock size and fishery mortality. This sensitivity tests were applied analysing the effect of the different assumed values of natural mortality (0.1, 0.2, 0.3 and the values obtained based on the method of Ault *et al*. (1998)) in the estimates of fishing mortality and stock size. When the results of the analysis were considered as not reliable (considering the knowledge of the current status of exploitation for the species -, fishing mortality should not be much lower than the natural mortality - see results and Chapter 1), I did not proceed with the sensitivity test.

For each scenario, the output of the length cohort analysis and VPA were used as input for the application of the predictive model of Thompson and Bell which projects yields at different levels of fishing mortality.

IV.II.3.2. Catch curve

For *L. vivanus* it is not available estimates of total landed catches and the value of total mortality Z was obtained based on the catch curve, which may be used in situations where only total sampled catch is obtainable. Graphing the natural logarithms of numbers surviving over successive years will therefore produce a straight line relationship referred to as a catch curve (Beverton & Holt, 1957; Ricker, 1975).

IV.II.4. <u>Predictive models</u>

IV.II.4.1. The predictive model of Thompson and Bell

Future yields and stock biomass levels can be predicted by means of mathematical models, which are similar to the ones behind VPA and the cohort analysis. The mathematical formulas for VPA and cohort analysis, that analyse the history of the fishery, can be transformed in such way that the knowledge of the past can be used to predict the future yields and biomass at different levels of fishing effort (or fishery mortality) (Sparre & Venema, 1998).

The main input of this model is the 'reference F-at-age' (or length)-array, an array of F-values per age (or length) group which is obtained from the analysis of historical data, VPA or cohort analysis. Another input parameters are the number of recruits (also may be obtained from VPA or cohort analysis) and the weight-at-age (or length) array, i.e. the weights of individual fish per age (length) group). The output of the model is a succession of predictions of the catch in numbers, the yield, the mean biomass, all per age (length) group related to the values of F for each group. New values of F can be obtained by multiplying the reference F-array as a whole by a certain factor usually called X (the so-called Factor X) (Sparre & Venema, 1998).

In this study, each set of growth parameters and estimates of natural mortalities determined different scenarios of projection of yield per factor. For each scenario, estimates of the biological reference points were obtained. It was calculated Fmax (value of fishing mortality F where the yield is maximum) or Emax (value of exploitation rate E (F/Z) where the yield is maximum) and the more conservative biological reference as $F_{0.1}$ (value of F where the instantaneous rate of variation of the yield is equal to 10% of the maximum rate) (Gulland & Boerema, 1973; Cadima, 2000). The use of $F_{0.1}$ as a reference point, although is regarded as more conservative, has the advantage of being applicable to species for which there is no evident maximum in the yield per recruit *vs*. F curve (Caddy & Mahon, 1995). This situation has been noted for some species in this study (see results).

IV.II.4.2. Relative yield per recruit of Beverton and Holt

To analyse the current state of the species *L. vivanus,* the model yield per recruit proposed by Beverton and Holt (1956; 1957), which do not need the estimates of total catch, was used.

The Beverton and Holt (1956; 1957) model estimates the potential yield of the stock in function of the fishery mortality and the length of first capture, using as input the growth parameters and an estimate of natural mortality. The fundamental yield-per-recruit model assumes a steady sate, i.e. that recruitment is constant, and hence the age structure of the population is the same as we would see if we followed a single cohort through time(Jennings *et al.*, 2001). Two outputs may be obtained considering that (1) all fish belonging to a given cohort recruit to the fishing grounds at the same time: 'knife-edge recruitment' or (2) fish of a given cohort recruit gradually following a smooth function (Sparre & Venema, 1998). The knife-edge selection should be considered a hypothetical model since it will never describe a real situation. Departure from knife-edge selection has a profound impact on yield-per-recruit estimation and one should use model incorporating realistic selection ogives (Gayanilo Jr. *et al.*, 1996).

This model can be regarded as a special application of the Thompson and Bell model, being, however, simpler and requiring less calculation. This model replaces the Thompson and Bell model in situations where VPA and Cohort analysis cannot be applied. This model uses as input the growth parameters and an estimate of natural mortality. The biological reference points F_{max} and $F_{0.1}$ were determined.

A flowchart illustrating the methods applied in this chapter is shown in Fig. IV.1.

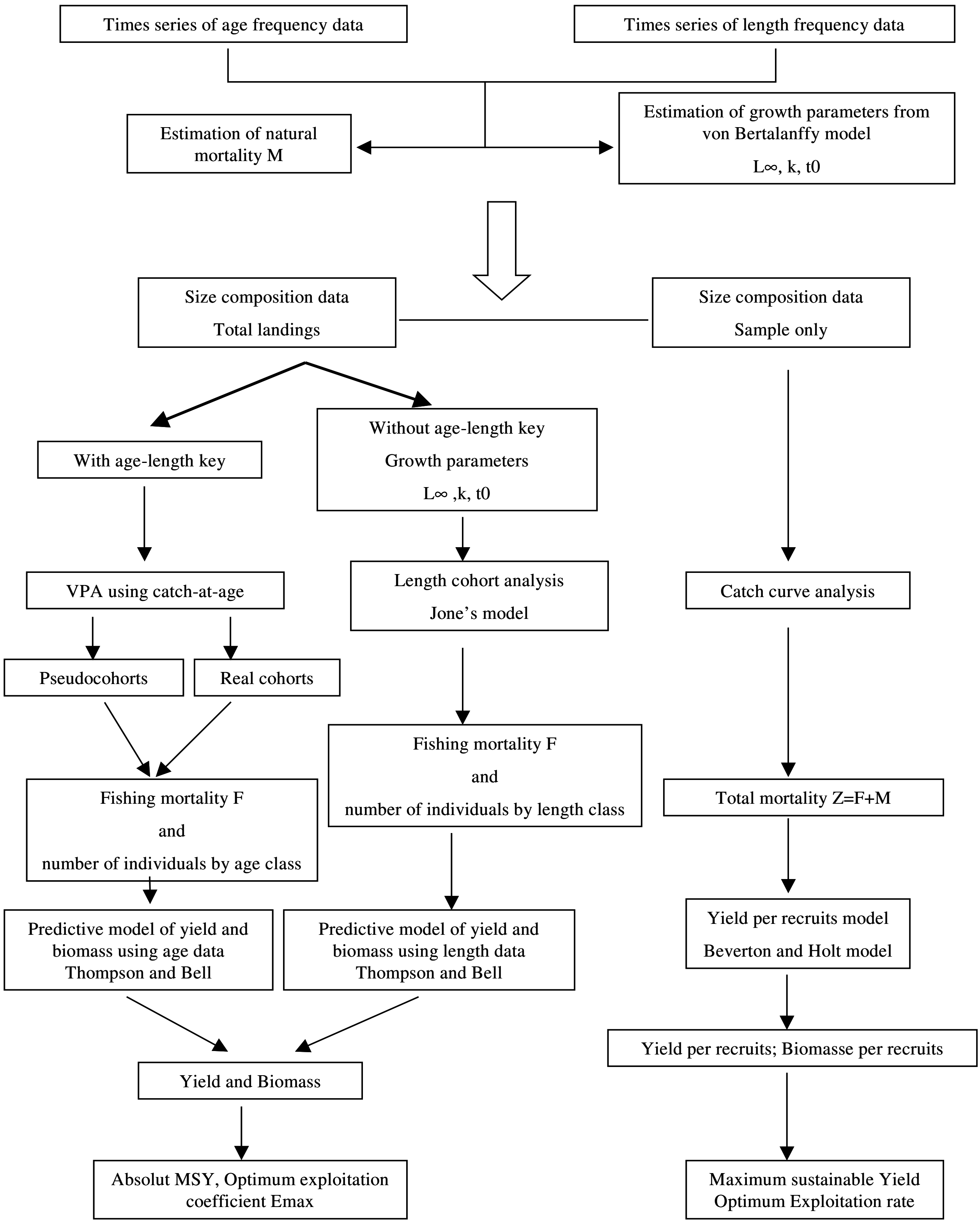


Fig. IV.1: Steps of the stock assessment

IV.III. Results

IV.III.1. *Lutjanus analis*, mutton snapper

The length at first capture (L_{50}) for *L. analis* is equivalent to 36.4 cm FL which is larger than the length at first maturity given to the species in Northeast Brazil (28 cm FL) (Ferreira *et al.*, 2004a).

The estimates of fishery mortality varied for *L. analis* from 0.008 to 0.909 depending on the scenario considered (Table IV.2). The estimates of biomass varied greatly from 1568 to 90.720 tonnes with an exploitation rate (E) varying between 0.037 and 0.901 in function of the scenario considered (Table IV.2). Considering the predictive model of Thompson and Bell, it was reported an optimum exploitation rate for a maximum yield (Emax) varying from 0.63 to 0.84 depending on the natural mortality and methods applied (Table IV.2).

Amongst all scenarios tested only scenarios 1c (Length cohort Analysis using as input the growth parameters based on the method of Jones (1984)) and 3 (Age-based VPA using real cohorts) with values of natural mortality up to 0.2 reached maximum values for the estimates of the optimum exploitation rate for the maximum yield (Emax) (Fig. IV.2). When the yield curve (based on the predictive model of Thompson and Bell) does not reach a maximum (curve has an asymptotic format), the value of Emax is not discernible and this biological reference point is not reliable for use.

Results of estimates of biomass and exploitation rates (F/Z) for different values of M were compared within the scenarios (excluding the scenarios where fishing mortality was lower than the expected pattern, considering the knowledge of the current exploitation of the species; see Chapter 1 for more explanations of the current exploitation of *Lutjanus* species). In Northeast Brazil, the exploitation of *L. analis* is reported for the region since 1978 and, currently around 600 tonnes is landed annually. Considering the current level of exploitation of this species, it is not expected that the fishing mortality F would be greatly lower to M. Moreover, when F is expected to be relatively small, then the reliability of estimates derived from models relying on catches may be questionable. If M is small compared to F it may not matter so much if M is not well estimated (Sparre & Venema, 1998).

For scenarios 1c and 3 (M = 0.1 and 0.2) (scenarios which the test of sensibility test was applied, Table IV.2), given all values of M, exploitation rates decrease with an increase in the assumed natural mortality.

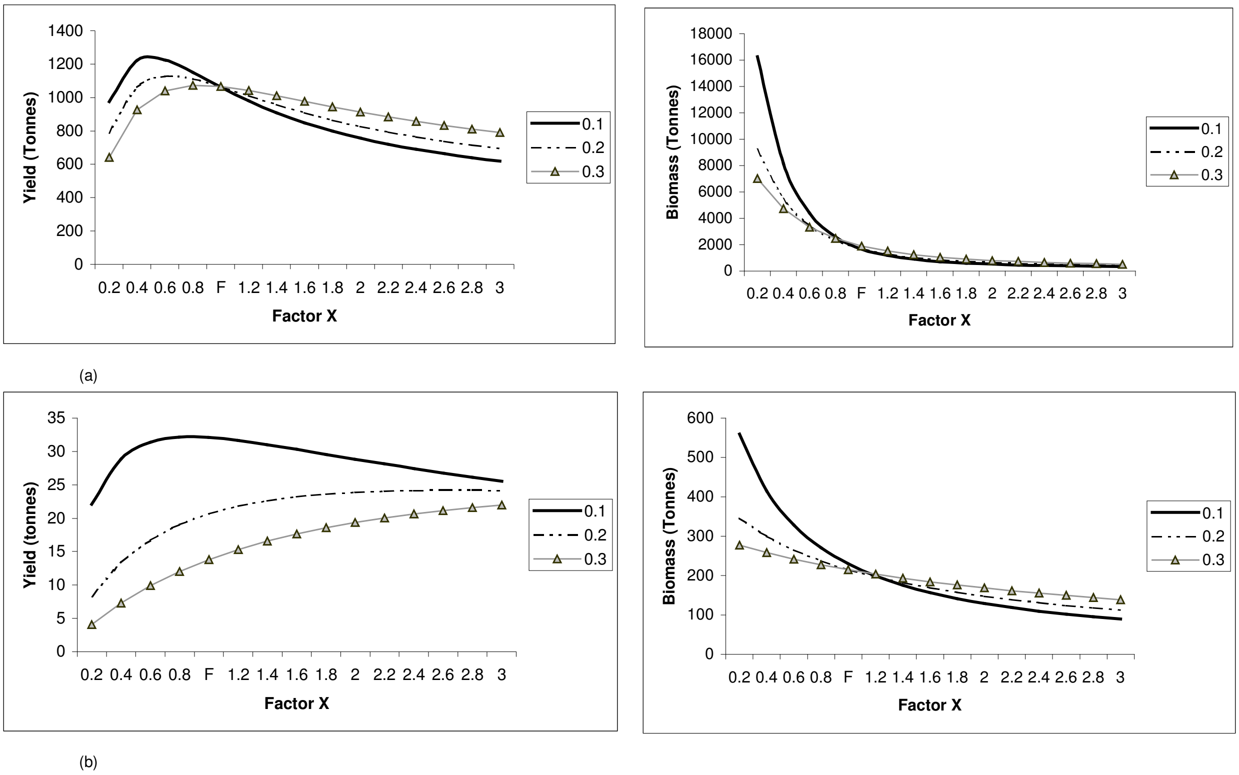


Fig. IV.2: Yield and biomass obtained by the predictive model of Thompson and Bell in function of the natural mortality M=0.1, M=0.2, M=0.3 for *L. analis*. (a) Based on scenario 1c (L∞ = 85 cm CF, k=0.48) (b) Based on scenario 3.

Table IV.2: Estimates of F (Fishery mortality), $E_{current}$ (current exploitation rate), biomass, Emax e Fmax (value of fishing mortality and exploitation rate where the yield is maximum respectively) and Factor X (multiplicative coefficient of F – relative to the mortality where Fmax is reached) for *L. analis* considering different methods and scenarios. [1] - Scenarios where the yield curve (obtained based on the predictive model of Thompson and Bell) is asymptotic, there is no evident value of Fmax or Emax.

Cohort analysis	Growth parameters	Scenario	M	Weighted mean F	E current	Biomass (T)	Emax	Fmax	Factor X
Jones´ Cohort analysis	Backcalculated lengths-at-age	1a	0.2	0.032	0.139	35123	--[1]	--[1]	--[1]
	Direct otolith reading	1b	0.2	0.008	0.037	90720	--[1]	--[1]	--[1]
	Derived by Jones (1984)	1c and Ault et al (1998)	0.1	0.909	0.901	1568	0.842	0.535	0.6
			0.2	0.807	0.801	1740	0.703	0.473	0.6
			0.3	0.702	0.700	2019	0.645	0.545	0.8
Pseudo-cohorts VPA	--	2	0.2	0.074	0.269	32591	--[1]	--[1]	--[1]
Real cohorts VPA	--	3	0.1	0.216	0.683	5889	0.633	0.173	0.8
	--		0.2	0.168	0.456	7912	0.685	0.436	2.6
	--		0.3	0.129	0.300	10962	--[1]	--[1]	--[1]

Due to all the limitations of the methods proposed by Jones (Length cohort analysis) and VPA using pseudo-cohorts (described in the introduction and discussion), it was considered that the analysis which uses the age-based VPA with real cohort (Scenario 3) is the most recommendable to evaluate the current status of the stock. It is also considered that the best choice of the value of M (used as input for the analysis) is the obtained based on the formulae of Ault *et al.* (1998), which has been designated as the most appropriate for the assessment of reef fish stocks. For a natural mortality M =0.1 (obtained according to the formulae of Ault *et al.* (1998), the maximum rate of exploitation for the maintenance of the sustainability of the stock of *L. analis* in the Northeast coast of Brazil was 0.63 (Fig. IV.3). Considering the current exploitation rate of *L. analis* ($E_{current}$ = 0.68), estimated as 20% greater than the estimated Emax, it could be inferred that *L. analis*, in Northeast Brazil is currently over-exploited. The biological reference $F_{0.1}$ was estimated as 0.022 (90% inferior than the $F_{current}$).

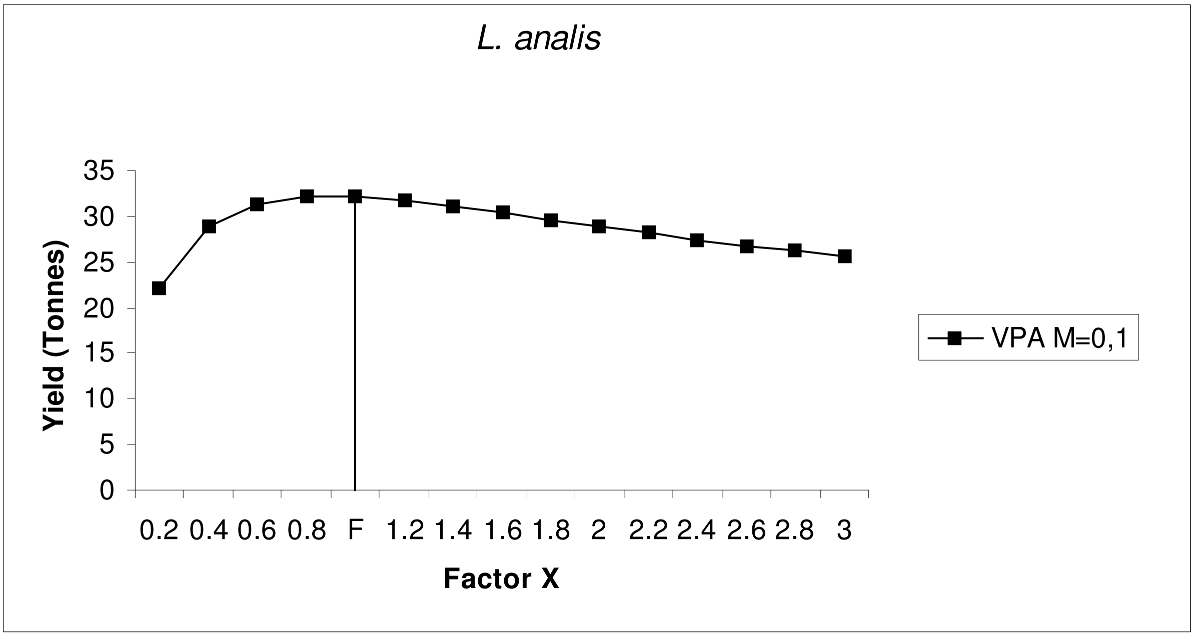
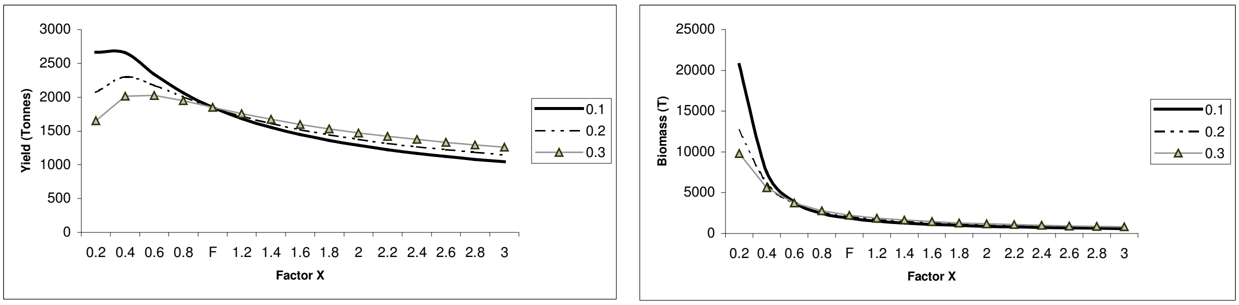


Fig. IV.3: Yield obtained by the predictive model of Thompson e Bell with M =0.1 based on Scenario 3. F is referred as the current exploitation *Lutjanus analis*, mutton snapper

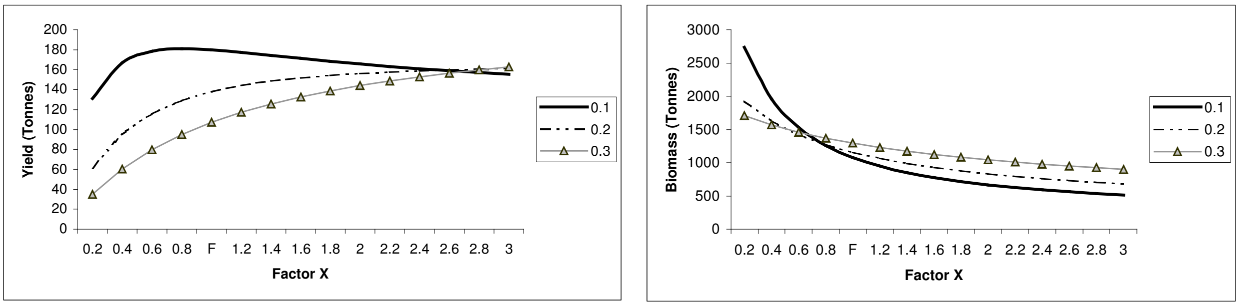
IV.III.2. *Lutjanus jocu*, dog snapper

The length at first capture for *L. jocu* is equal to 35 cm CF which is larger than the length at first maturity obtained for the species in Northeast Brazil (30 cm FL) (Ferreira *et al.*, 2004c).

The estimates of fishery mortality varied for *L. jocu* from 0.002 to 1.042 depending on the scenario considered (Table IV.3). The estimates of biomass varied greatly from 1862 to 948785 tonnes with an exploitation rate varying between 0.010 and 0.912 in function of the scenario considered (Table IV.3).



(a)



(b)

Fig. IV.4: Yield and biomass obtained by the predictive model of Thompson e Bell in function of the natural mortality M=0.1, M=0.2, M=0.3 for *L. jocu*. (a) Based on scenario 1c (L∞=105 cm CF, k=0.35) (b) Based on scenario 3.

Table IV.3: Estimates of F (Fishery mortality), Ecurrent (current exploitation rate), biomass,, Emax e Fmax (value of fishing mortality and exploitation rate where the yield is maximum respectively) and Factor X (multiplicative coefficient of F – relative to the mortality where Fmax is reached) for *L. jocu* considering different methods and scenarios. [1] - Scenarios where the yield curve (obtained based on the predictive model of Thompson and Bell) is asymptotic, there is no evident value of Fmax or Emax.

Cohort analysis	Growth parameters	Scenario	M	Weighted mean F	E current	Biomass (T)	Emax	Fmax	Factor X
Jones´ Cohort analysis	Backcalculated lengths-at-age	1a	0.2	0.002	0.010	948785	--[1]	--[1]	--[1]
	Direct otolith reading	1b	0.2	0.006	0.029	298324	--[1]	--[1]	--[1]
	Derived by Jones (1984)	1c	0.1	1.042	0.912	1862	0.806	0.417	0.2
			0.2	0.962	0.828	2029	0.658	0.385	0.4
			0.3	0.881	0.746	2233	0.540	0.353	0.6
		Ault et al (1998)	0.12	1.026	0.895	1892	0.774	0.410	0.4
Pseudo-cohorts VPA	--	2	0.2	0.002	0.010	30068	--[1]	--[1]	--[1]
Real cohorts VPA	--	3	0.1	0.253	0.717	9586	0.670	0.203	0.8
	--		0.2	0.199	0.499	12694	--[1]	--[1]	--[1]
	--		0.3	0.155	0.340	17324	--[1]	--[1]	--[1]
	--	Ault et al (1998)	0.12	0.242	0.668	10116	0.668	0.242	1

As for *L. analis,* maximum yield was reached for scenario 1c (with M of 0.1, 0.2, 0.3 and 0.12) and for scenario 3 with mortality M= 0.1 and 0.12 (Fig. IV.4). The maximum exploitation rates (Emax) were respectively 0.8, 0.66, 0.54 and 0. 77 (Table IV.3).

As for *L. analis*, it was also considered that the analysis which uses the real cohort is the most recommendable to evaluate the current status of the stock in Northeast Brazil. Considering the natural mortality M = 0.12 (obtained according to the formulae of Ault *et al.* (1998), I reported, for *L. jocu* the optimum exploitation equal to 0.668 (Table IV.3). Given that the current exploitation rate for the species is equivalent to the optimum rate for maximum yields ($E_{current}$ = 0.668), we consider the stock of *L. jocu*, in Northeast Brazil is fully exploited (Fig. IV.5). Given that the reference point $F_{0.1}$ as 0.036 is 85% inferior to the $F_{current}$, it is evident the need for a drastic reduction of the fishery mortality (see restrictions on the discussion).

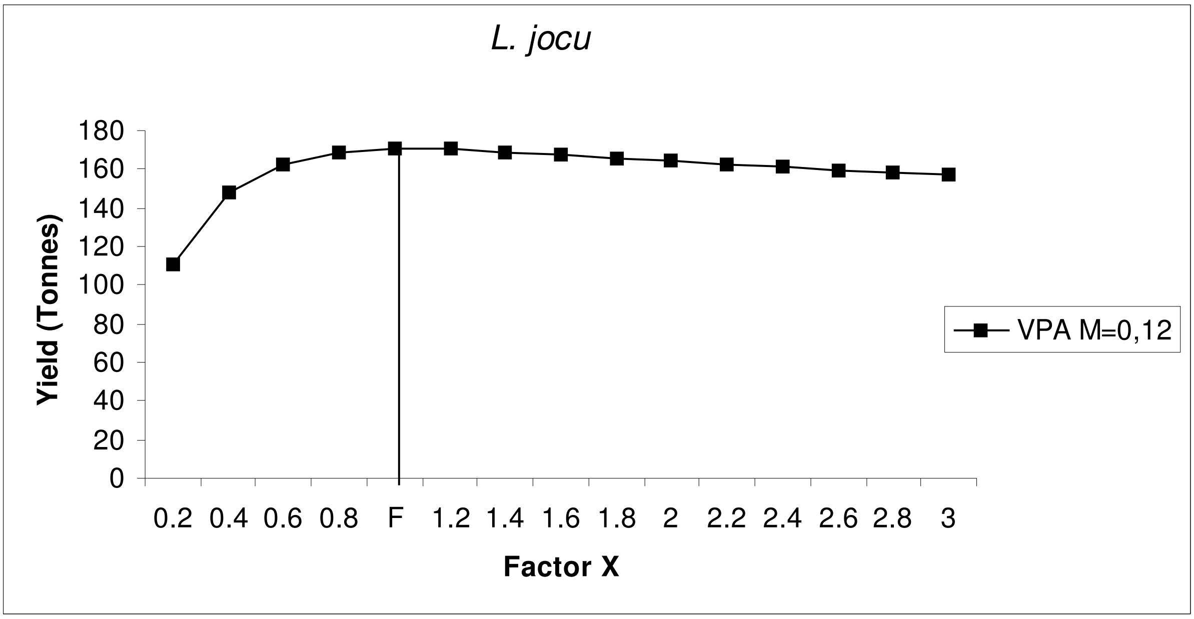


Fig. IV.5: Yield obtained by the predictive model of Thompson and Bell with M =0.12 based on Scenario 3. F is referred as the current exploitation

IV.III.3. *Lutjanus chrysurus*, yellowtail snapper

The length at first capture for *L. chrysurus* is 31.25 cm FL which is larger than the length at first maturity obtained for the species in Northeast Brazil (21.2 cm FL) (Ferreira *et al.*, 2004b).

The estimates of fishery mortality varied for *L. chrysurus* from 0.003 to 0.591depending on the scenario considered (Table IV.4). The estimates of biomass varied greatly from 4420 to 555770 tonnes with a current exploitation rate varying between 0.015 and 0.855 in function of the scenario considered (Table IV.4).

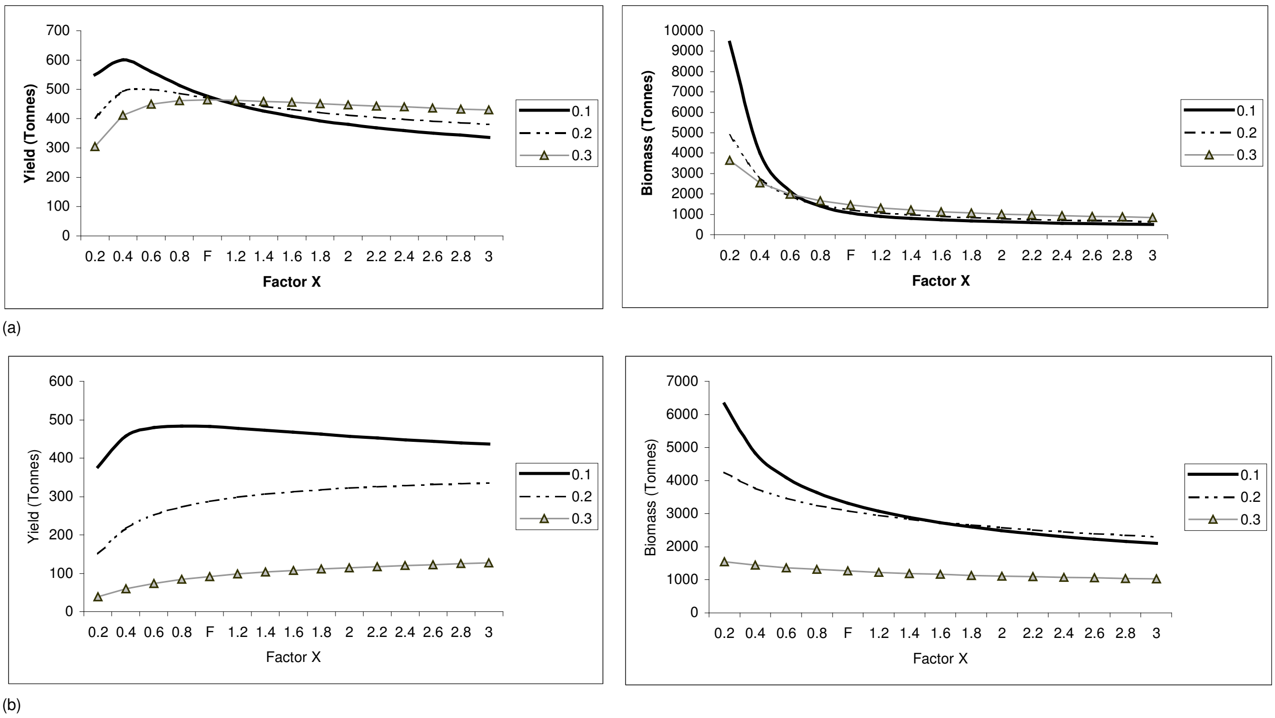


Fig. IV.6: Yield and biomass obtained by the predictive model of Thompson e Bell in function of the natural mortality M=0.1, M=0.2, M=0.3 for *L. chrysurus*. (a) Based on scenario 1c (L∞=90, k=0,096) (b) Based on scenario 3.

Table IV.4: Estimates of F (Fishery mortality), Ecurrent (current exploitation rate), biomass,, Emax e Fmax (value of fishing mortality and exploitation rate where the yield is maximum respectively) and Factor X (multiplicative coefficient of F – relative to the mortality where Fmax is reached) for *L. chrysurus* considering different methods and scenarios. [1] - Scenarios where the yield curve (obtained based on the predictive model of Thompson and Bell) is asymptotic, there is no evident value of Fmax or Emax.

Cohort analysis	Growth parameters	Scenario	M	Weighted mean F	E current	Biomass (T)	Emax	Fmax	Factor X
Jones´ Cohort analysis	Backcalculated lengths-at-age	1a	0.2	0.003	0.015	555770	--[1]	--[1]	--[1]
	Direct otolith reading	1b	0.2	0.052	0.205	45401	--[1]	--[1]	--[1]
	Derived by Jones (1984)	1c	0.1	0.591	0.855	4015	0.703	0.236	0.4
			0.2	0.518	0.721	4643	0.608	0.311	0.6
			0.3	0.447	0.598	5593	0.598	0.447	1
		Ault et al (1998)	0.17	0.539	0.760	4420	0.559	0.216	0.4
Pseudo-cohorts VPA	--	2	0.2	0.221	0.525	19337	--	--	--
Real cohorts VPA	--	3	0.1	0.308	0.755	10010	0.711	0.246	0.8
	--		0.2	0.261	0.566	12922	--[1]	--[1]	--[1]
	--		0.3	0.220	0.423	17016	--[1]	--[1]	--[1]
	--	Ault et al (1998)	0.17	0.274	0.617	11944	--[1]	--[1]	--[1]

Maximum yield was not very discernible for any scenario but it did reach a maximum value for scenario 1c (with M of 0.1, 0.2, 0.3 and 0.17) and for scenario 3 with mortality M= 0.1 (Fig. IV.6, Table IV.4).

For fish species, which show a very low growth, the yield per recruit curve has a wide flat top. In that case, the use of $F_{0.1}$ (or E0.1) has the very useful practical advantages of allowing a more precise target than Fmax (or Emax) (Jennings *et al.*, 2001). Considering the natural mortality as M = 0.17 (obtained according to the formulae of Ault *et al.* (1998), the reference point $F_{0.1}$ is 0.055 is 80% inferior to the $F_{current}$.

IV.III.4. *Lutjanus synagris*, lane snapper

The length at first capture for *L. synagris* is 19.4 cm FL which is equivalent to the length at first maturity obtained for the species in Northeast Brazil (18 cm FL) (Ferreira *et al.*, 2004d). The estimates of fishery mortality varied from 0.056 to 2.980 depending on the scenario considered (Table IV.5). The estimates of biomass varied greatly from 425 to 146759 tonnes with an exploitation rate varying between 0.040 and 0.968 in function of the scenario considered (Table IV.5).

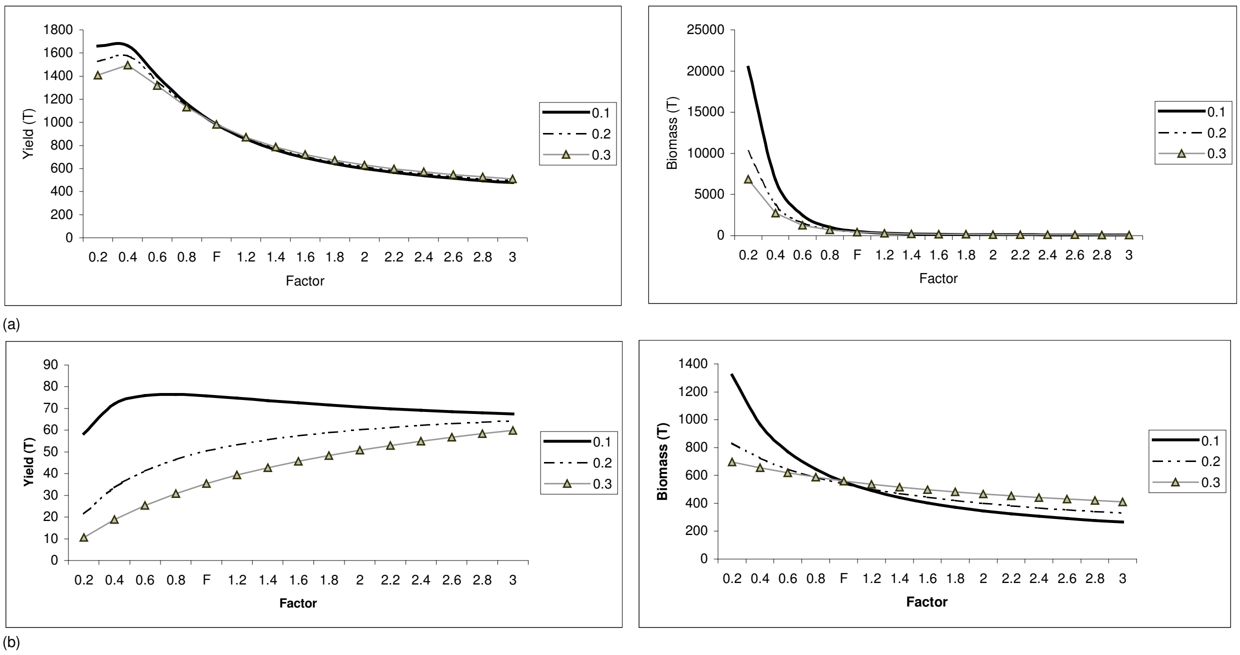


Fig. IV.7: Yield and biomass obtained by the predictive model of Thompson e Bell in function of the natural mortality M=0.1, M=0.2, M=0.3 for *L. synagris*. (a) Based on scenario 1c (L∞=65, k=0,73) (b) Based on scenario 3.

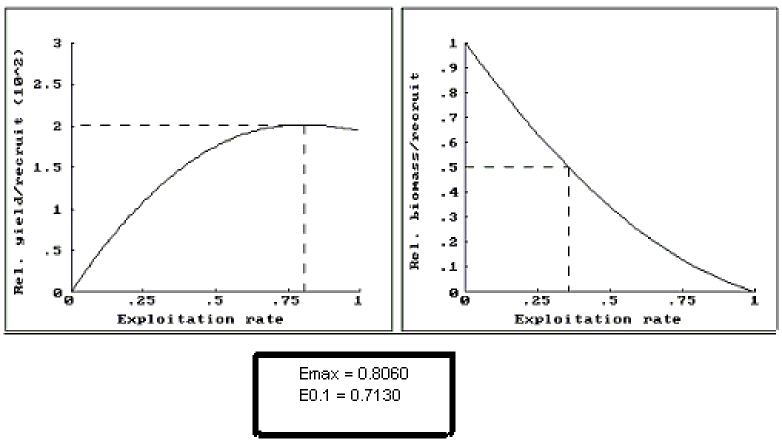
Table IV.5: Estimates of F (Fishery mortality), Ecurrent (current exploitation rate), biomass,, Emax e Fmax (value of fishing mortality and exploitation rate where the yield is maximum respectively) and Factor X (multiplicative coefficient of F – relative to the mortality where Fmax is reached) for *L. synagris* considering different methods and scenarios. [1] - Scenarios where the yield curve (obtained based on the predictive model of Thompson and Bell) is asymptotic, there is no evident value of Fmax or Emax.

Cohort analysis	Growth parameters	Scenario	M	Weighted mean F	E current	Biomass (T)	Emax	Fmax	Factor X
Jones´ Cohort analysis	Backcalculated lengths-at-age	1a	0.2	0.056	0.218	12589	--[1]	--[1]	--[1]
	Direct otolith reading	1b	0.2	0.008	0.040	146759	--[1]	--[1]	--[1]
	Derived by Jones (1984)	1c	0.1	2.980	0.968	505	0.856	0.596	0.2
			0.2	2.888	0.935	439	0.852	1.155	0.4
			0.3	2.796	0.903	425	0.788	1.118	0.4
		Ault et al (1998)	0.14	2.943	0.955	465	0.894	1.177	0.4
Pseudo-cohorts VPA	--	2	0.2	0.093	0.317	22243	--	--	--
Real cohorts VPA	--	3	0.1	0.214	0.682	6501	0.632	0.172	0.8
	--		0.2	0.172	0.462	8417	--[1]	--[1]	--[1]
	--		0.3	0.137	0.313	11119	--[1]	--[1]	--[1]
	--	Ault et al (1998)	0.14	0.197	0.584	7191	0.771	0.472	2.4

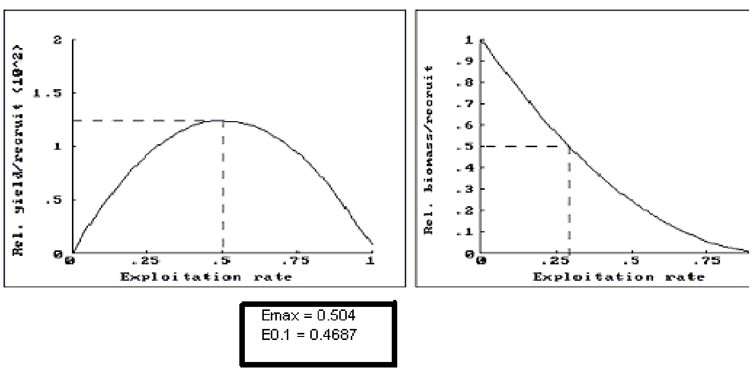
As for *L. chrysurus,* maximum yield was not very discernible for any scenario but it did reach a maximum value for scenario 1c (with M of 0.1, 0.2, 0.3 and 0.14) and for scenario 3 with mortality M= 0.1 (Fig. IV.7). The maximum exploitation rates (Emax) were respectively 0.86, 0.85, 0.79, 0.89 and 0.63 (Table IV.5). In that case, also the use of F.0.1 (or E0.1) was recommended and considering the natural mortality as M = 0.14 (obtained according to the formulae of Ault *et al.* (1998), the reference point $F_{0.1}$ was 0,029, 85% inferior than $F_{current}$. If this conservative reference point is considered, the species will be considered as overexploited.

IV.III.5. <u>*Lutjanus vivanus*, silk snapper</u>

The yield per recruit model reported a maximum exploitation rate for maximum yield as E = 0.80 if considered the method of ‘knife-edge’ and 0.50 if considered the ´selection ogive´ method (Fig. IV.8). The current exploitation rate obtained for the Northeast Brazil was of E=0.7 and the stock is regarded as fully exploited.



(a)



(b)

Fig. IV.8: The yield per recruit model of Beverton and Holt (1956) for *L. vivanus*. (a) ‘knife-edge’ method and (b) ogive selection method.

IV.IV. Discussion

IV.IV.1. The assessment of *Lutjanus* species using traditional approaches

In this study, many traditional approaches, which have been used for tropical fisheries, were tested. However, due to the assumptions of those models (see later section), they are limited and results should be taken with caution.

The extended longevity and low rates of natural mortalities for most of the snappers indicate that these species are unlikely to sustain high harvest rates of exploitation (Newman & Dunk, 2002) and, for most species commercially exploited, they are, currently, regarded as over-exploited. For *L. sebae*, a long-lived species (longevity of up 35 years), the optimum fishing mortality was estimated as 0.05-0.0611 and, considering the current exploitation (F = 0.120-0,27), only approximately 6% of the available stock should be harvested in a sustainable manner (Newman & Dunk, 2002). For the red snapper, *L. malabaricus* (longevity of 31 years) of Australia, the biological reference point used, F_{limit} is 0.0769 which indicates that approximately 7% of the available stock can be harvest on an annual basis (Newman & Dunk, 2002). For the mutton snapper *L. analis* and for the grey snapper *L. griseus* of Florida, total mortality obtained was 0.49 and 0.34 – 0.95 respectively, but no biological reference limit was calculated (Burton, 2001; Burton, 2002). For *L. synagris* in Puerto Rico, the Beverton and Holt yield per recruit model indicated that the current fishery harvest approximately 91% of the potential yield (Acosta & Appeldoorn, 1992). *L. peru* have been also regarded as over-exploited in the coast of Mexico (Santa Maria & Chavez, 1999).

In this study, according to the stock assessment models applied, all the species under investigation are also regarded as fully or over-exploited depending on the biological reference limit considered. For some studied species, the concept of the optimum level of fishing mortality (F_{max}) which results in the maximum sustainable yield (MSY) is not viable by the management point of view since there is no clear maximum value in the yield per recruit curve for these species. As alternative, some authors have suggested the biological reference point $F_{0.1}$ (proposed by Gulland and Boerema (1973). This reference point does not require a maximum value and it is referred as the mortality rate in the point of the yield curve located where the slope is 10% of the maximum slope (Gulland & Boerema, 1973; Caddy & Mahon, 1995; Cadima, 2000). According to Caddy and Mahon (1995) the use of $F_{0.1}$, although arbitrary, is a management measure based on a bio-economic criteria, as most of the managers would not see an economic return in an increase of the effort (and hence fishing mortality) for an increase of the yield level inferior to 10%.

For *L. chrysurus* and *L. synagris*, since the yield curve (F x yield) was regarded as asymptotic and no maximum value was observed. This would mean that effort can be increased considerably without any decrease of yield. Obviously this scenario does not represent the reality.. Only the $F_{0.1}$ can be used as a sensible biological reference point. For all species, the results considering $F_{0.1}$ as the biological reference point indicated an imminent need for a drastic reduction of the fishing mortality. This reference point is more conservative than Fmax, which also illustrated the intensive status of exploitation for *Lujanus* species in Northeast Brazil. The low value of the reference limit $F_{0.1}$ has been found for other *Lutjanus* species (Newman *et al.*, 2000). However, if considered the life history of the lutjanids, it seems obvious that these species are very vulnerable, which led, recently, the American Fisheries Society, to recommend that these stock should be exploited with fishing mortalities similar to the natural mortality (Coleman *et al.*, 2000).

IV.IV.2. The limitation of the models applied

IV.IV.2.1. Models based on length based methods

Models based on length frequency distributions are extremely sensitive to the choice of the growth parameters. In this study, it could be observed a wide variation of the estimates of the fishing mortality by length class, depending on the choice of the growth parameters. The variation of the mortality estimates depending on the method applied for the determination of the growth parameters has been reported by Newman *et al.* (2000). Consequently, the biological reference points calculated also varied according.

The length cohort analysis (Jones, 1984) is a simplified approximation of the Virtual Population Analysis (VPA), which uses pseudo-cohorts instead of real cohorts. Jones (1987; 1990) alerts that the length cohort analysis using the growth parameters of Von Bertalanffy which converts length to age based on the inverse equation of Von Bertalanffy results in values of F significantly lower than those obtained by VPA using the catch-at-age and real cohorts. However, it is possible to apply the model of Jones to a real cohort but this implies in the knowledge of the age of individuals (in length based methods the time that a group of fish that reach a following length class in not the same for all classes). In this case, the assumption of steady state disappears and the annual data could be analysed separately allowing the identification of the recruitment and mortalities patterns. If annual data is to be analysed separately with the length frequency distribution, fish should be referred by age groups with fixed intervals, which is often 1 year. For the application of such approach, catches which length classes belonging to the same age class are grouped and it is obtained the catch-at-age matrix (Cadima, 2000). This approach is called slicing technique. However, it also shows weakness since the true age of the fish is not known (age is based on the inverse equation of Von Bertalanffy) and an arbitrary value of t0 is used. The differences between ages ´dt´ are the values used, eliminating the t0.

Another alternative suggested by Jones (1984), is to use growth parameters obtained through an ´empirical´ procedure based on a $L\infty$ slighty superior to the maximum age (Lmax) and, the growth parameters K is compatible to the calculated $L\infty$. The growth parameter K is obtained according to the method of Ford and Walford (Ford, 1933; Walford, 1946). However, considering that is based on fictitious parameters, the method is subjected to criticisms.

Even if the slicing technique or the determination of the growth parameters empirically may help the application of the length cohort analysis, it has been shown above the limitations and restrictions of those methods.

IV.IV.2.2. Virtual Population Analysis using ages

IV.IV.2.2.1 Using pseudo-cohorts

Although the cohort analysis by age using pseudo-cohort does not convert length on age using the inverse equation of von Bertalanffy (as the method proposed by Jones), this method may be also inadequate due to the limitation of the use of steady state over the study period. This assumes that rates of recruitment and mortality are constant during the entire life of the species studied. This assumption, however, is rarely fulfilled in real life. Thus, real cohort VPA should be preferred when time series is available (even short ones).

IV.IV.2.2.2 Real cohorts

Virtual Population Analyses (VPA) was used with real cohorts for the 5 years period. However, the short time series available is possibly a weakness as the studied species are long lived (from 18 to 29 years respectively for *L. chrysurus* and *L. analis* (Rezende & Ferreira, *in press*). This may affect the accuracy of the results obtained based on this analysis as a data series of 5 years may not comprise of the contrasts needed for the best use of the models. The concept ‘backwards’ of VPA makes the arbitrary choose of the terminal F important for the all the estimated F by age-classes. The longer is the temporal series the less important will be the weight of the terminal F choice. Also, VPA tends to estimate erroneously the fishing mortality when the catchability increases while the stock is under decline. In this case, the assumption that the terminal F did not alter for the last years is a systematic underestimation of the stock size, which may lead the decision makers to believe that the stock is not declining as it is (Hilborn & Walters, 1992). More sophisticated models as catch at age models, which includes the estimate of catchability, terminal F and calculation of confidence intervals for parameter estimates may be used (see Deriso *et al.*, 1985).

Considering that, the precautionary approach developed at the 1992 United Nations Conference on Environment and Development states that 'where there are threats of serious or irreparable damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'. In such a situation, fishery managers can either make use of the available information or wait for an improved infrastructure, sampling and data collection. The latter option is risky as fish stocks may be depleted by the time accurate data become available (Reis, 1992). In that case, considering the traditional approaches in stock assessment, VPA has shown to be the most stable model and the one, which most represents the current status of the reef fish in Northeast Brazil.

IV.IV.2.3. Consequences of a erroneous choice of M

Various authors proposed methods for the estimation of M based on empirical formulae, some based on doughty hypothesis as the supposition that tropical fishes are less long lived, fast growing and show higher natural mortality (Pauly, 1980a; Hoening, 1983). The incorrect use of the mortality rate has a great impact over the reconstruction of the stock size specially when values of F are relatively near or inferior to the estimates of M. If the estimates of M are higher than the real values, the cohort size will be over-estimated and consequently the estimates of fishing mortality will be under-estimated and *vice versa*.

In this study, simulations carried out supported the argument already well described in the literature that estimates can be extremely sensitive to the natural mortality used as input. Newman *et al*. (2000) also noted this sensitivity and stated that the over-estimation of M resulted in an underestimate of actual yield-per-recruit for the red snappers *L. erythropterus, L. malabaricus* and *L. sebae.*

It is well reported that the instantaneous rate of natural mortality varied greatly depending on the method considered. For the mutton snapper in the coast of Florida, M varied from 0.28 (Hoenig (1983)formulae) to 0.39 (Pauly, 1980a, formulae) (Burton, 2002). For

Lutjanus malabaricus of Australia, M varied from 0.115 to 0.134 (Newman & Dunk, 2002). For *L. sebae* of north-western Australia, estimates of M also varied form 0.10 to 0.12 (Newman & Dunk, 2002). In this study, the estimates of natural mortality also varied greatly but, I consider that the best method is the one which deals with data of the stock itself and that was developed for reef fishes, as the method proposed by Ault *et al.* (1998) that take into account the maximum age registered and was applied to Florida reef fishes.

Even when estimates of M are obtained experimentally (which rarely happens with fish stocks poorly known), an additional assumption is that M is constant. Unfortunately, it is known that natural mortality varies according to a complex of ecological variables as predation, habitat, availability of food, and also according the growth phase and the age of the cohort.

IV.IV.2.4. Consequences of bias in the age-length keys

Virtual Population Analysis is fundamentally based on historical series of catch-at-age. Hence, bias in the construction of this series will cause systematic effects on the output estimates and influence all the stock assessment (Hilborn & Walters, 1992).

The usual lack of older individuals in samples, which is due to the high fishing mortality of those age-classes, may have hampered the results of some of the studied species, mainly *L. chrysurus* and *L. synagris*. The absence of older individuals in samples will lead to an under-estimation of the longevity and hence an over-estimation of M, which will lead to consequences for the estimate of Emax. Also, the absence of older individuals greatly interferes in the calculation of K and L_∞, which may results in an inadequate M/K relationship, that is used as input for the models (as the Yield per Recruit model of Beverton and Holt). The problem of the absence of the youngest individuals in samples (they are not fully recruited to the fishery) can be overcame with the use of back-calculated lengths-at-age, at least to what refers to the estimates of the growth parameters.

Although the problem of the absence of the oldest individuals have been refereed in the beginning of data collection for the Program REVIZEE, numerous attempts of selectively collect larger individuals was no guarantee of getting older individuals, since from a certain age, the relationship age-length is not directly correlated to individuals that reach larger sizes and ceases the growing process. Little is known on how the population is truncated by fishing and it may be more relevant to take such uncertainty associated to their absence rather than trying to find the rare individuals.

Recent studies have shown that the Lutjanidae are much older than what was long thought (Wilson & Nieland, 2001; Newman & Dunk, 2002) as it was found for other coral reef fishes such as Acanthuridae and Scaridae (Choat & Axe, 1996; Choat *et al.*, 1996). These results were obtained partly due to the development of refined techniques, but mainly, to the great sample size (more than 3000 individuals samples for both sexes). In the case of the lutjanids of Northeast Brazil, future studies with larger sampled individuals may verify the hypothesis of a higher longevity of the studied species.

IV.IV.2.5. Predictive Models yield per recruit model of Beverton and Holt (1956; 1957)

In this study, predictive models as Thompson and Bell (1934) and the yield per recruit Beverton and Holt (1956; 1957) were applied for the species under study. The output is similar for both approaches (Sparre & Venema, 1998).

Amongst others assumptions, the equilibrium condition implies a situation where all fish alive have been subjected by the same exploitation pattern since they have been recruited. Other assumptions are also considered: constant recruitment, date of birth uniform for all individuals of the same cohort; fishing and natural mortality constant for all cohort since the fishery recruitment and, a relationship length-weight with the parameter b=3. Although many of those assumptions are not applicable, this technique allows a quantitative evaluation of the exploited species when only few data are available (Goevender, 1995).

One of the inputs needed for the application of the yield per recruit model is the M/K relationship. Beverton and Holt (1957) show that for most fish species this relationship varied from 0.8 to 2.2. However, Gulland (1969) noted that this relationship is between 1 and 2 for small pelagics and, between 2 and 3 for demersal fish. It is precisely for these groups of species (small pelagic and demersals) that the model requires major cautions in relation to its application and interpretation. Short-lived fish species show high natural mortality rates and the yield per recruit curve is flat with maximum values not very discernible (Cergole, 1993). In the other hand, fish with slow growth (high M/K rate), show an asymptotic curve and also a maximum point is not visibly clear (Megrey, 1989). In this study, demersal fish specially *L. chrysurus* and *L. synagris* showed flat toped curves of yield per recruit

Finally, considered all the methods tested within this chapter, VPA using true cohorts is the most appropriated method for the estimation of the exploitation rates of the reef species in Northeast Brazil, as this method is free of constraining assumptions (equilibrium conditions, length converted to age). According to this method, the 5 species of *Lutjanus* analysed may be regarded as fully or over-exploited, depending on the biological reference point considered (F_{max} or the most conservative $F_{0.1}$).

Main conclusions and thesis outlook

This chapter had the objective to describe the current status of *L. analis, L. chrysurus, L. jocu, L. synagris* and *L. vivanus* of Northeast Brazil using traditional approaches. A number of methods were performed as the yield per recruit model, the method described by Jones, VPA and the predictive model of Thompson and Bell.

It was evident that length based models are not suitable for the studied species and may not be adequate for many other reef species. Although it may also considered limited, due to the short data series, VPA based on age and true cohorts has shown to be the most appropriate, within the traditional methods applied, for the assessment of the reef fish in Northeast Brazil.

For the next chapters, alternatives of evaluating the reef fishes are tested. In chapter 5, considering the multispecies nature of the reef fishery in Northeast Brazil, the production model will be applied for aggregated yields of individual species. This approach has been already used in tropical fishery (Ralston and Polovina, 1982), where the huge diversity of fishes is often related in fishers' catches. The technological interaction will be also considered within the biomass model, the Thompson and Bell predictive model and statistical catch-at-age model. In Chapter 6, using as case study a system in South Pernambuco, we test the indicator of abundance using fishery independent method as UVC (underwater visual censuses) together with catch data.

Chapter V. Stock assessment of snappers based on a multispecies and multi-fleet approach

V.I. Introduction

Fisheries biology has often focussed on the biological processes present within exploited fish stocks. This narrow focus has led to management strategies that ignore the dynamic response of fishermen to developments in the stock and to management regulations itself (Hilborn & Walters, 1992). Fisheries science has recognised that fish species do not exist in isolation from one another and that they are not harvested independently (Dann, 1987; Magnusson, 1995; Jennings *et al.*, 2001). The multi-species nature of combined fisheries arises for biological, technical and economic reasons (Magnusson, 1995).

Considering the interactions within the multi-species nature of fisheries, interactions arising from technical concerns are more realistically identified and can actually be applied in stock assessment and management Technical interactions arise through the incidental catch of non-target species (by-catch) in targeted fisheries or by the exploitation of a target group of species by the same gear and, mainly by the co-existence of fleets exploiting the same resource and/or the same fishing grounds.

Considering the technical interactions which deal with the simultaneous catch of groups of species, models of the joint capture of species that do not interact biologically (conversely to trophic interactions i.e. multispecies virtual population analysis, MSVPA) have been developed by Murawski (1984). Biomass dynamic models for aggregate species group were developed for jointly caught species (Ralston & Polovina, 1982). Models of this type can be appropriate for both interacting and non-interacting species (Hollowed *et al.*, 2000). The advantage of such approaches is that as there is no specific target species (a group of species instead), each species will have a sustainable yield and the total sustainable yield from this fishery is the sum of those from all species (Anderson, 1986). This combination of yield was designated by Eide and Flaaten (1998) as the maximum sustainable frontier (MSF) and it is the long run limit to what can be harvested from all the species. According to these authors 'the harvesting of less than a combination of yields on the MSF does not necessarily secure a sustainable harvest'.

Considering the technical interactions arising by the co-existence of fleets exploiting the same resource, it is well reported that most tropical fisheries support a large number of gears whose biological impact vary. Models for the management of single species fished by one type of gear may be inadequate to apply to most tropical fisheries and to predict changes at the assemblage level. These technical interactions caused by different fishing gears exploiting the same resource are simple to study and useful results can be obtained (Pikitch, 1988). Several species are caught by the same type of gear and one cannot target effort efficiently on a species by species basis.

In the Northeast reef fishery, both types of technical interactions are reported. Reef species are caught by different fleets, which exploit the stocks in distinctive ways (Chapters 2 and 3). Effort relying on a specific species may be re-allocated by gear aiming the species sustainability. The exploitation would hence be gear (or fleet) specific and the effect of the different gears on the stock structure should be considered. Also, for all gears and fleets that exploit the reef species in Northeast Brazil, a group rather than individual species is caught by the same gear/fleet.

The ultimate motivation of all fisheries models, whether single- or multispecies, is (1) to describe the fisheries patterns, and (2) to understand and inform decision-makers of the consequences of possible fishing activities. In has been reported in the last years a growth in the number and type of multispecies models incorporating technical interactions (Pascoe, 2000; Ulrich *et al.*, 2001; Lucena *et al.*, 2002; Ulrich *et al.*, 2002). Within these approaches, every kind of gear seems to have some degree of size/age selectivity and unequal catchability as members of a cohort will have differential vulnerability to the fleet depending on fish size or other attribute (as bathymetric distribution for example). The multi-fleet exploitation is considered in such approaches. Although these models are in general quite advanced, tropical fishery models tend to be rather simple. The main limitation is the amount and the quality of data (Appeldoorn, 1996). It is recommended a comparison of results obtained by various modelling techniques (Hilborn & Walters, 1992).

This chapter has the objective of evaluating the exploitation of the snappers fishery in Northeast Brazil using a multi-fleet and multi-species approach. Also, considering the multi-species nature of the reef fishery, I analyse the different outputs models (considering both types of technical interactions), discussing limitations and advantages of each one. We compare the more sophisticated approaches with the traditional techniques familiar to the fishery biologists.

V.II. Method

Three models with different need of data and perspectives were used: (a) the Thompson and Bell predictive model (Thompson & Bell, 1934; Sparre & Venema, 1998) including the effect of different fleets exploiting the same resource, (b) the dynamic biomass model with aggregate species (Ralston & Polovina, 1982), and finally (c) the multi-fleet catch-at-age model (Fournier, 1996). Data was obtained through the Project REVIZEE where fish of 5 *Lujanus* species (*L. analis, L. jocu, L. chrysurus, L. synagris* and *L. vivanus*) were measured in 5 states of the northeast Brazil (see Chapter 2 for more details).

V.II.1. Thompson and Bell's predictive model

This model (Thompson & Bell, 1934) was used to predict the effect of changes in the fishing pattern considering the multi-fleet exploitation of the reef fishery in Northeast Brazil (see Chapter 4). The reef species in the studied area are exploited by 4 different fleets: motorised boats (BOM), sailing boats (BOV), 'jangadas' (JAN), 'paquetes' (PQT) (see Chapter 2 for details). The fleet 'BOT' (mixed propulsion boats) are not considered in this Chapter because total catch is not reported in the official statistics (Estatpesca, 2000). Within this approach, the total fishing mortality is analysed considering the 4 different types of exploitation caused by different fleets (based on the proportions of the numbers of fish caught by each fleet).

The fishing mortality exerted by one fleet i is:

$$F_i = F_{total}*C_i/C_{total} \quad (5.1)$$

where F_{total} is the total fishing mortality, C_i the catch of the fleet *i* and C_{total} is the summed catch of all fleets.

Thus, yields are easily separated into fleet components using the exponential decay model and the catch equation (see Chapter 4 for details Sparre & Venema, 1998):

$$N_t = N_{t+1}*\exp^{-Z} \quad \text{(exponential decay)} \quad (5.2)$$

$$C = N* F/Z *(\exp^{-Z} - 1) \quad \text{(catch equation)} \quad (5.3)$$

Where t is the year of the analysis, analysis, N is the number of individuals and Z is the total mortality.

Simulation within this approach will be carried out varying or keeping constant the factor X for each fleet. This will lead to the assessment of the effect of regulatory measures for each fleet component as long as effort is proportional to fishing mortality F.

Initially, the total yield was decomposed by fleet and the same factors, $X_{BOM} = X_{BOV} = X_{PQT} = X_{jan}$ are applied to the F-values for each fleet. This corresponds to a situation where the fishery mortality for each fleet is always in the same proportion of the total fishing mortality. Four other scenarios were analysed and corresponded to a change in fishery mortality for one fleet while the others are assumed to remain at the same level. The scenarios were chosen considering that the reef fishery dynamic is driven by the different fleet category exploiting the resources (see Chapter 2), i.e., fleets which operate mostly in shallower waters (as 'paquete', 'jangada') exploit mainly the coastal resources whilst boats categories which operates in deeper waters (sailing boat 'BOV', motorised boat 'BOM') are more related to the species which is mainly distributed in deep waters..

The scenarios considered are listed below:

Scenario 1: Factors X_{BOM} and X_{BOV} are kept constant whereas X_{PQT} and X_{JAN} are allowed to vary. This scenario explores the situation where fishery mortality is allowed to vary for 'paquetes' PQT and 'jangadas' JAN fisheries whereas the Boats categories fishery mortalities (BOM and BOV) remain constant.

Scenario 2: Factors X_{PQT} and X_{JAN} are kept constant whereas X_{BOM} and X_{BOV} are allowed to vary.

Scenario 3: Factors X_{BOV}, X_{PQT} and X_{JAN} are kept constant whereas X_{BOM} is allowed to vary.

Scenario 4: (a) Factors X_{BOV}, X_{BOM} and X_{JAN} are kept constant whereas X_{PQT} is allowed to vary. This applies for *L. chrysurus* and *L. synagris* only as *L. analis* and *L. jocu* did not present significant catch of 'paquete' PQT. (b) Factors X_{JAN} and X_{BOM} are kept constant whereas X_{BOV} is varied. This applies for *L. analis* and *L. jocu* only.

V.II.2. Biomass model

In some fisheries, the gear comes into contact with stocks of different species, and this could often result in mixed catches due to the exploitation of technologically interdependent species (Anderson, 1986). Fish resources in tropical area are mostly multispecies with complex interactions and significant technological interrelationships in the harvesting process are identified. The less demanding data model to account for the multispecies nature of a fishery is the surplus production model (requires only data series of catch and effort for each fishery) also referred as the biomass dynamic models (Jennings *et al.*, 2001).

Although biomass dynamic models (or production models) are commonly considered as 'second-class' model (Hilborn & Walters, 1992), they often provide as good estimates of management parameters as age-structured approaches. Three basic approaches have been used: (1) the Schaefer model (1954), (2) the Pella & Tomlinson (Pella & Tomlinson, 1969) model, and (3) the difference models (Walters & Hilborn, 1976). The simple Production Model Schaefer Model adapted by Walters & Hilborn (1976) is derived from the dome-shaped production model from a function that describes the growth rate of the population according to the population size.

$$dB/dt = g(B) - Y \tag{5.4}$$

Where B is the exploited population biomass at time t, g(B) is the surplus production as a function of biomass, and Y is the yield of the fishery (in biomass). Fishery biologists usually call this the Schaefer curve (Schaefer, 1954). Schaefer used it to develop a mathematical basis for fitting surplus production models as the following:

$$g(b) = rB\,[1 - (B/B_{max})] \tag{5.5}$$

where r is the intrinsic rate of population increase and the Bmax is the parameter which corresponds to the unfished equilibrium stock size i.e., the carrying capacity (Schaefer, 1954). The methods of fitting these models rely on the assumption that an index of abundance can be related to true abundance, as for example the CPUE:

$$CPUE_t = qB_t \tag{5.6}$$

where B is the population biomass at time t and q is the catchability coefficient. The development of such model requires information on specific catch and effort by gear.

These parameters are obtained through mathematical program such as 'R' (Ihaka & Gentleman, 1996), which uses an automatic differentiation algorithm to estimate the parameters of a non-linear function, based on an appropriate likelihood function.

Its is common practice to assume log-normal distributions for the errors because the random processes are usually multiplicative and using a normal distribution could lead to negative values of biomass or index of abundance (Hilborn & Mangel, 1997).

$$L = \frac{1}{I_{obs}\sqrt{2\pi\sigma}} e^{\left[\frac{-(\ln(I_{obs}) - \ln(I_{est}))^2}{2\sigma^2}\right]} \tag{5.7}$$

where L is the likelihood, I is the index of abundance (here CPUE in weight) observed (obs) and estimated (est) and σ is the standard deviation of $\ln(I_{obs})$.

Considering the multispecies nature of fisheries, the production model can be applied for aggregated yields of individual species. This approach is used in tropical fishery, where the large diversity of fishes is often related in fishers' catches, which may contain 40 or more species of economic importance (Jennings *et al.*, 2001).

In this study, the equation 5.6 may become an aggregated CPUE (total capture/ total effort) of the four snapper species studied (*Lutjanus analis, L. jocu, L. chrysurus, L. synagris*). *L. vivanus* is not considered in this chapter because this species is not reported by the official statistics.. This method has been already applied by Ralston and Polovina on deep-sea hand-line fishery in Hawaii (1982) and Koslow *et al.* reef fisheries of Jamaica and Belize (1994).

V.II.3. Multi-fleet catch-at-age model

In the proposed model, the exploitation will be fleet specific in order to consider the effect of the different fleet on the stock structure of each species of *Lutjanus* analysed. The catch-at-age model requires data on numbers-at-age and fishing effort by gear and by year and an assumption about natural mortality.

The catch-at-age model was implemented in the program 'AD Model Builder' (Fournier, 1996). This program is a tool for the rapid development and implementation of non-linear statistical models.

Given that *i* indicates the fishing year, *j* the index age class and *f* the fleet. Denote catchability by gear (q_f) and the selectivity coefficients by gear and age ($S_{g(j)}$).

The instantaneous fishing mortality rate by fleet, year and age , $F_{f(ij)}$, is given by:

$$F_{f(ij)} = q_f \, E_{g(i)} \, S_{f(j)} \exp\{\varphi_{f(i)}\} \tag{5.8}$$

where $E_{f(i)}$ is the observed fishing effort by gear in year i and $\varphi_{f(i)}$ are deviations from the expected relationship between the observed fishing effort and the resulting fishing mortality in year i. Specifically, $F_{PQT(ij)}$, $F_{JAN(ij)}$, $F_{BOV(ij)}$ and $F_{BOM(ij)}$ denote the fishery mortality by year and age for 'paquete' (PQT), 'jangada' (JAN), 'sailing boats' (BOV) and 'motorised boats' (BOM) exploitation, respectively. Total fishery mortality is then given by the summation

$$F_{ij} = F_{PQT(ij)} + F_{JAN(ij)} + F_{BOV(ij)} + F_{BOM(ij)} \tag{5.9}$$

The model considered different fleets for each species. For *L. analis* and *L. jocu,* 'jangada' 'sailing boats' and motorised boats' were relevant within the exploitation of these species. For *L. synagris* and *L. chrysurus*, 'paquete' is also included in the analysis. Furthermore, it is assumed that the natural mortality rate M is known (see Chapter 4 for the natural mortality assumed for each *Lutjanus* species).

Total mortality (Z) is given by:

$Z_{(ij)} = F_{(ij)}+M$ (5.10)

An iterative estimation approach is used to estimate parameters such as the catchability and selectivity. The iterative scheme implemented requires initial estimates of population scale and relative population (denoted relpop) but these are subsequently updated iteratively. For all years, estimates of recruits (at age 1) and numbers-at-age of all ages for the first year of analysis are given by: log (initial population) = log (relpop) + log (population scale)

$N_{(i,1)}$= exp{log (initial population(i))} (5.11)

$N_{(1,j)}$= exp{log (initial population(j))} (5.12)

Providing estimates of the initial population in year 1, $N_{1,1}$, $N_{1,2}$..., $N_{1,j}$ and the knowledge of recruitment in each year ($N_{1,1}$, $N_{2,1}$,...) the seasonal exponential decay equation yields:

$N_{(i+1,\, j+1)} = N_{(i,j)}S_{v(i,j)}$ (5.13)

where $S_{v(i,j)}$, the survival by year and age class, is $S_{v(i,j)} = \exp^{-Z}$

The biomass (B) at the beginning of the year (1st of January) is calculated through the equation:

$Bi = \Sigma W_j N_{(ij)}$ (5.14)

Where Wj is the weight-at-age. (5.15)

The predicted catch by each fleet, year *i* and age *j*, ($C_{PQT(i,j)}$, $C_{JAN(i,j)}$ $C_{BOV(i,j)}$ and $C_{BOM(i,j)}$ respectively) is given by:

$$C_{bom(ij)} = (F_{bom(ij)} / Z_{(ij)})[1 - S_{v(ij)}]N_{(i,j)} \quad (5.16)$$

$$C_{bov(ij)} = (F_{bov(ij)} / Z_{(ij)})[1 - S_{v(ij)}]N_{(i,j)} \quad (5.17)$$

A statistical model is constructed with two elements – catch and effort (c.f. Fournier, 1996) - from which parameter estimates are derived. The true catches $C_{PQT(i,j)}$, $C_{JAN(i,j)}$, $C_{BOV(i,j)}$ and $C_{BOM(i,j)}$ each year for each fleet, are not known but estimates $Co_{PQT(i,j)}$, $Co_{JAN(i,j)}$, $Co_{BOV(i,j)}$ and $Co_{BOM(i,j)}$ (observed catches – input catch-at-age matrix by fleet) respectively, are recorded.)

Parameter estimation is based on maximum likelihood (L) with catches assumed to follow a Normal distribution with likelihood functions given by:

$$L1=\prod_{i=1}^{I}\prod_{j=1}^{J}(2\pi\sigma^2)^{-1/2}\exp(-(Co_{bom(i,j)}-C_{bom(i,j)})^2/C_{bom(i,j)})+\prod_{i=1}^{I}(2\pi\sigma^2)^{-1/2}\exp(-\tfrac{1}{2}(\varphi_{l(i)}^2)) \quad (5.18)$$

$$L2=\prod_{i=1}^{I}\prod_{j=1}^{J}(2\pi\sigma^2)^{-1/2}\exp(-(Co_{bov(i,j)}-C_{bov(i,j)})^2/C_{bov(i,j)})+\prod_{i=1}^{I}(2\pi\sigma^2)^{-1/2}\exp(-\frac{1}{2}(\varphi_{l(i)}^2)) \quad (5.19)$$

$$L3=\prod_{i=1}^{I}\prod_{j=1}^{J}(2\pi\sigma^2)^{-1/2}\exp(-(Co_{jan(i,j)}-C_{jan(i,j)})^2/C_{jan(i,j)})+\prod_{i=1}^{I}(2\pi\sigma^2)^{-1/2}\exp(-\frac{1}{2}(\varphi_{l(i)}^2)) \quad (5.20)$$

$$L4=\prod_{i=1}^{I}\prod_{j=1}^{J}(2\pi\sigma^2)^{-1/2}\exp(-(Co_{pqt(i,j)}-C_{pqt(i,j)})^2/C_{pqt(i,j)})+\prod_{i=1}^{I}(2\pi\sigma^2)^{-1/2}\exp(-\frac{1}{2}(\varphi_{l(i)}^2)) \quad (5.21)$$

The parameters of the model are estimated by maximising the sum of the independent log-likelihoods log L1 + log L2 + log L3+ log L4. Note that only three log-likelihood (*L*1, *L*2 and *L*3) were calculated for *L. analis* and *L. jocu* as the fleet PQT is not relevant within the exploitation of these species.

V.III. Results

V.III.1. Thompson and Bell model simulations

V.III.1.1. *Lutjanus analis,* mutton snapper

Motorised boats (BOM) most influence the yield curve for *L. analis* as this fleet is responsible by the major part of the species capture When fishing mortality for all fleets similarly increase (factors X equals), the stock was found fully exploited by the BOM fishery whereas BOV did not reach a maximum and JAN was found already over the maximum yield (Fig. 1A). This is expected and already described by Sparre and Venema (1998), i.e., the higher the effort of the most relevant fleet (in that case BOM) the smaller share is left for the fleets which are responsible by the lower catches.

Considering the scenarios, when the 'jangada' (JAN) or the sailing boat (BOV) fishery increased and the other remained constant, i.e. scenario 1 (factors X_{BOM} and X_{BOV} are kept constant whereas X_{PQT} and X_{JAN} are varied) and 4 (factors X_{JAN} and X_{BOM} are kept constant whereas X_{BOV} is varied), the yield does not relevantly change within the range of the X-factor considered (Fig. V.1B). This is mainly related to the fact that the fleets that are allowed to vary within these scenarios (JAN and PQT) are not relevant within the exploitation of this species (Fig. V.1B). The scenario 2 (factors X_{PQT} and X_{JAN} are kept constant whereas X_{BOM} and X_{BOV} are varied) has shown a maximum yield at the current fishing mortality (F). However, in the situation of scenario 3 (factors X_{BOV}, X_{PQT} and X_{JAN} are kept constant whereas X_{BOM} is varied), the F_{MAX} for BOM is a little beyond the current F (Fig. 1B).

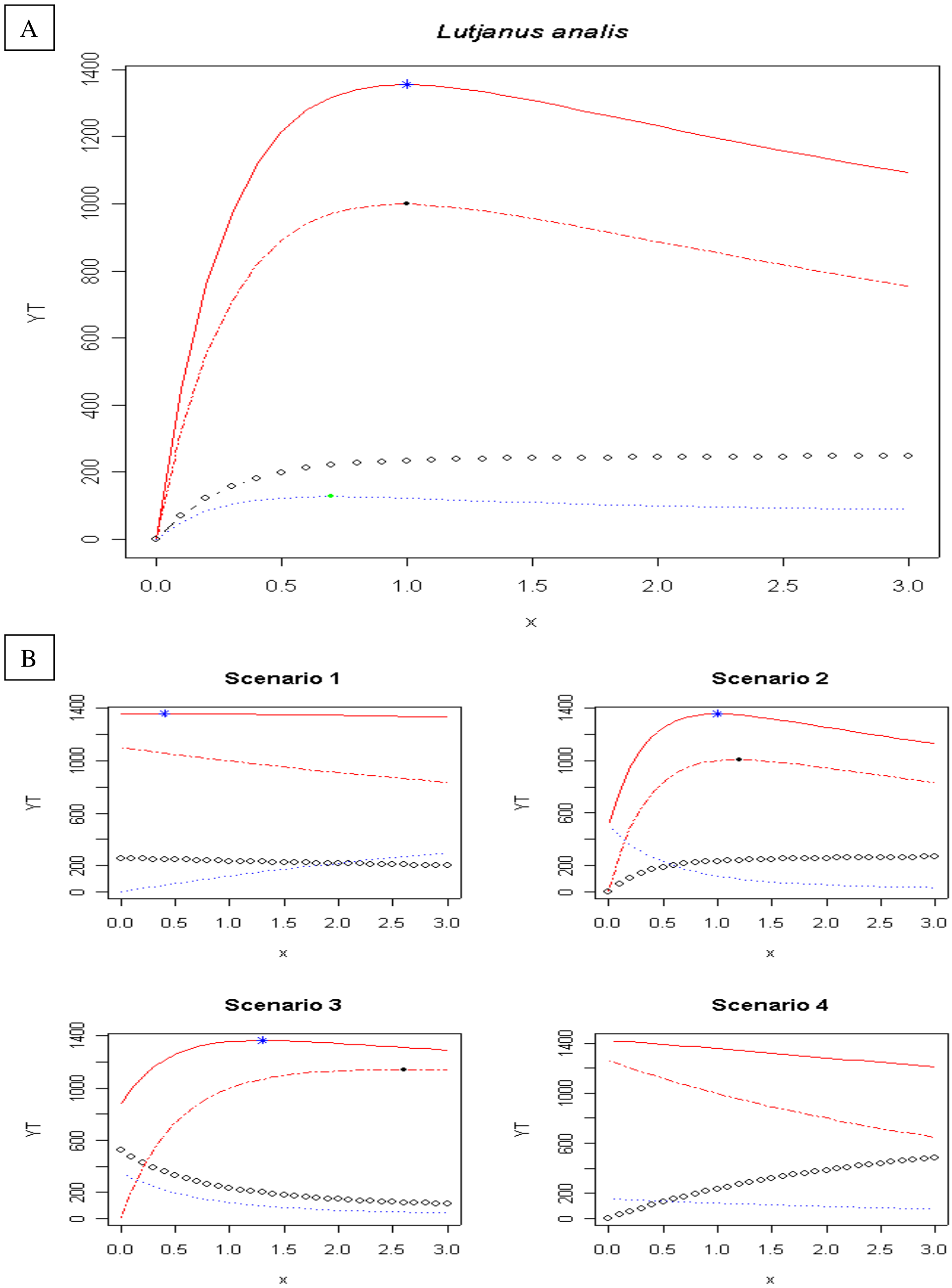


Fig. V.1: Total yield per 1000 recruits of *L. analis* separated into fleet component. (A) Situation where the X-factors vary equally. (B) Scenarios where X-factor are allowed to vary differently by fleet: Scenario(1): changes of effort in JAN. (2) changes of effort in BOM and BOV. (3) changes of effort in BOM, (4) changes of effort in BOV. Red dashed line: BOM, blue dotted line: JAN, dash and circle line: BOV, red full line: total yield. Coloured dots represent the F_{MAX} for each fleet.

V.III.1.2. *Lutjanus jocu*, dog snapper

The fishing mortality at maximum yield was 20 % superior to the current F (Fig. 2A). When the fishery mortality is considered fleet specific (factors X equals for all fleets), the F_{MAX} for JAN and BOM were respectively 20% and 40% superior to the current F (X-factor = 1) whereas the optimum F for BOV should be reduced by 10% (Fig. V.2A). Effect of changes in the 'jangadas' JAN fishery while boat fishery (BOM, BOV) is kept at a constant level (scenario 1) was relatively low which means that this fleet does not have great influence on the yield for this species (Fig. 2B). Considering the scenarios where fishing mortality is allowed to vary for both 'boats' fisheries (scenario 2), BOM only (scenario 3), and BOV only (scenario 4), it is evident that only the BOM fishery had a significant impact on the total yield. One may note that the dog snapper fishery is already at full exploitation and that efficient management action should target the BOM fishery.

V.III.1.3. *Lutjanus chrysurus*, yellowtail snapper

The total yield did not find a maximum within the range of the factor X varying from 0 to 3 (Fig. 3). As reported in Chapter 4, maximum yield was not very discernible for any scenario. This is probably related to fish species that show a very low growth rate (see Chapter 4). For this reason, Fmax could be reached when factor X is out of the range considered for this fishery. However, as the yield curve presents an asymptotic shape, the increase in factor X from one (current F - X-factor = 1) does not relevantly changes the yield. This would mean that, if exploitation reaches more than currently reported (X-factor = 1), the species could be already considered as fully exploited. Considering the scenarios 1 to 4, no maximum level of factor-X within the considered range was observed (Fig. 3b). The combination of scenarios highlighted the influence of the BOM fleet within the exploitation of the species.

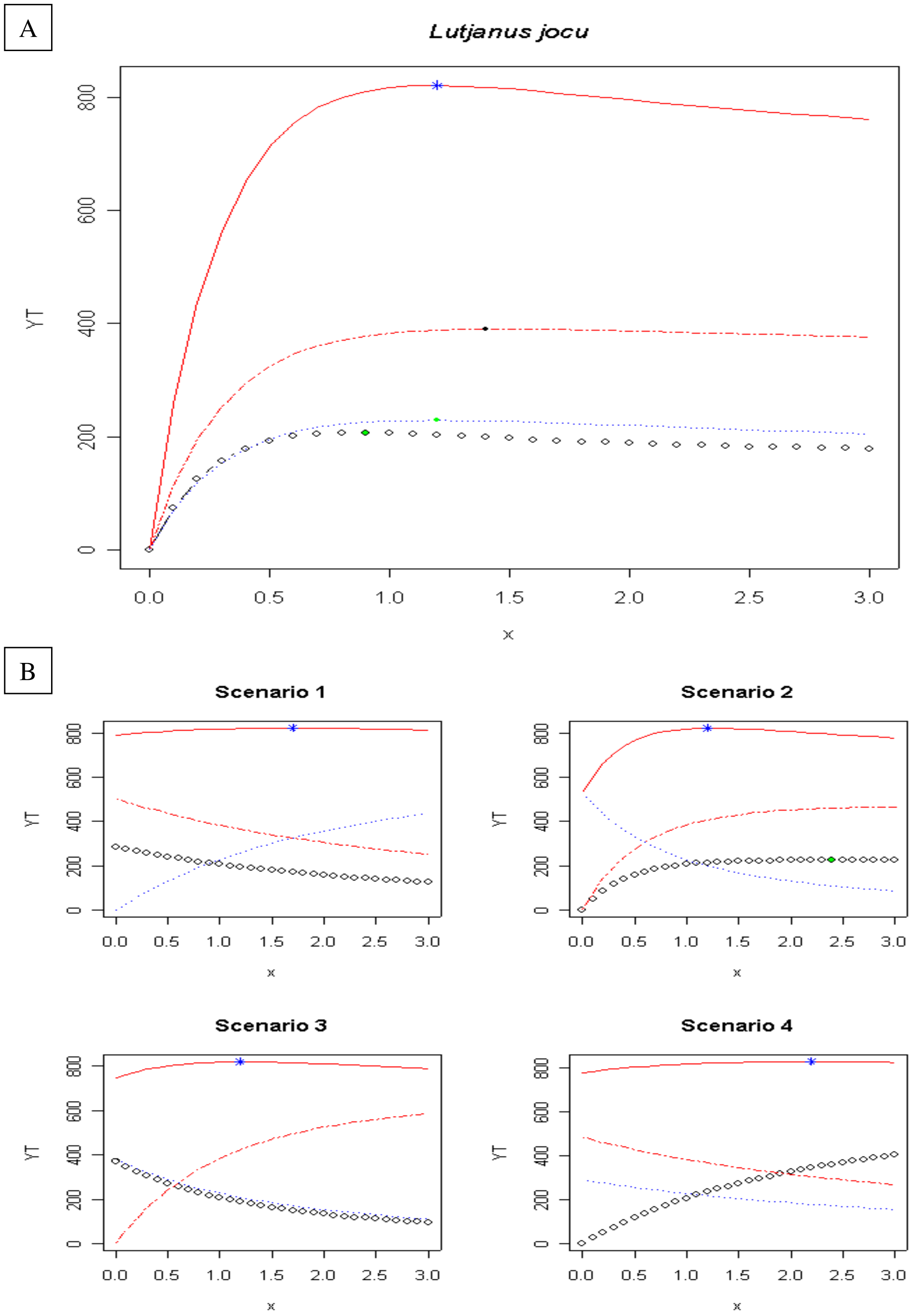


Fig. V.2: Total yield per 1000 recruits of *L. jocu* separated into fleet component. (A) Situation where the X-factors vary equally. (B) Scenarios where X-factor are allowed to vary differently by fleet: Scenario (1): changes of effort in JAN. (2) changes of effort in BOM and BOM. (3) changes of effort in BOM, (4) changes of effort in BOV. Red dashed line: BOM, blue dotted line: JAN, black dash and circle line: BOV, red full line: total yield. Coloured dots represent the F_{MAX} for each fleet.

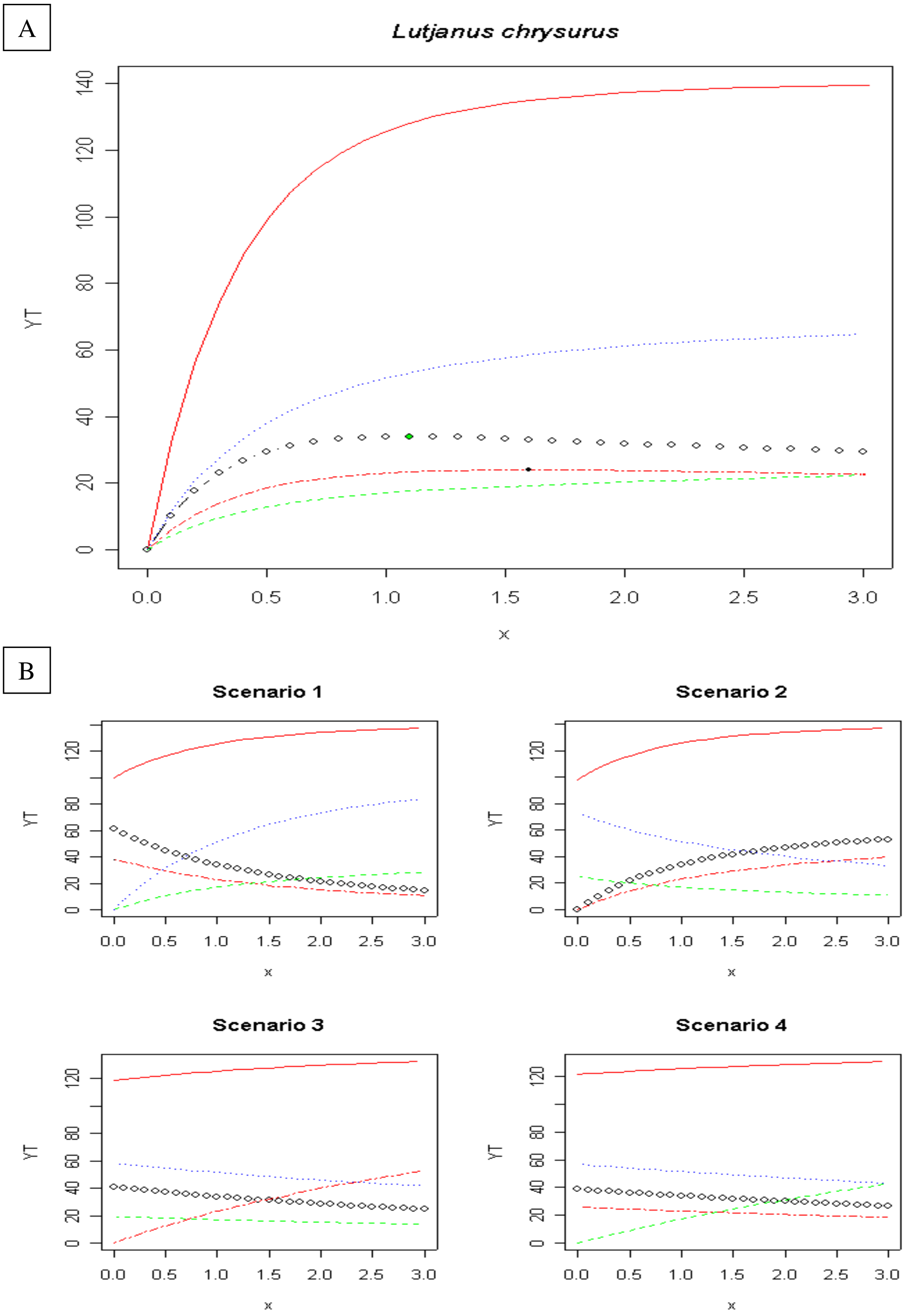


Fig. V.3: Total yield per 1000 recruits of *L. chrysurus* separated into fleet component. (A) Situation where the X-factors vary equally. (B) Scenarios where X-factor are allowed to vary differently by fleet: Scenario (1): changes of effort in JAN. (2) changes of effort in BOM and BOM. (3) changes of effort in BOM, (4) changes of effort in PQT. Red dashed line: BOM, blue dotted line: JAN, black dash and circle line: BOV, green dashed line: PQT, red full line: total yield. Coloured dots represent the F_{MAX} for each fleet.

V.III.1.4. *Lutjanus synagris*, lane snapper

Effect of change for each fleet showed that, considering any scenario, that the yield curve, as for *L. chrysurus* is also similar to an asymptotic and no maximum value is easily discernible (Fig. V.4). The Fmax could be reached when factor X is 2.4, but as for *L. chrysurus*, given that the yield curve presents an asymptotic shape, the increase in factor X from one (current F - X-factor = 1) does not relevantly changes the yield and this species could be already considered as fully exploited. For *L. synagris,* it is evident that JAN and PQT play an important role in the exploitation of this species.

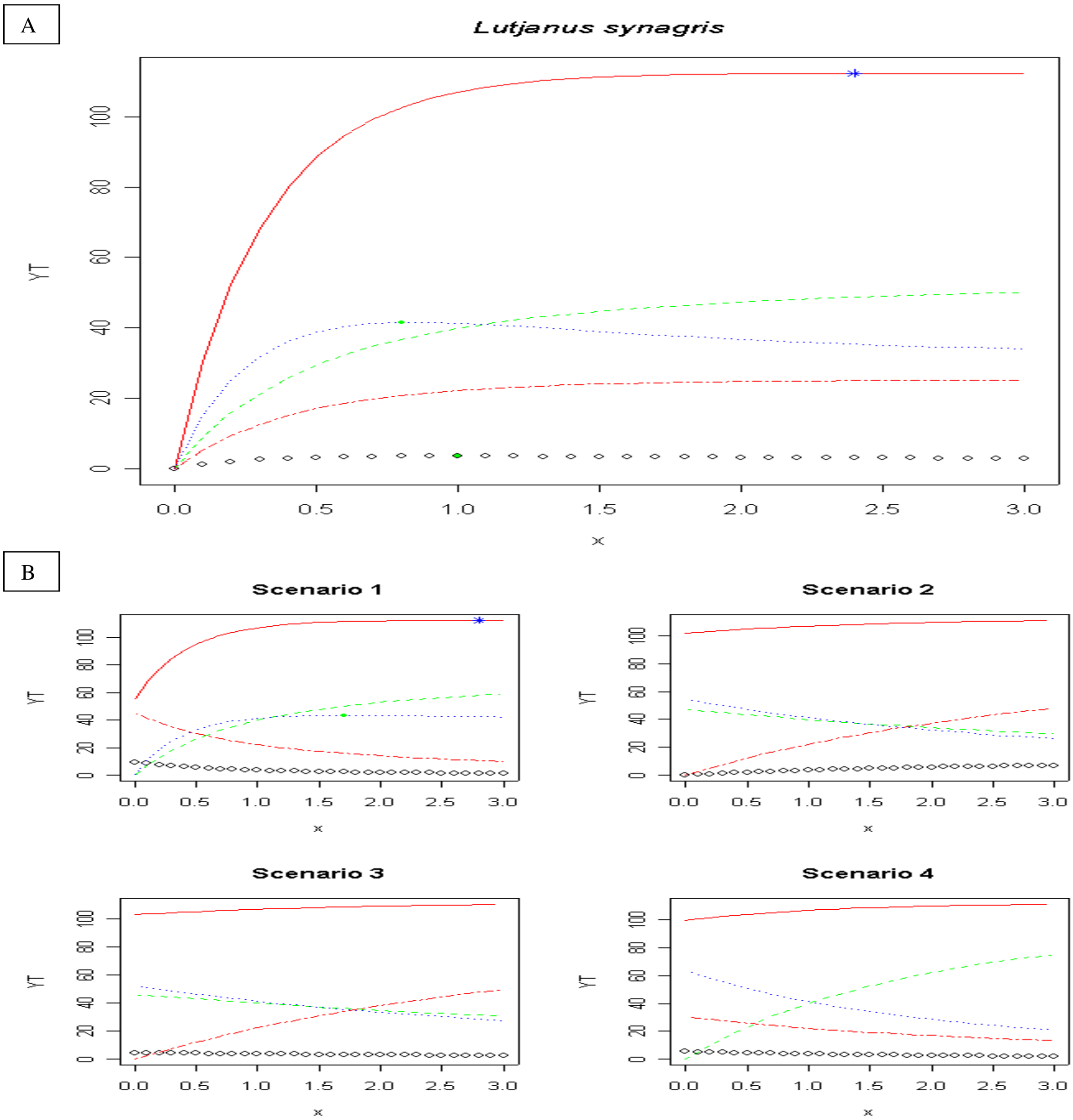


Fig. V.4: Total yield per 1000 recruits of *L. synagris* separated into fleet component. (A) Situation where the X-factors vary equally. (B) Scenarios where X-factor are allowed to vary differently by fleet: Scenario (1): changes of effort in JAN. (2) changes of effort in BOM and BOM. (3) changes of effort in BOM, (4) changes of effort in PQT. Red dashed line: BOM, blue dotted line: JAN, black dash and circle line: BOV, green dashed line: PQT, red full line: total yield. Coloured dots represent the F_{MAX} for each fleet.

V.III.2. Biomass model

A non-equilibrium Schaefer surplus production model was fitted to the data of the four snappers (lumped together) reported in the reef fishery of Northern Brazil (*L. analis, L. chrysurus, L. synagris, L. jocu*). These species were considered as relevant within the reef fishery in northeast Brazil (see Chapter 2). The log likelihood was maximised to 4.6 and the parameters r, q, K, σ and MSY is reported in Table V.1. The observed catch per unit of effort (CPUE in number) was plotted along to the predicted CPUE and the biomass against the studied period (Fig. V.5). The convergence to the best set of parameters, that minimise the function (negative likelihood) was a critical task. The high uncertainty and a goodness-of-fit surface with multiple peak interfered to the determination of a satisfactory set of parameter. Because of a very short time series for this kind of model and the low contrast of the data (ideally, alternate periods of low and high abundance of the fish stock is required, according to Hilborn & Walters, 1992), several sets of parameters could maximise the likelihood. For this reason, and considering the high uncertainty, further development of the model was not continued.

Table V.1: Estimated parameters with the Schaefer model

Parameters	*Observation uncertainty*
K	26314881
r	0.43610568
q	2.92723E-05
MSY	2869017.32
sigma	0.1065865

Fig. V.5: Observed index of relative abundance (CPUE) and estimated biomass *vs*. years, with best fit predicted CPUE superimposed.

V.III.3. Multi-fleet catch-at-age model

V.III.3.1. *L. analis*

The multi-fleet catch-at-age optimisation (maximisation the likelihood) algorithm for this species did not converge to an optimum solution. Then, further development of this model for this species was not continued.

V.III.3.2. *L. jocu*

During the period 1996-2001, BOM (motorised boats) was the dominant mode of exploitation for *L. jocu* in Northeast Brazil (Fig V.6). Age-classes 4 to 10 were exposed to the highest fishing mortality (Table V.2). Total fishing mortality (for the weighted mean F) was 0.05 (Fig 6) and E (exploitation rate; E=F/Z) was equal to 0.30, which means that 30% of the mortality of this species is due to fisheries.

For 1996 - 2001, biomass decreased from around 70 to 10 thousand of tonnes over the period (Fig. V.7). Catchability of BOV was similar to BOM and higher than for JAN (Table V.2).

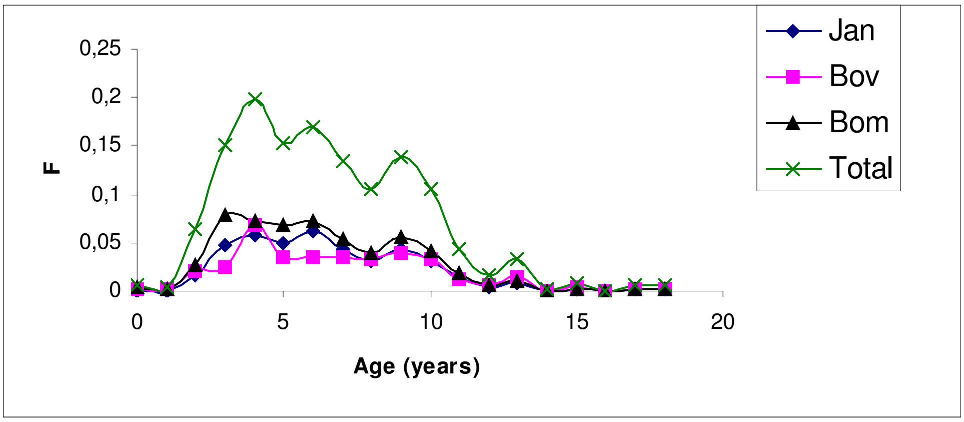


Fig. V.6: Fishing mortality split by fleet for all age classes of *L. jocu*

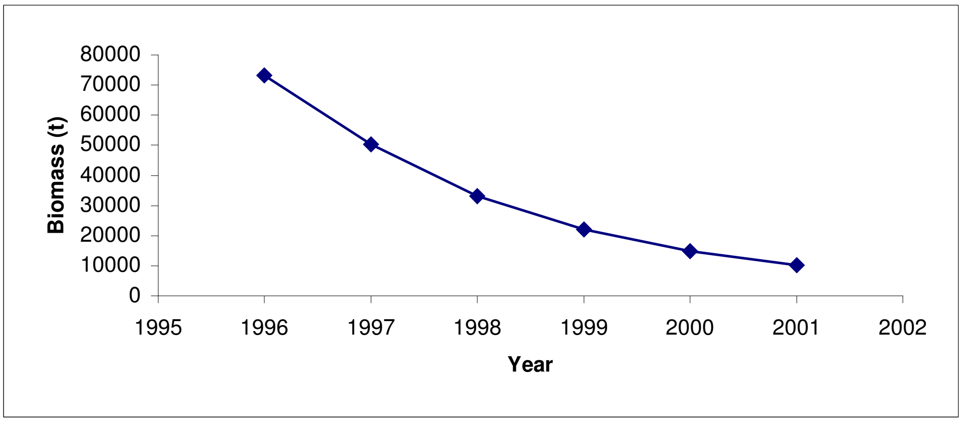


Fig. V.7: Biomass profile during the studied period

Table V.2: Fishing mortality F and log catchability for L. jocu in 1996 to 2001. JAN= ´Jangada´ ; BOV = sailing boat and BOM = motorised boats.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
JAN																			
1996	0.000222194	0.000185	0.003996	0.011641	0.014111	0.012168	0.015042	0.010896	0.0077	0.010636	0.007755	0.003392	0.001195	0.002238	5.63E-05	0.000376	3.58E-05	0.000508	0.000399
1997	0.000354229	0.000294	0.00637	0.018559	0.022496	0.019398	0.02398	0.01737	0.012276	0.016956	0.012364	0.005408	0.001904	0.003568	8.98E-05	0.000599	5.71E-05	0.000809	0.000636
1998	0.000614886	0.000511	0.011057	0.032215	0.039049	0.033672	0.041626	0.030152	0.021309	0.029433	0.021462	0.009388	0.003306	0.006194	0.000156	0.00104	9.9E-05	0.001405	0.001104
1999	0.000774933	0.000644	0.013935	0.040601	0.049213	0.042436	0.05246	0.038	0.026855	0.037094	0.027048	0.011831	0.004166	0.007806	0.000196	0.001311	0.000125	0.00177	0.001391
2000	0.000915021	0.000761	0.016454	0.04794	0.05811	0.050108	0.061944	0.04487	0.03171	0.043799	0.031937	0.01397	0.004919	0.009217	0.000232	0.001548	0.000147	0.00209	0.001642
2001	0.00254294	0.002114	0.045728	0.13323	0.161493	0.139255	0.172149	0.124698	0.088125	0.121722	0.088757	0.038824	0.013672	0.025615	0.000645	0.004302	0.00041	0.005809	0.004565
Mean	0.000904034	0.000751	0.016257	0.047364	0.057412	0.049506	0.0612	0.044331	0.031329	0.043273	0.031554	0.013802	0.00486	0.009106	0.000229	0.001529	0.000146	0.002065	0.001623
log q (se)	-14.31 (0.303)																		
BOV																			
1996	0.000920856	0.000772	0.010255	0.011887	0.033346	0.016985	0.017144	0.016991	0.016233	0.018941	0.015593	0.006112	0.002853	0.006792	0.000263	0.002099	0.000156	0.000905	0.001083
1997	0.00131988	0.001106	0.014699	0.017038	0.047795	0.024344	0.024573	0.024353	0.023266	0.027149	0.022349	0.00876	0.00409	0.009735	0.000377	0.003009	0.000224	0.001298	0.001552
1998	0.00058967	0.000494	0.006567	0.007612	0.021353	0.010876	0.010978	0.01088	0.010395	0.012129	0.009985	0.003914	0.001827	0.004349	0.000169	0.001344	0.0001	0.00058	0.000693
1999	0.000851517	0.000714	0.009483	0.010992	0.030835	0.015706	0.015853	0.015712	0.01501	0.017515	0.014419	0.005651	0.002638	0.006281	0.000244	0.001941	0.000144	0.000837	0.001001
2000	0.00151572	0.00127	0.01688	0.019566	0.054887	0.027957	0.028219	0.027967	0.026719	0.031177	0.025666	0.01006	0.004696	0.01118	0.000433	0.003455	0.000257	0.00149	0.001782
2001	0.00620574	0.0052	0.069111	0.080106	0.224722	0.114461	0.115533	0.114503	0.109392	0.127646	0.105081	0.041187	0.019228	0.045774	0.001775	0.014146	0.001053	0.006101	0.007296
Mean	0.001900564	0.001593	0.021166	0.024533	0.068823	0.035055	0.035383	0.035068	0.033502	0.039093	0.032182	0.012614	0.005889	0.014019	0.000543	0.004332	0.000323	0.001869	0.002234
log q (se)	-12.13 (0.306)																		
BOM																			
1996	0.00165215	0.000966	0.011399	0.034705	0.032226	0.029855	0.032092	0.024094	0.017706	0.024888	0.01822	0.007884	0.002929	0.004335	0.000225	0.001049	0.000137	0.001	0.000784
1997	0.00214428	0.001254	0.014794	0.045042	0.041825	0.038748	0.041651	0.03127	0.02298	0.032301	0.023647	0.010232	0.003802	0.005627	0.000292	0.001362	0.000177	0.001298	0.001017
1998	0.00334782	0.001958	0.023098	0.070323	0.065301	0.060496	0.06503	0.048822	0.035878	0.050431	0.03692	0.015976	0.005935	0.008785	0.000456	0.002126	0.000277	0.002027	0.001588
1999	0.00518725	0.003033	0.035789	0.108962	0.10118	0.093735	0.100759	0.075646	0.05559	0.078139	0.057205	0.024753	0.009197	0.013611	0.000706	0.003294	0.000429	0.00314	0.00246
2000	0.00413015	0.002415	0.028496	0.086757	0.080561	0.074633	0.080226	0.06023	0.044262	0.062216	0.045547	0.019709	0.007322	0.010837	0.000562	0.002623	0.000341	0.0025	0.001959
2001	0.00602692	0.003524	0.041582	0.1266	0.117558	0.108908	0.117069	0.087891	0.064589	0.090788	0.066465	0.02876	0.010685	0.015815	0.000821	0.003827	0.000498	0.003649	0.002859
Mean	0.003748095	0.002192	0.02586	0.078732	0.073109	0.067729	0.072804	0.054659	0.040167	0.05646	0.041334	0.017886	0.006645	0.009835	0.00051	0.00238	0.00031	0.002269	0.001778
log q (se)	-12.8 (0.304)																		

V.III.3.3. *L. synagris*

During the period 1996-2001, JAN and PQT were the dominant mode of exploitation for *L. synagris* in Northeast Brazil (Fig V.8). Individuals older than 12 years were exposed to the highest fishing mortality (Table V.3). Total fishing mortality (for mean weighted F) was 0.16 (Fig V.8) and E was equivalent to 0.53, which means that more than half of stock dies by fisheries causes.

For the whole period, biomass slightly decreased from 13 to 12 thousands of tonnes. (Fig. V.9). Catchability of PQT was highest than the reported for the others fleets (Table V.3).

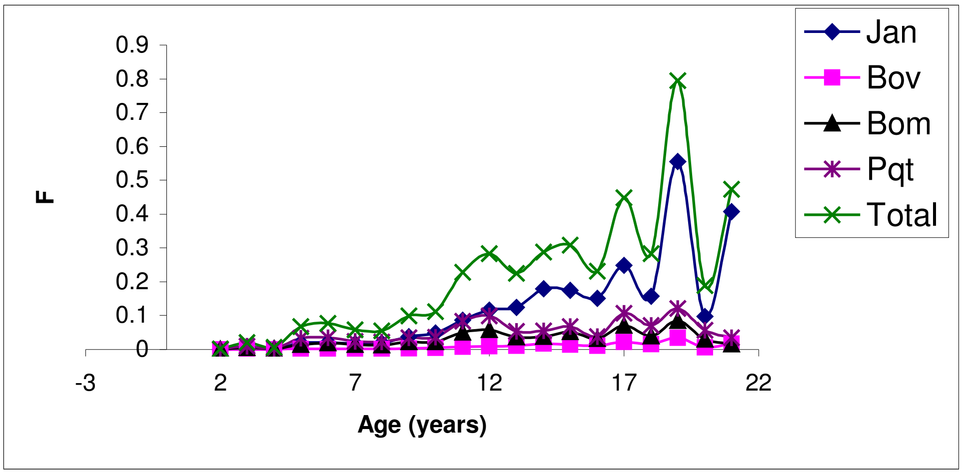


Fig. V.8: Fishing mortality split by fleet for all age classes of *L. synagris*

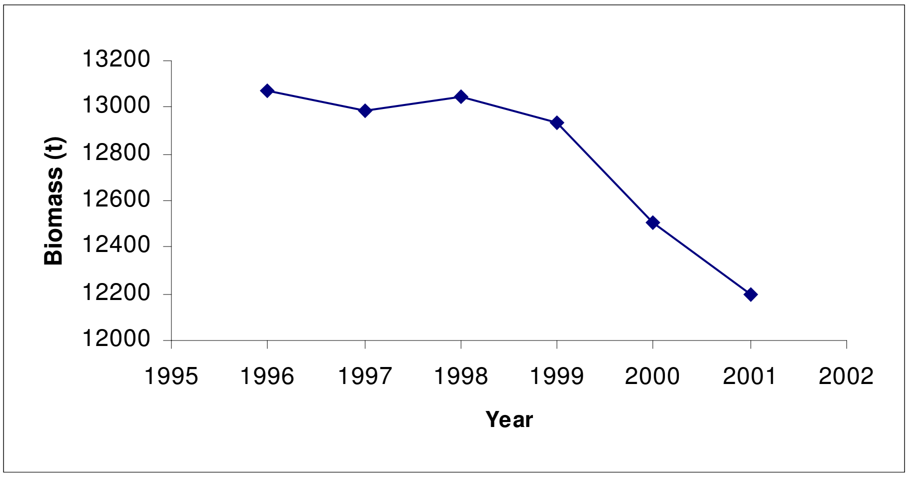


Fig. V.9: Biomass profile during the studied period

Table V.3: Fishing mortality F and log catchability for *L. synagris* in 1996 to 2001. PQT='paquete'; JAN= ´Jangada´ ; BOV = sailing boat and BOM = motorised boats.

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
PQT																				
1996	0.000171416	0.004219	0.001282	0.014203	0.014974	0.01019	0.00922	0.015081	0.015812	0.035637	0.042554	0.023032	0.023539	0.029075	0.016147	0.046239	0.030762	0.051876	0.024435	0.014827
1997	0.000294269	0.007244	0.002201	0.024382	0.025705	0.017493	0.015828	0.025889	0.027145	0.061177	0.073052	0.039539	0.040409	0.049913	0.027719	0.079378	0.052809	0.089056	0.041948	0.025453
1998	0.000375064	0.009232	0.002805	0.031076	0.032763	0.022296	0.020174	0.032997	0.034598	0.077974	0.093109	0.050394	0.051504	0.063617	0.035329	0.101172	0.067308	0.113507	0.053465	0.032442
1999	0.000540336	0.013301	0.004042	0.04477	0.0472	0.032121	0.029063	0.047537	0.049843	0.112333	0.134138	0.0726	0.074199	0.09165	0.050897	0.145753	0.096967	0.163524	0.077025	0.046737
2000	0.000458427	0.011284	0.003429	0.037984	0.040045	0.027252	0.024658	0.040331	0.042287	0.095305	0.113804	0.061595	0.062952	0.077757	0.043182	0.123659	0.082268	0.138735	0.065349	0.039652
2001	0.000548374	0.013498	0.004102	0.045436	0.047902	0.032599	0.029496	0.048244	0.050584	0.114004	0.136133	0.07368	0.075303	0.093013	0.051654	0.147921	0.09841	0.165956	0.078171	0.047432
Mean	0.000397981	0.009796	0.002977	0.032975	0.034765	0.023659	0.021406	0.035013	0.036711	0.082738	0.098798	0.053473	0.054651	0.067504	0.037488	0.107354	0.071421	0.120442	0.056732	0.034424
log q (se)	-10.90 (0.0934)																			
JAN																				
1996	0.000307983	0.0085	0.002083	0.026088	0.029306	0.024721	0.026061	0.052299	0.066842	0.120489	0.160583	0.172835	0.248031	0.243357	0.20974	0.344309	0.217916	0.771167	0.135273	0.564534
1997	0.000184766	0.005099	0.00125	0.015651	0.017581	0.014831	0.015635	0.031376	0.0401	0.072284	0.096338	0.103688	0.1488	0.145996	0.125828	0.206559	0.130733	0.462641	0.081153	0.338677
1998	0.000194088	0.005356	0.001313	0.016441	0.018468	0.015579	0.016424	0.032959	0.042123	0.075931	0.101198	0.108919	0.156307	0.153362	0.132176	0.21698	0.137328	0.485982	0.085248	0.355764
1999	0.000236195	0.006518	0.001598	0.020008	0.022475	0.018959	0.019987	0.040109	0.051262	0.092405	0.123153	0.132549	0.190218	0.186634	0.160852	0.264054	0.167122	0.591417	0.103742	0.432948
2000	0.000185293	0.005114	0.001253	0.015696	0.017631	0.014873	0.015679	0.031465	0.040215	0.072491	0.096613	0.103983	0.149224	0.146412	0.126187	0.207148	0.131106	0.463962	0.081385	0.339644
2001	0.000223618	0.006171	0.001512	0.018942	0.021278	0.017949	0.018922	0.037973	0.048532	0.087484	0.116595	0.125491	0.180089	0.176695	0.152287	0.249993	0.158223	0.559924	0.098218	0.409893
Mean	0.000221991	0.006126	0.001501	0.018804	0.021123	0.017818	0.018785	0.037697	0.048179	0.086847	0.115747	0.124578	0.178778	0.175409	0.151178	0.248174	0.157071	0.555849	0.097503	0.40691
log q (se)	-11.8 (0.0951)																			
BOV																				
1996	1.75E-05	0.000154	0.000116	0.001015	0.001111	0.001125	0.001085	0.00204	0.002574	0.004527	0.005182	0.006323	0.009445	0.007461	0.006269	0.012288	0.008348	0.019042	0.003355	0.009215
1997	1.48E-05	0.00013	9.81E-05	0.000856	0.000937	0.000949	0.000916	0.001721	0.002172	0.00382	0.004372	0.005336	0.007971	0.006296	0.00529	0.01037	0.007045	0.016069	0.002831	0.007776
1998	4.83E-05	0.000423	0.00032	0.002794	0.003058	0.003097	0.002987	0.005617	0.007087	0.012463	0.014267	0.01741	0.026007	0.020543	0.017262	0.033834	0.022986	0.05243	0.009238	0.025372
1999	2.36E-05	0.000207	0.000157	0.001368	0.001497	0.001516	0.001462	0.002749	0.003469	0.006101	0.006983	0.008522	0.01273	0.010056	0.00845	0.016562	0.011251	0.025664	0.004522	0.012419
2000	3.59E-05	0.000315	0.000238	0.002079	0.002275	0.002305	0.002223	0.004179	0.005274	0.009274	0.010616	0.012955	0.019352	0.015286	0.012844	0.025176	0.017104	0.039012	0.006874	0.018879
2001	4.93E-05	0.000432	0.000327	0.002853	0.003122	0.003163	0.00305	0.005736	0.007237	0.012726	0.014568	0.017778	0.026556	0.020977	0.017626	0.034549	0.023471	0.053537	0.009433	0.025907
Mean	3.15696E-05	0.000277	0.000209	0.001827	0.002	0.002026	0.001954	0.003674	0.004636	0.008152	0.009331	0.011387	0.01701	0.013436	0.01129	0.02213	0.015034	0.034292	0.006042	0.016595
log q (se)	-12.4 (0.107)																			
BOM																				
1996	0.00013956	0.002789	0.001277	0.00984	0.013364	0.010134	0.008908	0.015018	0.015415	0.0343	0.040145	0.024297	0.025302	0.035283	0.021129	0.048623	0.02698	0.05786	0.019926	0.010948
1997	0.000157494	0.003148	0.001441	0.011105	0.015082	0.011437	0.010052	0.016948	0.017396	0.038708	0.045304	0.027419	0.028553	0.039817	0.023844	0.054871	0.030447	0.065295	0.022487	0.012355
1998	0.000128988	0.002578	0.00118	0.009095	0.012352	0.009367	0.008233	0.01388	0.014247	0.031702	0.037104	0.022456	0.023385	0.032611	0.019529	0.04494	0.024936	0.053477	0.018417	0.010119
1999	0.000197584	0.003949	0.001808	0.013932	0.018921	0.014348	0.012611	0.021262	0.021824	0.048561	0.056836	0.034399	0.035822	0.049953	0.029914	0.068839	0.038197	0.081916	0.028211	0.0155
2000	0.000229178	0.00458	0.002097	0.016159	0.021946	0.016642	0.014628	0.024662	0.025314	0.056326	0.065925	0.039899	0.04155	0.057941	0.034697	0.079846	0.044305	0.095014	0.032722	0.017978
2001	0.000373018	0.007455	0.003413	0.026302	0.03572	0.027087	0.023809	0.04014	0.041202	0.091678	0.107301	0.064941	0.067628	0.094306	0.056475	0.12996	0.072111	0.154648	0.053259	0.029262
Mean	0.000204304	0.004083	0.001869	0.014405	0.019564	0.014836	0.01304	0.021985	0.022566	0.050213	0.058769	0.035568	0.03704	0.051652	0.030931	0.07118	0.039496	0.084702	0.02917	0.016027
log q (se)	-12.1 (0.0973)																			

V.III.3.4. *L. chrysurus*

During the period 1996-2001, JAN was the dominant mode of exploitation for the youngest age classes (3 to 9) and BOV dominated from age 11 (Table V.4). Individuals all age classes were exposed to similar fishing mortality (total mean weighted fishing mortality was 0.14) (Fig. V.10) and E was equivalent to 0.45.

For the whole period, biomass decreased from around 12 to 3.3 thousand of tonnes (Fig. V.11). Catchability of BOV was highest than the reported for the others fleets (Table V.4).

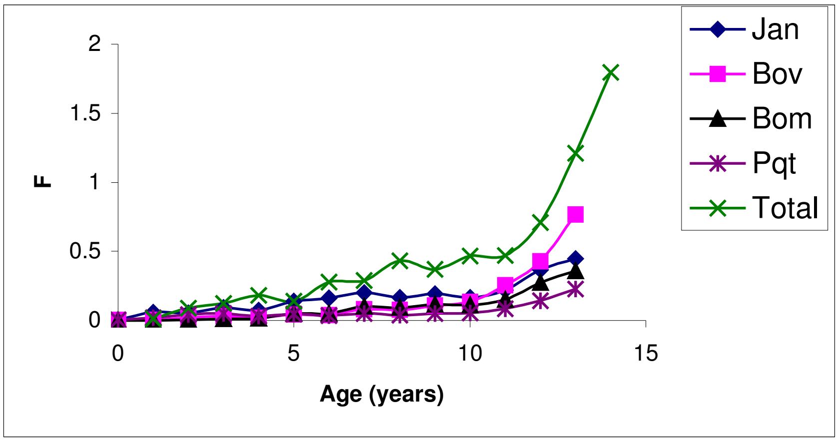


Fig. V.10: Fishing mortality split by fleet for all age classes of *L. chrysurus*

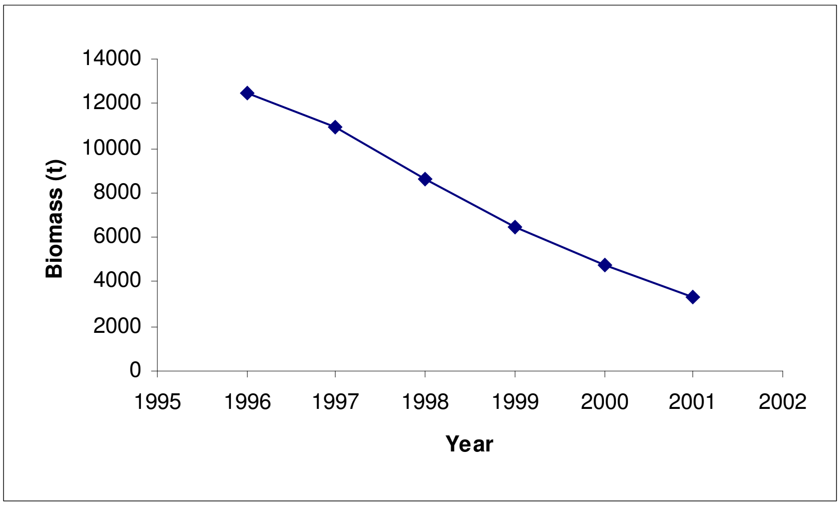


Fig. V.11: Biomass profile during the studied period

Table V.4: Fishing mortality F and log catchability for *L. chrysurus* in 1996 to 2001. 2001. PQT='paquete'; JAN='Jangada'; BOV= sailing boat and BOM = motorised boats.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13
PQT														
1996	0.00312129	0.012065	0.025294	0.028227	0.017668	0.026407	0.020803	0.02817	0.022837	0.028738	0.031555	0.049462	0.081387	0.129753
1997	0.00404527	0.015637	0.032782	0.036582	0.022898	0.034223	0.026962	0.036509	0.029597	0.037245	0.040897	0.064104	0.10548	0.168164
1998	0.00287615	0.011118	0.023308	0.02601	0.01628	0.024333	0.01917	0.025958	0.021043	0.026481	0.029077	0.045577	0.074995	0.119563
1999	0.00415448	0.016059	0.033667	0.03757	0.023516	0.035147	0.02769	0.037495	0.030396	0.038251	0.042001	0.065834	0.108328	0.172704
2000	0.00471408	0.018222	0.038202	0.042631	0.026684	0.039882	0.031419	0.042545	0.034491	0.043403	0.047658	0.074702	0.122919	0.195966
2001	0.0137816	0.053273	0.111683	0.12463	0.07801	0.116594	0.091855	0.124381	0.100833	0.126889	0.139328	0.218392	0.359354	0.572908
Mean	0.005448812	0.021062	0.044156	0.049275	0.030843	0.046098	0.036316	0.049176	0.039866	0.050168	0.055086	0.086345	0.142077	0.22651
log q (se)	-10.07 (0.0942)													
JAN														
1996	0.000771592	0.020922	0.019196	0.032688	0.026063	0.049462	0.056781	0.070982	0.057725	0.067692	0.058365	0.077184	0.129449	0.157265
1997	0.00157482	0.042702	0.039179	0.066716	0.053195	0.100952	0.115891	0.144875	0.117818	0.138159	0.119123	0.157533	0.264206	0.320978
1998	0.00129337	0.03507	0.032177	0.054792	0.043688	0.08291	0.095179	0.118983	0.096761	0.113467	0.097833	0.129379	0.216987	0.263612
1999	0.00184116	0.049923	0.045806	0.077999	0.062192	0.118025	0.135491	0.169377	0.137743	0.161525	0.139269	0.184176	0.308889	0.375262
2000	0.00220545	0.059801	0.054869	0.093432	0.074497	0.141378	0.162299	0.20289	0.164997	0.193484	0.166825	0.220617	0.370006	0.449512
2001	0.00547232	0.148383	0.136144	0.231829	0.184847	0.350797	0.402708	0.503425	0.409402	0.480087	0.413937	0.54741	0.918084	1.11536
Mean	0.002193119	0.059467	0.054562	0.092909	0.07408	0.140587	0.161392	0.201755	0.164074	0.192402	0.165892	0.219383	0.367937	0.446998
log q (se)	-11.3 (0.0962)													
BOV														
1996	0.00151692	0.002385	0.009225	0.014262	0.010211	0.020781	0.018985	0.039266	0.037163	0.052771	0.066476	0.123215	0.209018	0.372882
1997	0.00204814	0.00322	0.012456	0.019256	0.013787	0.028058	0.025633	0.053017	0.050177	0.071252	0.089756	0.166364	0.282214	0.503463
1998	0.00444576	0.00699	0.027037	0.041798	0.029926	0.060904	0.055639	0.115081	0.108916	0.154661	0.194827	0.361117	0.612585	1.09284
1999	0.0027106	0.004262	0.016484	0.025484	0.018246	0.037134	0.033924	0.070166	0.066407	0.094298	0.118787	0.220174	0.373496	0.666307
2000	0.00177228	0.002786	0.010778	0.016662	0.01193	0.024279	0.02218	0.045877	0.043419	0.061655	0.077667	0.143958	0.244205	0.435655
2001	0.00620164	0.00975	0.037715	0.058306	0.041745	0.084959	0.077614	0.160533	0.151933	0.215745	0.271775	0.503741	0.854529	1.52446
Mean	0.00311589	0.004899	0.018949	0.029295	0.020974	0.042686	0.038996	0.080657	0.076336	0.108397	0.136548	0.253095	0.429341	0.765935
log q (se)	-9.76 (0.0942)													
BOM														
1996	0.000212453	0.00049	0.001421	0.003652	0.004689	0.016951	0.017432	0.034097	0.030815	0.038862	0.038143	0.051265	0.092404	0.121599
1997	0.000298746	0.000689	0.001998	0.005136	0.006594	0.023837	0.024512	0.047946	0.043332	0.054646	0.053635	0.072088	0.129936	0.17099
1998	0.000325832	0.000751	0.002179	0.005601	0.007192	0.025998	0.026734	0.052293	0.04726	0.059601	0.058498	0.078624	0.141717	0.186493
1999	0.000388535	0.000895	0.002598	0.006679	0.008576	0.031001	0.031879	0.062356	0.056355	0.071071	0.069756	0.093754	0.168989	0.222381
2000	0.000482839	0.001113	0.003229	0.0083	0.010658	0.038525	0.039616	0.077491	0.070033	0.088321	0.086687	0.116509	0.210006	0.276357
2001	0.00204514	0.004713	0.013677	0.035157	0.045142	0.163179	0.167801	0.328226	0.296638	0.374096	0.367175	0.493494	0.889513	1.17055
Mean	0.000625591	0.001442	0.004184	0.010754	0.013809	0.049915	0.051329	0.100402	0.090739	0.114433	0.112316	0.150956	0.272094	0.358062
log q (se)	-11.7 (0.1245)													

V.IV. Discussion

According to Hilborn and Mangel (1997) four components that ecological scientist needs to be taken into account are: (i) determination of *hypotheses* because science consists of confronting different descriptions of how the studied system might work (ii) getting 'good' data, good means informative in the context of a particular view of the system (iii) *goodness of fit* which measure how well the description of the system by the model fits the observations (iiii) *numerical procedure* that help the investigator to rapidly and efficiently find the best fit (explore the goodness of fit). In fishery science and particularly in tropical fishery, management needs to have a good knowledge of the population dynamics of the exploited fish stock focusing on how the fish stocks have responded to exploitation, and also what may be the future response to fishing pressure to this stock. The broad issue of fishing activity simultaneously involves the production and the conservation at sustainable levels for futures catches, as well as the social considerations that arise specially when various fishers categories are involved in the harvest. All fishery models are approximations, and consequently many analysts prefer using more than one model to analyse a stock, as does, e.g., the ICCAT (International Commission for the Conservation of the Atlantic Tuna) (Prager, 2003). Indeed, each model provides, from its particular perspective, an imperfect view of the reality (Prager, 2003). Within this chapter, three different models were applied to data obtained from the Northern Brazilian fishery in order to get more perception of the current status of the snappers caught by the reef fishery in Northeast fishery

The results of Thompson and Bell model suggest that some fleet components already reached or exceed their optimum fishing mortality level (see Chapter 4). The multi-fleet characteristic of the reef fishery in Northeast Brazil is clear when the fishery mortality is analysed by fleet. The discrimination by fleet followed the same pattern observed in previous chapter (Chapter 2): 'paquete' and 'jangada' fleets affected primarily the stock of *L. synagris* and in a lesser instance, *L. chrysurus* whereas 'boats', particularly BOM, were the main fleet that exploited *L. analis* and *L. jocu*. As a result, scenarios in which Boats remained constant (scenarios 1, 4) showed a yield almost unchanged. The opposite pattern is observed for scenario 2 and 3. This would mean that fishery should be mostly controlled for the fleets, which most influence the dynamic of each species (or group of species).

Biomass dynamic models for aggregate species groups can be specified for jointly harvested species (Ralston & Polovina, 1982). Models of this type can be appropriate both for interacting and non-interacting species groups (Hollowed *et al.*, 2000). These models can provide useful guidance in fisheries where there are insufficient resources for time consuming and costly research vessel surveys and analysis of age structure (Jennings *et al.*, 2001). Biomass dynamic models have formed the major assessment tools for many fisheries, e.g. ICCAT, IATTC (International American Tropical Tuna Commission), ICSEAF (International Commission for South East Atlantic Fisheries), amongst others (Hilborn & Walters, 1992). However, the use of these models depends greatly on the nature of available data. From a technical point of view, data produced according to clear and balanced designs are very seldom available; the 'experimental design' is given by fishermen working to satisfy their own needs, not those of the scientists (Pech *et al.*, 2001). Although the surplus production model presented various theoretical advantages (robustness, multispecific approach and possibility of considering technological interactions), in this study, the output obtained from surplus production model was not satisfactory as the Brazilian snapper fishery illustrates several of the common problems faced by the fishery scientist who works on applied problems. The data are not determined in controlled experiments and involve untested assumptions (such as the CPUE is proportional to abundance, the data reported are of high quality, there is no process uncertainty included), and the time series available is too short. The basic assumption in using CPUE data is that changes in CPUE accurately reflect changes in the abundance of fish in the stock. However, there are many circumstances in which measures of CPUE are poor indices of abundance. In our case rough effort unit (days spent at sea) and the high variety of gears that present a wide range of catchability (technological characteristics of each gear may vary given are likely to provide low quality estimates). Also, the fishing power and spatial effects may result in CPUE being a poor index: the fishing units in a fleet (i.e. 'jangadas') are unlikely to have equal abilities to catch fish. Furthermore, consider a fishing activity in an area. As catches begin to fall, fishers move to other grounds where catch rates may remain high. Even though stocks from the previous area are being depleted, CPUE will remain high as fishers move to a previously unexploited part of the stock in the new area. Conversely, if only part of the stock is fished, CPUEs may fall dramatically even though overall stock numbers remain high considering the stock's total distribution. As a result, the answers obtained are not clean or clear. Unfortunately, although these models can incorporate the multispecies aspects of the fisheries, in Northeast Brazil, the data available were not adequate and estimated parameters can not be safely used for predictions of this fisheries. It should be necessary a longer time series of data for a safer use in the reef fishery in Northeast Brazil.

The catch-at-age model showed for most species a high exploitation rate and a decrease of the biomass along the studied period, which suggests an overexploitation or at least a fully exploited state of the snappers in Northeast Brazil (see Chapter 4). This was a pattern identical to those found with the Thompson and Bell model. However, the patterns found for *L. jocu* by the catch-at-age and Thompson and Bell model were not similar. According to the catch-at-age model, current F is equal to 0.05 and this species is then not necessarily over-exploited where the Thompson and Bell model reported a fully exploited state for this species. In that case a precautionary approach should be chosen looking forward to collect further data for a more definitive conclusion.

Main fishing effect of 'jangada' and 'paquete' were reported for typical shallower waters species, namely *L. synagris* and *L. chrysurus*. The 'boats' (BOM, BOV) mainly affected *L. jocu.* Within this model was also evident that members of a cohort may have differential vulnerability to the fleet depending on fish size. For example, young dog snapper *L. jocu* (small fish) that live on shallower waters were preferentially affected by 'paquetes' and 'jangadas'. *L. chrysurus* was exposed to similar fishing mortality for all age classes, whereas *L. synagris* had the older specimen more affected. Total fishing mortality obtained with VPA analysis was close to the one computed by catch-at-age model. In chapter 4, it was reported F equivalent to 0.24, 0.27 and 0.19 for *L. jocu, L. chrysurus* and *L. synagris* respectively. Also biomass values were within similar range for both approaches. However the advantage of the catch-at-age model here applied is that it may predict catches considering that the exploitation is fleet specific and it is evident the effect of the different boats categories on the stock structure. Also, the computational program is a powerful in estimating non-linear equations which contains ´free parameters´ (as catchability and errors coefficients).

The interesting point, and somehow reassuring, is that the output of the different models was similar from one to another despite the different perspective of each model. Biomass dynamic and catch-at-age models have different basis of parameter calculation and, if biomass dynamic methods provide a different answer to the catch-at-age model, then one should try to understand why they are different and analyse the management implication of the different predictions, rather than concentrating on deciding which method is correct (Hilborn & Walters, 1992). There are no model that can be qualified the 'best', that is why contrary output should be carefully considered as different model's assumptions may help the scientist to make the right conclusion. Charles (1998) stated that fishery management framework validity does not imply certitude on the structure of the 'real fishery system'. However, they must be coherent with available data and their validity relies on their capacity to give some answer to relevant management questions. Despite limitations, applied models satisfactorily reflected the dynamic of the stocks.

Fishing activity partly depends on the state of the resource, which itself partly depends on the fishing activity. This means that knowledge is needed on each of those two components and on their interactions (Hilborn & Walters, 1992). Such frameworks that attempted to estimate tropical stocks by fitting model of multifleet multispecies fisheries to data have already been proposed: biomass models (Ault *et al.*, 1999; Ould Dedah *et al.*, 1999; Mendoza & Larez, 2003), age structured model, i.e. ASAP, (RFSAP - Reef Fish Stock Assessment Panel, 1999), Yield-per-recruit model (Ault *et al.*, 2001; Ault *et al.*, 2002), or others (McClanahan, 1995; Labrosse *et al.*, 2000; Pech *et al.*, 2001). Focus on multidimensional fishery appears to be a very important point. Koslow *et al.* (1988) suggested that the complexity of coral reef fisheries may take them less stable and more vulnerable to overfishing. When looked at snappers' stock assessment, the general conclusion that came up from different studies warned that fishing levels were beyond an sustainable levels or at least beyond any conservative reference point (RFSAP - Reef Fish Stock Assessment Panel-, 1999; Ault *et al.*, 2001; Ault *et al.*, 2002; Mendoza & Larez, 2003). These findings were not only reported for the snappers of the Northeast Brazil, but also to others stocks in others regions as for example the Florida Keys reef ecosystems (Ault *et al.*, 2001; Ault *et al.*, 2002).

Main conclusions and thesis outlook

This chapter had the objective to look at the multispecies and multi-gear aspect of the exploitation of *L. analis, L. chrysurus, L. jocu, L. synagris* exploring the diverse models, which can incorporate these aspects.

Three models were applied and based on the results of two of the approaches used (the predictive model of Thompson and Bell and the catch-at-age model), it was evident that different fleets played distinctive roles on the life history of the snappers in Northeast Brazil. The fishery mortality of JAN and PQT is higher for the typical shallower waters species as *L. synagris*. Conversely, *L. jocu* is most affected by the boats categories (BOM and BOV) which exploits mainly deeper waters. Within each species, it is also evident the multi-fleet aspects as, for example, for *L. jocu*, all stages of its life history is exploited but, distinctively for each fleet 'paquete' PQT mainly exploits the juveniles and boat exploitation relies on larger individuals).With these results some management options could be implemented by acting on different fishing mortality by fleet through spatial regulation (i. e closed area) as spatial distribution of both species and fleet operation played an important role in the Northeastern

Brazilian artisanal fishery. These aspects, together with the others findings within this study will be discussed in Chapter 7, when contributions to a management plan will be proposed for the reef fishery in Northeast Brazil.

For the next chapter, alternatives of evaluating the reef fishes are considered as it will be tested the indicator of abundance using fishery independent method as UVC (underwater visual censuses) together with catch data using as a study case a system in South Pernambuco.

Chapter VI. The Underwater Visual Census Technique – A direct estimate of biomass.

VI.I. Introduction

Reef fisheries in Brazil is multispecific, multigear and is characterised by multiple landings stations as often is the case with most coastal small scale reef fisheries (Samoilys, 1997). Management of such fishery requires a good knowledge of the condition of the stocks, of the structure of the fish community and of how this structure may be influenced by fishing activity (Polunin & Roberts, 1996; Jennings *et al.*, 2001). Reliable estimates of basic parameters such as abundance, catch and effort are essential to a proper description of stock conditions.

Both fishery-dependent and fishery-independent methods of estimating the size of fish stock have inherent strengths and weakness. One of the central problems in fishery stock assessment is to obtain an abundance index that is proportional to the stock size and will reflect trends. Many stock assessment procedures are carried out assuming that CPUE from commercial catch and effort data is adequate for this purpose, but CPUE may not be strongly correlated to abundance (Hilborn & Walters, 1992). In some cases, the CPUE will remain high until the stock is badly depleted (due to fish aggregation and efficient search) whereas in other cases it will fall very rapidly while the stock is hardly being affected. In this case, species are distributed between fragmented habitats and are not efficiently exploited due a search deficiency.

Underwater Visual Census (UVC) techniques can provide rapid estimates of the relative reef fish abundance, density, biomass and diversity as these non-destructive methods present a good alternative way to assess abundance estimates (Harmelin-Vivien et al. 1985). In a fishery context, visual census estimates are particularly useful because they are independent of fishing methods that may be affected by the equipment and the gear selectivity. However, the UVC methods are restricted to relatively shallow depths due to SCUBA-diving constraints and to species that are diurnal, visually obvious and not repulsed or attracted by divers. This bias may be worsened by the acquired behaviour of target species (Kulbicki, 1998). There are other drawbacks such as sampling bias from diver in estimating erroneously numbers and sizes of fishes (Harmelin-Vivien et al. 1985).

In this study case, visual census techniques were carried out on the Tamandaré-Maragogi reef complex. This complex is located between the Pernambuco and Alagoas state. The coral reef formations in Tamandaré-Maragogi represent a good example of the Brazilian coastal reefs (Maida & Ferreira, 1997). This area was defined as a 'hot-spot' by the biodiversity commission for the coastal zone as it presents a high biological importance and a intense human activity (Anon, 2002). The area was estimated of extreme biological importance considering the rich fauna and flora living in various environment like mangroves, estuaries, coastal lagoons and coral reefs. However, human activity has great impact on the local environment through chemical and biological wastes from urban and industrial activity, sugarcane culture, fish or shrimp farming, deforestation and overfishing (see for details Anon, 2002). In the overall, 185 fish species belonging to 129 genera and 64 families were recorded in protected area 'APA dos corais' (Ferreira *et al.*, 1999; Ferreira & Cava, 2001). From these species 128 were reported by underwater visual census between the shore to the 30m deep (Ferreira & Cava, 2001).

Here, comparisons of abundance estimates obtained by UVC and by inshore small scale fishery survey were considered. Information of fish abundance were collected by underwater visual census (UVC), which is a fishery-independent method and compared to abundance index obtained from fishing activity, catch per unit effort surveys (CPUE). Estimates of fish abundance and CPUE were used to detect trends or perturbations in stocks. The survey methods were compared using multivariate analysis which can offer an interesting insights for the analysis of pattern in a multispecific system (Connell *et al.*, 1998).

VI.II. Methods

VI.II.1. <u>Study area</u>

This study was carried out at two localities Tamandaré (Pernambuco) and Maragogi (Alagoas) that present coastal coral reefs (Fig VI.1) and are part of the Environmental Protection Area (APA) Costa dos Corais, a multiple use protected area were fishing is allowed. This conservation unit has a total area of 4135 km^2, running along 135 km of coastline. Fishing is allowed but restricted to local fishermen (living within the conservation unit) that have been registered. The sampled area was chosen with the purpose to look at snapper community. The Tamandaré complex of elongated banks, patch and attached bank reefs runs parallel to the coast. According to Maida and Ferreira (1997), the reefs are arranged in three lines. The first line, of few meters wide, next to the beach, consists of shallow sandstone structure exposed at low tide. Fifty meters away, the second line depth ranged between 1 to 8 m at different distance from the seacoast. They consist in elongated banks that delimit a back reef zone where patch reefs (that may exceed 50 m wide) grow seaward of the attached banks. Their tops may be emerged at low tide. The third line forms a barrier like reef that is typical of the complex (Maida & Ferreira, 1997). This barrier is formed by isolated columns, the tops of which extended laterally and coalesced. Fifty meters away from the coast began the study area comprising the reef formations that occur along the shelf, also arranged in fragmented line roughly parallel to the coast. These geomorphological units were probably originated by the previous coastline that moved through the geological periods (Mabesoone & Coutinho, 1970). These drowned reefs may be of various shapes according to their heights, width and surface roughness. The reef formations are called locally 'cabeços', 'taçis' and 'lages'. 'Cabeços' are drowned reef knolls, 'Taçis' are irregular platforms and 'Lages' are even platform of low height. The two latter formations are possibly buried reef constructions. Although roughness has not been measured, occurrence of cavities may be categorised into the reef types in decreasing order of complexity:

- knolls (K), pinnacles of 5 to 10 m of diameter that rises up 10 m from the sea floor. These structures may occur in clusters and are typically surrounded by large sand plains.
- irregular platforms (IP): contiguous reef substrate of moderate vertical relief and complexity. Relief consists in caverns/undercuts into the substrate.
- even platform (EP): contiguous reef characterised by a low structural complexity with a low relief hard bottom

The fishing grounds surveyed range from 9m to 29m deep and are usually frequented by artisanal fishers using basic fishing techniques such as hand line or harpoon. One site called 'Os Claros', which is positioned on the limit of a no-take area prohibiting any type of human activities (fishing and tourism) was also surveyed. Created in 1999, the no-take area limited at the Tamandaré Bay is part of the protected area 'APA Costa dos Corais' and is located in front of the base of the 'Projeto Recifes Costeiros' (see footnote chapter 1) and covers 2.5 km². The substratum consists of an area of soft sediments and sand scattered with coral and sandstone. Local fishermen do not make any use of advanced technological instrumentation to detect fish or localise fishing ground. Traditionally, positioning is made by visual triangulation through terrestrial marks.

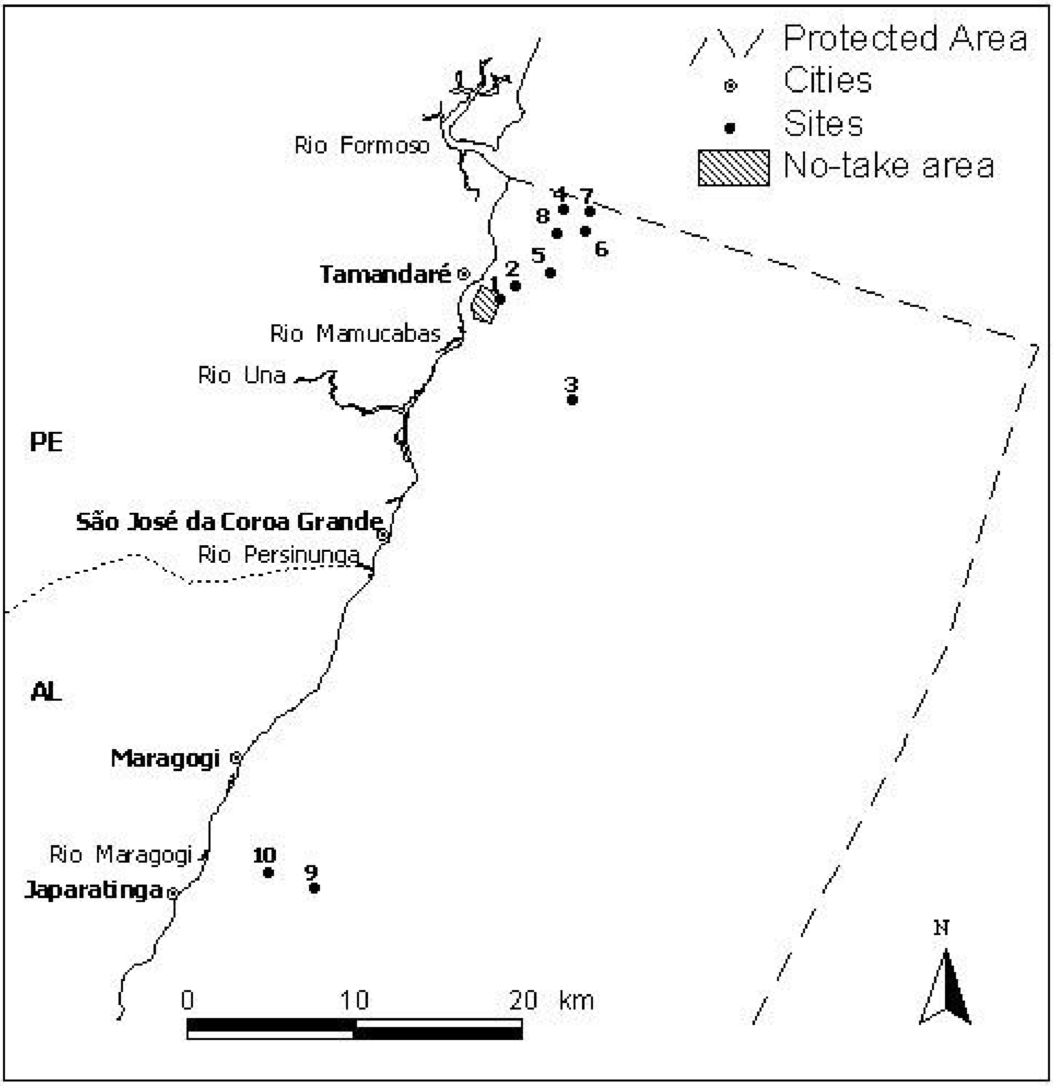


Fig. VI.1: Study area. Numbered dot are the sampled sites. The dashed area represents the MPA 'Costa dos corais'. Sites denomination: (1) 'Os Cláros', (2) Âncora, (3) Carapitanga, (4) Rubens 2, (5) Thierry 06, (6) Rubens 3, (7) Rubens 1, (8) Santa Ana, (9) Maragogi 1, (10) Maragogi 2. All data were collected during this study except at the site (1) where previous data from the 'Projeto Recifes Costeiros' were included.

VI.II.2. UVC method

To study the fish community structure, through the definition of patterns in species composition and species abundance, stationary visual censuses were carried out in ten stations by two divers. The sampling was undertaken during summertime (October 2002 to March 2003, austral summer) which corresponds to the dry season when water visibility, affected by wind and rain (terrestrial runoff) is best. A standard 6 m radius point count of 10 min duration was performed (adapted from Bohnsack & Bannerot, 1986; Samoilys & Carlos, 2000). The point count was preferred to other methods because it can deal satisfactorily with the heterogeneity of the habitats sampled (Bohnsack & Bannerot, 1986). The reduction of Bohnsack & Bannerot's 7.5 radius point count was due to habitual low visibility in the area which was about 7m. Visual censuses were done during day-light.

Ten sites covering the different characteristics of the study area were sampled 111 times (Table VI.1). Censuses were always performed at same point along the period considered. Homogenous census design was hampered by the water turbidity and the absence of specific reef formation within a particular depth strata. Such problem was overcome using non-parametric based multivariate analysis (MDS, ANOSIM, etc)

Table VI.1: Census performed by habitats, stations (=local), and depth strata (cabeços= knolls, tacis = IP, lage=EP)

Habitat	**Local**	**<10**	**10-20**	**>20**	**Total**
Cabeços	Maragogi 1			7	
	Rubens 1		2		
	Rubens 2		11		
	Thierry 06			18	
Sum					***38***
Taçis	Âncora		16		
	Maragogi 2	11			
	Santa ana		1		
Sum					***28***
Lage	Carapitanga			3	
	Os Cláros	37			
	Rubens 3			5	
Sum					**45**
Total		***48***	***30***	***33***	111

The total lengths (TL) of individuals observed were estimated visually to the nearest cm. Before the study, divers were trained to estimate lengths of fish with wooden models of fish. Biomass was estimated by converting individual length data to weight using length-weight relationships obtained from the REVIZEE program or from the FishBase database when not available. The habitat characteristic of every site was determined qualitatively within 3 categories of geomorphological unit (Knoll, irregular platform, even platform) as described above.

VI.II.3. Sampling local hand line fishery

The studied sites as well as fishing zone were chosen aiming at encompassing lutjanids distribution. Catch records were obtained from fishermen that fished all year round within the area surveyed. The fishing effort, estimated by Ferreira *et al.* (2000) as 49 fishermen per day in the Tamandaré coastal area alone, concentrates along the very near coast, where fishing ground is reached walking (at low tide), swimming or rowing (Ferreira *et al.*, 2000). The gears used are hand line and spears. Few others operated farther within the area of interest and used 'paquetes' with sail and use hand line as gear.

Ninety-one catches reported at five landing sites within the study area (fishers operating on hard bottoms common to the UVC censused area where snappers occur) were randomly selected for the analysis. Information was gathered and provided details on the gear, the species, length and weight of individual fish as well as of the total catch weight in order to estimate the CPUE as number and weight per trip per fisher. From this sampled catches, the major part (over 90%) of the catch originated from knolls at 20m deep.

VI.II.4. Data analysis

Data from each UVC was used to calculate fish density (number of individuals per sampled area), fish biomass (weight per sampled area). Relative abundance were tested for the main family according to depth, reef morphology and in/out of the marine protected area using Kruskall and Wallis procedure. The Shannon diversity (H') was estimated at specific levels. Analyses of variance (ANOVA) were performed on diversity to detect differences between groups (depth strata, sampled, reef type). Mean fish density, mean fish length and mean fish biomass were estimated for the fish community.

Comparisons between data from UVC and from fishing activity were carried out through an analysis of the variation of abundance by species and family. In order to detect patterns of similarity among underwater visual censuses, then between UVC and hand line fishery records, multidimensional scaling (MDS, see material and methods' section of chapter 2) representation based on similarity matrix built on Bray-Curtis coefficient was used. As data from UVC and CPUE are determined with a different effort type, the data used for the joined analysis fishery-UVC were standardised using the percentage of the relative abundance caught or sighted during a trip or a count. In order to get a realistic comparison between fishery and UVC abundance estimates, species not vulnerable to fishing activity were excluded following the Connell *et al.* method (1998). Then, only species found in common in the two dataset were selected from the joint analysis. Two dimensional MDS plots were presented with a stress value that measures the 'accuracy' of the representation. According to Clarke (1993), stress values between 0.1 and 0.2 lead to a usable picture, value between 0.2 and 0.25 may picture an inadequate summary then a higher –dimensional representation was plotted which had a reduced stress (less than 0.2). However, conclusions from 3-D representation did not differ from the 2-D plot, therefore 2-D plots only were pictured as it is a much clearer representation.

Possible clusters identified in MDS were tested statistically using the ANOSIM (analysis of similarities) permutation test (Clarke, 1993; Clarke & Warwick, 1994). Abiotic factors as depth, geomorphology (or reef types) were tested for differences between community structure using the BIO-ENV routine (Clarke & Ainsworth, 1993; Clarke & Warwick, 1994).

Similarity of percentage (SIMPER) analysis identified species which typified artisanal catches and underwater counts and also identified species which discriminated them (Clarke, 1993).

VI.III. Results

VI.III.1. Underwater visual census (UVC)

In the fish assemblage studied, 60 species belonging to 21 families was recorded (Table VI.2), the families with the major number of species were Haemulidae (8 species), followed by Scaridae (6), Carangidae (6) and Lutjanidae (6). Of the 60 species censused, *Haemulon aurolineatum, Chromis multilineata, Acanthurus coeruleus* and *Sparisoma axillare* represented in frequency number over 50%. *Scarus zelindae* switched *Chromis multilineata* represented over 50 % of the total biomass censused. The more common species, present during most of the census were *Cephalopholis fulvus* (8 times out of 10) and *Acanthurus coeruleus* (7 times out of 10). The total abundance was 67.1 individuals/census while, the total relative biomass was 9.6 kg/census.

Table VI.2: Species reported during UVC surveys. n, total number of individuals, size range (cm TL) censused, Frequency times of species presence, relative abundance (number (nb) by censuses), relative biomass (weight by censuses) '-' symbols represents lack of information.

Familly	Species	Code	n	Range	Frequency (%)	Relative abundance (nb/census)	Relative biomass (kg/census)
Muraenidae	*Gymnothorax funebris*	Gym fun	1	-	0.9	0.01	-
	Gymnothorax moringa	Gym mor	1	-	0.9	0.01	0.001
Holocentridae	*Holocentrus adscencionis*	Hol ads	30	8 - 35	13.5	0.27	0.028
	Myripristis jacobus	Myr jac	4	8 - 20	2.7	0.04	0.004
Clupeidae	-	Clu sp	10	-	0.9	0.09	0.002
Scombridae	*Scomberomorus brasiliensis*	Sco bra	9	40 - 50	5.4	0.08	0.121
Acanthuridae	*Acanthurus bahianus*	Aca bah	155	5 - 45	30.6	1.40	0.420
	Acanthurus chirurgus	Aca chi	254	5 - 30	33.3	2.29	0.094
	Acanthurus coeruleus	Aca coe	694	4 - 40	70.3	6.25	2.935
Ephippidae	*Chaetodipterus faber*	Cha fab	33	20 - 40	17.1	0.30	0.064
Blenniidae	*Ophioblennius atlanticus*	Oph atl	2	-	1.8	0.02	-
Labridae	*Bodianus rufus*	Bod ruf	218	5 - 40	60.4	1.96	0.314
	Halichoeres brasiliensis	Hal bra	172	5 - 40	53.2	1.55	0.180
	Halichoeres cyanocephalus	Hal cya	4	15 - 20	2.7	0.04	0.002
	Halichoeres poeyi	Hal poe	12	10 - 35	6.3	0.11	0.014
Pomacanthidae	*Holacanthus ciliaris*	Hol cil	10	10 - 40	7.2	0.09	0.076
	Holacanthus tricolor	Hol tri	26	10 - 35	14.4	0.23	0.026
	Pomacanthus paru	Pom par	9	10 - 50	4.5	0.08	0.101
Pomacentridae	*Abudefduf saxatilis*	Abu sax	274	5 - 25	40.5	2.47	0.236
	Chromis multilineata	Chr mul	743	5 - 25	29.7	6.69	0.172
	Microspathodon chrysurus	Mic chr	15	15 - 25	10.8	0.14	0.013
	Stegastes fuscus	Ste fus	80	-	10.8	0.72	-
	Stegastes variabilis	Ste var	60	-	10.8	0.54	-
Scaridae	*Scarus trispinosus*	Sca tri	21	20 - 55	5.4	0.19	0.297
	Scarus zelindae	Sca zel	106	10 - 40	33.3	0.95	0.422
	Sparisoma amplum	Spa amp	37	10 - 50	15.3	0.33	0.197
	Sparisoma axillare	Spa axi	545	3 - 45	64.9	4.91	0.823
	Sparisoma frondosum	Spa fro	38	10 - 50	9.0	0.34	0.132
	Sparisoma sp	Spa sp	8	15 - 35	2.7	0.07	0.004
Carangidae	*Alectis ciliaris*	Ale cil	1	25 - 25	0.9	0.01	0.001
	Carangoides bartholomaei	Car bar	6	10 - 35	2.7	0.05	0.022
	Carangoides crysos	Car cry	2	25 - 35	1.8	0.02	0.019
	Caranx sp	Car sp	2	30 - 30	0.9	0.02	0.008
	Pseudocaranx dentex	Pse den	8	10 - 20	6.3	0.07	0.005
	Selene vomer	Sel vom	1	20 - 20	0.9	0.01	0.001
Chaetodontidae	*Chaetodon striatus*	Cha str	10	10 - 15	6.3	0.09	0.003
Haemulidae	*Anisotremus moricandi*	Ani mor	11	15 - 35	5.4	0.10	0.041
	Anisotremus surinamensis	Ani sur	35	20 - 50	12.6	0.32	0.215
	Anisotremus virginicus	Ani vir	145	5 - 30	57.7	1.31	0.305
	Haemulon aurolineatum	Hae aur	1821	5 - 25	51.4	16.41	0.745
	Haemulon cf macrostomum	Hae mac	11	20 - 25	8.1	0.10	0.016
	Haemulon parra	Hae par	55	15 - 30	13.5	0.50	0.083
	Haemulon plumieri	Hae plu	189	10 - 40	19.8	1.70	0.173
	Haemulon squamipinna	Hae squ	463	5 - 20	32.4	4.17	0.193
Kiphosidae	*Kyphosus sp*	Kyp sp	1	25 - 25	0.9	0.01	0.001
Lutjanidae	*Lutjanus analis*	Lut ana	16	20 - 45	5.4	0.14	0.052
	Lutjanus apodus	Lut apo	2	15 - 15	1.8	0.02	0.002
	Lutjanus chrysurus	Lut chr	22	5 - 35	11.7	0.20	0.030
	Lutjanus griseus	Lut gri	5	25 - 40	3.6	0.05	0.027
	Lutjanus jocu	Lut joc	46	20 - 80	23.4	0.41	0.364
	Lutjanus synagris	Lut syn	203	10 - 40	21.6	1.83	0.301
Mullidae	*Pseudupeneus maculatus*	Pse mac	80	5 - 30	23.4	0.72	0.066
Pempheridae	*Pempheris schomburgki*	Pem sch	300	-	0.9	2.70	-
Sciaenidae	*Odontoscion dentex*	Odo den	10	15 - 25	2.7	0.09	0.015
Serranidae	*Cephalopholis fulvus*	Cep ful	406	5 - 45	82.9	3.66	0.074
	Epinephelus adscencionis	Epi ads	17	20 - 35	9.9	0.15	0.054
	Epinephelus itajara	Epi ita	2	60 - 80	1.8	0.02	0.083
	Mycteroperca bonaci	Myc bom	2	40 - 50	1.8	0.02	0.018
Balistidae	*Balistes sp*	Bal sp	2	15 - 25	0.9	0.02	0.004
Ostraciidae	*Acanthostracion quadricornis*	Aca qua	1	35 - 35	0.9	0.01	0.012

Table VI.3: ANOSIM pairewise tests between depth strata (a) number of fish (b) weight of fish underlined bold are significant (p<0.05)

(a) (b)

Groups	R Statistic	Significance Level %	Groups	R Statistic	Significance Level %
Sample statistic (Global R): 0.486			Sample statistic (Global R): 0.531		
Significance level of sample statistic: 0.1%			Significance level of sample statistic: 0.1%		
Santa ana, Âncora	0.04	35.3	Santa Ana, Âncora	0.089	47.1
Santa ana, Os Cláros	0.127	26.3	Santa Ana, Os Cláros	0.169	24.3
Santa ana, Maragogi 1	0.633	12.5	Santa Ana, Maragogi 1	0.333	37.5
Santa ana, Maragogi 2	0.309	25	Santa Ana, Maragogi 2	0.2	16.7
Santa ana, Rubens 1	0	66.7	Santa Ana, Rubens 1	1	33.3
Santa ana, Rubens 2	-0.302	91.7	Santa Ana, Rubens 2	-0.212	58.3
Santa ana, Thierry 06	0.102	36.8	Santa Ana, Thierry 06	0.131	31.6
Santa ana, Carapitanga	-0.333	75	Santa Ana, Carapitanga	-0.333	75
Santa ana, Rubens 3	-0.56	100	Santa Ana, Rubens 3	-0.2	66.7
Âncora, Os Cláros	**0.157**	1	Âncora, Os Cláros	**0.27**	0.2
Âncora, Maragogi 1	**0.44**	0.1	Âncora, Maragogi 1	**0.634**	0.1
Âncora, Maragogi 2	**0.392**	0.1	Âncora, Maragogi 2	**0.395**	0.1
Âncora, Rubens 1	**0.841**	0.7	Âncora, Rubens 1	**0.758**	0.7
Âncora, Rubens 2	**0.42**	0.1	Âncora, Rubens 2	**0.538**	0.1
Âncora, Thierry 06	**0.635**	0.1	Âncora, Thierry 06	**0.542**	0.1
Âncora, Carapitanga	**0.396**	3.8	Âncora, Carapitanga	**0.47**	1.2
Âncora, Rubens 3	**0.524**	0.3	Âncora, Rubens 3	**0.439**	0.2
Os Cláros, Maragogi 1	**0.767**	0.1	Os Cláros, Maragogi 1	**0.899**	0.1
Os Cláros, Maragogi 2	**0.551**	0.1	Os Cláros, Maragogi 2	**0.56**	0.1
Os Cláros, Rubens 1	**0.751**	0.7	Os Cláros, Rubens 1	**0.734**	0.4
Os Cláros, Rubens 2	**0.689**	0.1	Os Cláros, Rubens 2	**0.798**	0.1
Os Cláros, Thierry 06	**0.77**	0.1	Os Cláros, Thierry 06	**0.783**	0.1
Os Cláros, Carapitanga	**0.468**	1.7	Os Cláros, Carapitanga	**0.398**	2.1
Os Cláros, Rubens 3	**0.607**	0.1	Os Cláros, Rubens 3	**0.516**	0.2
Maragogi 1, Maragogi 2	**0.565**	0.1	Maragogi 1, Maragogi 2	**0.641**	0.1
Maragogi 1, Rubens 1	**0.844**	2.8	Maragogi 1, Rubens 1	**0.779**	2.8
Maragogi 1, Rubens 2	-0.034	58.9	Maragogi 1, Rubens 2	0.034	32.3
Maragogi 1, Thierry 06	0.157	7.2	Maragogi 1, Thierry 06	**0.285**	0.6
Maragogi 1, Carapitanga	**0.702**	0.8	Maragogi 1, Carapitanga	**0.52**	0.8
Maragogi 1, Rubens 3	**0.534**	0.1	Maragogi 1, Rubens 3	**0.701**	0.1
Maragogi 2, Rubens 1	**0.773**	1.3	Maragogi 2, Rubens 1	**0.703**	1.3
Maragogi 2, Rubens 2	**0.421**	0.1	Maragogi 2, Rubens 2	**0.422**	0.1
Maragogi 2, Thierry 06	**0.756**	0.1	Maragogi 2, Thierry 06	**0.597**	0.1
Maragogi 2, Carapitanga	0.339	6	Maragogi 2, Carapitanga	0.247	12.6
Maragogi 2, Rubens 3	**0.635**	0.1	Maragogi 2, Rubens 3	**0.448**	0.1
Rubens 1, Rubens 2	0.015	46.2	Rubens 1, Rubens 2	-0.045	55.1
Rubens 1, Thierry 06	-0.03	50.5	Rubens 1, Thierry 06	-0.003	47.9
Rubens 1, Carapitanga	0	60	Rubens 1, Carapitanga	0.25	40
Rubens 1, Rubens 3	-0.091	66.7	Rubens 1, Rubens 3	-0.036	52.4
Rubens 2, Thierry 06	0.116	6.1	Rubens 2, Thierry 06	**0.174**	2.1
Rubens 2, Carapitanga	0.192	19.2	Rubens 2, Carapitanga	0.224	16.5
Rubens 2, Rubens 3	0.069	25	Rubens 2, Rubens 3	-0.029	57.2
Thierry 06, Carapitanga	**0.569**	0.6	Thierry 06, Carapitanga	**0.487**	1.5
Thierry 06, Rubens 3	**0.333**	1.5	Thierry 06, Rubens 3	0.231	5.7
Carapitanga, Rubens 3	0.138	25	Carapitanga, Rubens 3	0.292	5.4

The Shannon diversity index along with the species richness did not present significant differences when tested between sites, geographical zone (Tamandaré *vs*. Maragogi), depth strata, geomorphological characteristics, or fished and protected area (Fig VI.2). However, analysis of similarities between sites showed a highly significant difference for both density and biomass between sites (Global R=0.486, p<0.001 and Global R=0.531, p<0.001 respectively ; Table VI.3). A certain contrast MPA *versus* non MPA was observed as the sampled site located within the MPA 'Os cláros' was different to every other site but Santa Ana (too low number of sample from Santa Ana make a too low number of permutation) (Fig VI.3, Table VI.3).

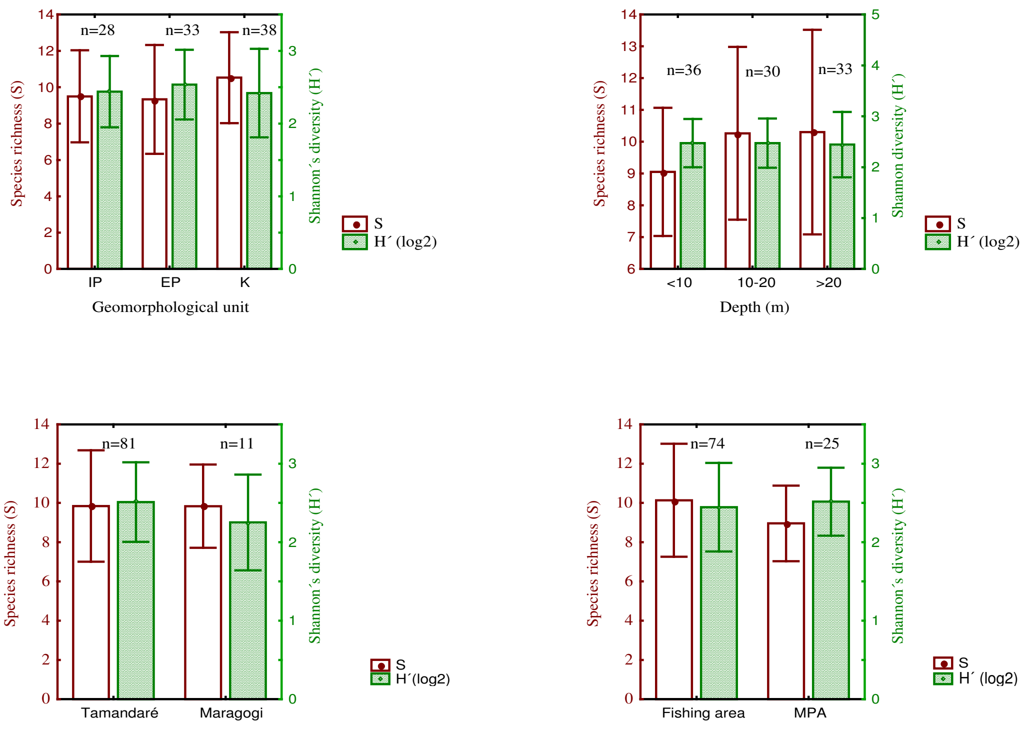


Fig. VI.2: Mean Shannon diversity. Clockwise diversity by depth, geomorphological unit, area, fishing area *vs*. MPA.

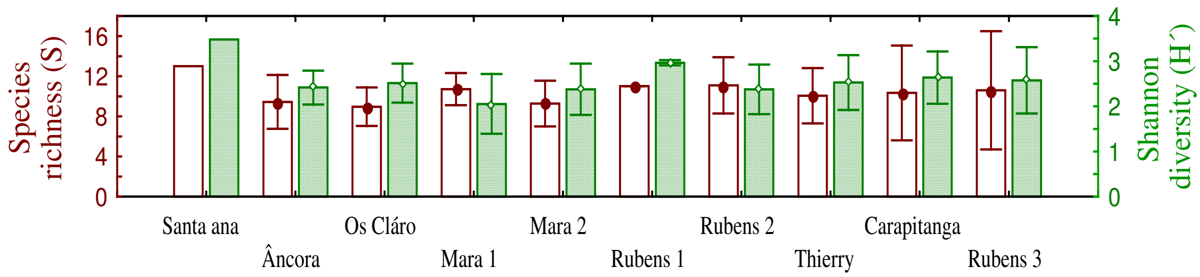
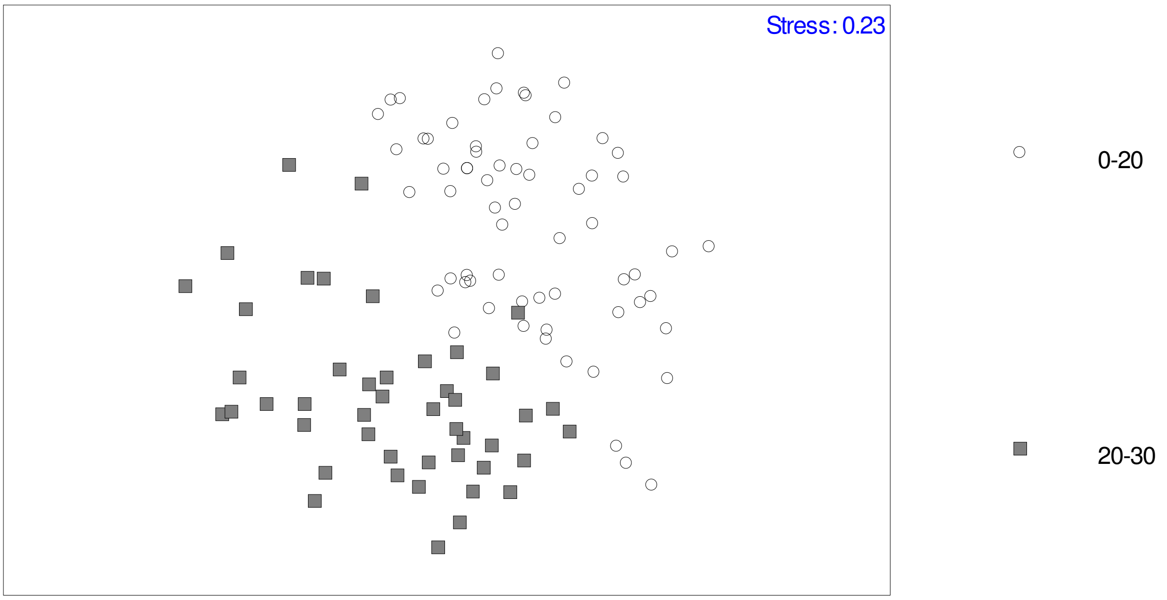
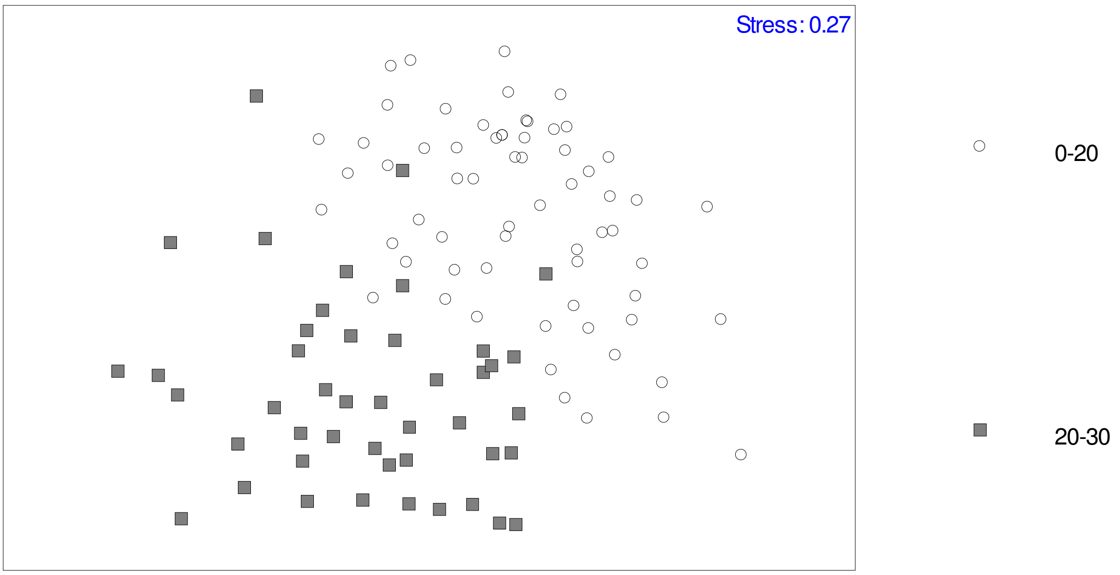


Fig. VI.3: Mean Shannon diversity H' by censused site.

MDS representations according to depth show that fish assemblage discriminated two layers below 20 m and above 20 m (Fig VI.4), this pattern was then test by ANOSIM procedure (Table VI.4).



(a)



(b)

Fig. VI.4: Two- dimensional MDS representation of visual censuses (a) relative abundance fish number (b) relative biomass weight according to depth strata. ANOSIM found that in both cases the two depth strata presented significantly different fish assemblage (a) R=0.531, (b) R=0.490.

Table VI.4 ANOSIM pairwise tests between depth ranges (a) number of fish (b) weight

Abundance	**R Statistic**	**Significance Level %**
Numerical	0.508	0.1
Biomass	0.465	0.1

Reef type was also represented and differences tested (Fig VI.5, Table VI.5). Differences between geomorphological units were statistically significant, the R statistic was higher between groups representing the extremes in the complexity range considered and low between contiguous groups.

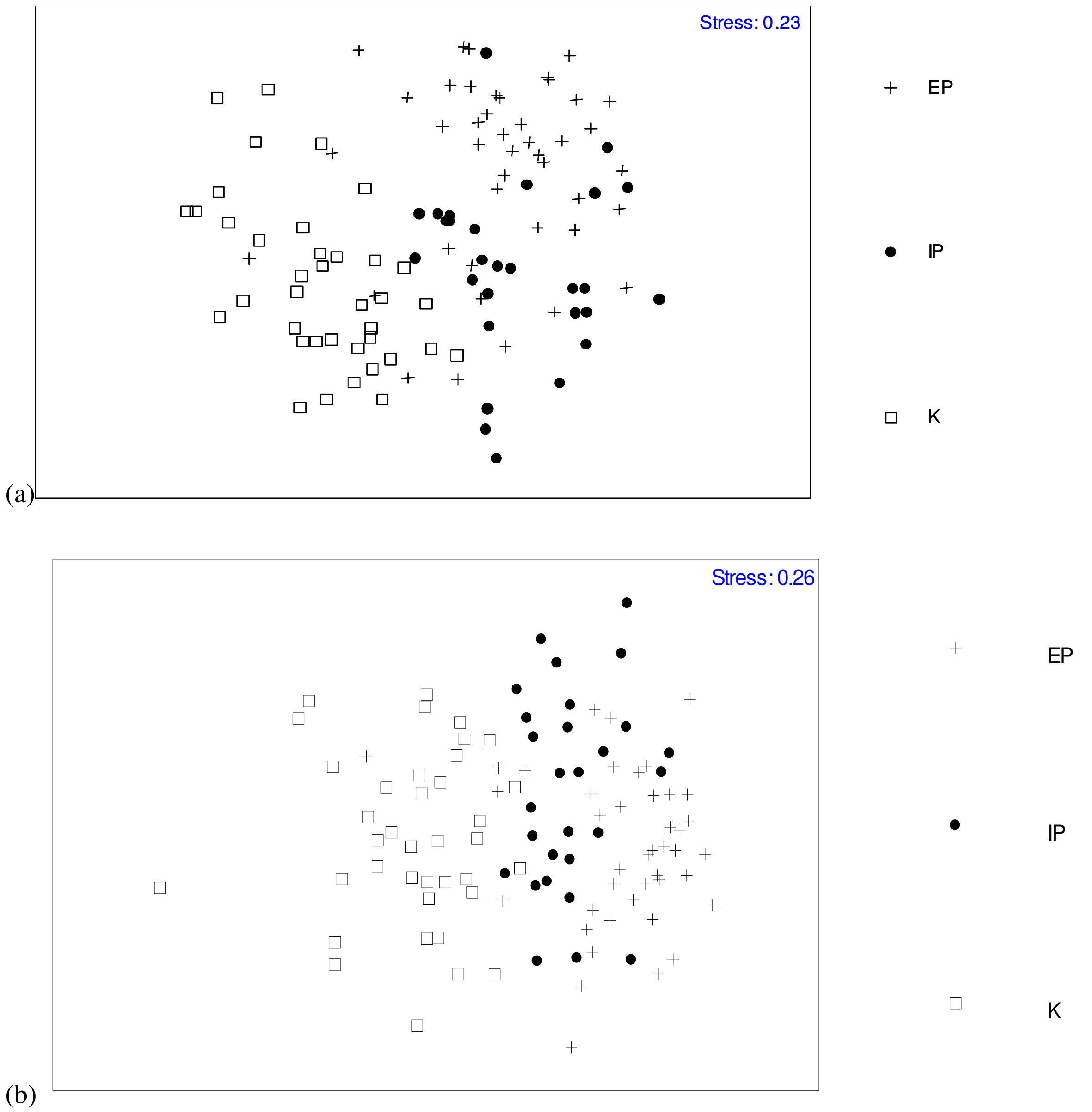


Fig. VI.5: Two- dimensional MDS representation of visual censuses (a) relative abundance fish number (b) relative biomass weight according to geomorphological unit. EP: even platform, IP irregular platform, K: knoll

Table VI.5: ANOSIM pairwise tests between geomorphological type (a) number of fish (b) weight

Sample statistic (Global R): 0.411
Significance level of sample statistic: 0.1%

Groups	R Statistic	Significance Level %
IP, EP	0.149	0.1
IP, K	0.444	0.1
EP, K	0.592	0.1

(a)

Sample statistic (Global R): 0.395
Significance level of sample statistic: 0.1%

Groups	R Statistic	Significance Level %
IP, EP	0.186	0.1
IP, K	0.385	0.1
EP, K	0.562	0.1

(b)

Relative abundance was observed at a family level. Variations between factors such as depth strata, Reef morphology and marine protected area were analysed. On the overall, haemulids, pomencentrids, acanturids and scarids are the main families. Table VI.6 and Figure VI.6 suggest that labrids, haemulids and lutjanids were important at deeper range as well as on knolls. Acanthurids, scarids, and pempherids were in higher relative abundance and relative biomass in shallow water (<20) whilst lutjanids, haemulids were preferentially in deeper range (>20m). Among the lutjanids, *Lutjanus vivanus* did not occur in the visual census as its distribution range was defined much deeper (see Chapter 3). Pomacentrids were in high relative abundance in shallow water but also showed a maximum abundance in deeper water. Contrasting results were found depending on the family considered. Significant increase in abundance occurred within MPA for acanthurids, scarids, while a decrease was reported for labrids, haemulids, lutjanids and serranids.

Table VI.6: Mean density (nb/census) and mean biomass (kg/census) of main fish families per depth, type of reef ad level of protection.

	0-20 m		*20-30 m*		*Knoll*		*irregular platform*		*Even platform*		*MPA*		*non-MPA*		*All*	
Family	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*	*Density*	*Biomass*
Acanthuridae	**15**	**5.55**	2.783	0.478	1.658	0.227	5.714	1.214	**19.556**	**7.561**	**22.03**	**8.835**	3.892	0.756	9.937	**3.449**
Balistidae			0.043	0.009					0.044	0.009			0.027	0.005	0.018	0.004
Blenniidae	0.031						0.071						0.027		0.018	
Carangidae	0.077	0.020	0.326	0.106	0.342	0.126			0.156	0.032	0.135	0.036	0.203	0.066	0.180	0.056
Chaetodontidae	0.046	0.001	0.152	0.005	0.132	0.004	0.036	0.001	0.089	0.003	0.054	0.002	0.108	0.004	0.090	0.003
Clupeidae	0.154	0.003					0.357	0.007					0.135	0.003	0.090	0.002
Ephippidae	0.062	0.026	0.630	0.117	0.763	0.142	0.071	0.038	0.044	0.014	0.054	0.018	0.419	0.087	0.297	0.064
Haemulidae	13.03	1.014	**40.93**	**2.841**	**45.92**	**2.929**	**22**	1.285	8.20	1.096	6.243	0.809	**33.77**	**2.252**	**24.59**	1.771
Holocentridae	0.138	0.008	0.543	0.063	0.500	0.050	0.286	0.019	0.156	0.023	0.027	0.0004	0.446	0.046	0.306	0.031
Kiphosidae	0.015	0.001							0.022	0.002	0.027	0.002			0.009	0.001
Labridae	3.154	0.388	4.370	0.682	4.421	0.669	3.964	0.468	2.822	0.402	2.541	0.328	4.216	0.601	3.658	0.510
Lutjanidae	0.677	0.315	5.435	1.426	6.500	1.709	0.429	0.176	0.778	0.360	0.865	0.420	3.541	0.953	2.649	0.775
Mullidae	0.108	0.014	1.587	0.139	0.974	0.054	0.071	0.003	0.911	0.114	0.135	0.022	1.014	0.087	0.721	0.066
Muraenidae	0.015	0.002	0.022		0.026		0.036	0.004					0.027	0.002	0.018	0.001
Ostraciidae			0.022	0.029	0.026	0.035							0.014	0.018	0.009	0.012
Pempheridae	4.615						10.714						4.054		2.703	
Pomacanthidae	0.138	0.106	0.783	0.340	0.868	0.319	0.286	0.244	0.089	0.080	0.027	0.002	0.595	0.304	0.405	0.203
Pomacentridae	8.323	0.265	13.717	0.642	14.237	0.696	8.179	0.429	8.933	0.183	8.432	0.140	11.622	0.561	10.559	0.421
Scaridae	10.262	2.756	1.913	0.628	1.658	0.408	6.607	**2.332**	11.267	2.827	13.027	3.077	3.689	1.273	6.802	1.874
Sciaenidae			0.217	0.037	0.263	0.045							0.135	0.023	0.090	0.015
Scombridae	0.077	0.117	0.087	0.126	0.079	0.105			0.133	0.209	0.135	0.206	0.054	0.078	0.081	0.121
Serranidae	3	0.254	5.043	0.196	5	0.217	2.893	0.117	3.467	0.311	3.081	0.357	4.230	0.166	3.847	0.230

VI.III.2. Local fishing activity

Catch were represented by 42 species (Table VI.7). The three species most commonly found in the catch were *Lutjanus synagris, Scomberomorus brasiliensis* and *Cephalopholis fulvus*. In terms of relative abundance (number by census, i.e. per landings) *L. synagris* and *C. fulvus* presented the highest values and, in terms of relative biomass, *S. brasiliensis* and *L. synagris* were the most part of the catch. Between the three reef types, a clear preference of 'cabeços' or reef knolls as fishing ground was observed, with nearly 90% of the landings surveyed. However, no significant difference was found between geomorphological types (ANOVA F=0.6, df=2, p= ns).

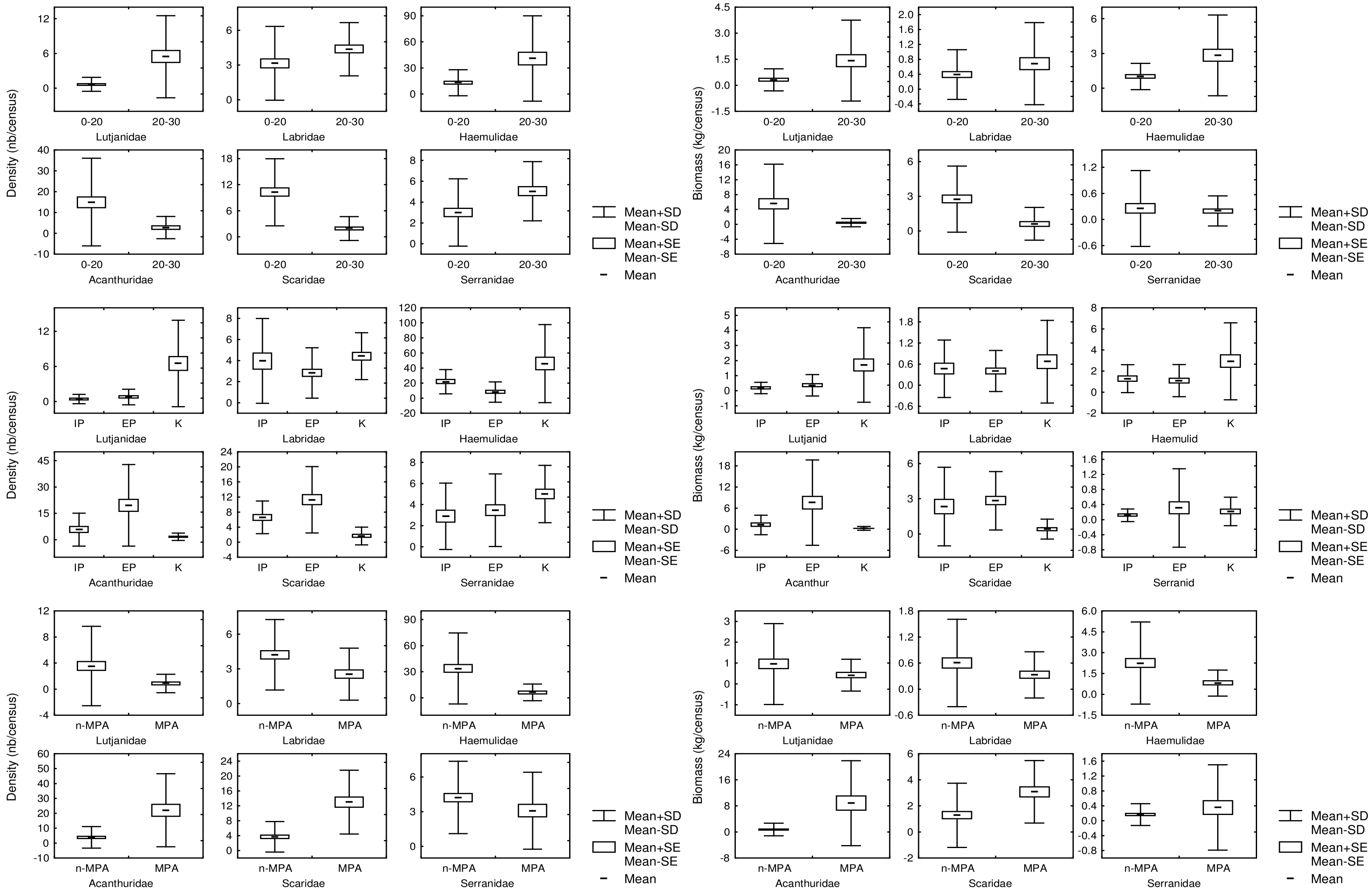


Fig. VI.6: Relative abundance (density and biomass) of the main families by depth strata, reef morphology and area (protected/unprotected).

Table VI.7: Species reported during CPUE surveys. n, total number of individuals, size range sampled, Frequency times of species presence, relative abundance (number by trip), relative biomass (weight by trip).

Family	Species	Code	n	Range	Frequency (%)	Relative abundance (nb/census)	Relative biomass (kg/census)
Belonidae	*Strongylura marina*	Str mar	1		1.5	0.015	0.017
Holocentridae	*Holocentrus adscencionis*	Hol ads	3	16 - 18	3.0	0.045	0.003
Clupeidae	*Opisthonema oglinum*	Opi ogl	51	12 - 27	9.0	0.761	0.235
Engraulidae	*Lycengraulis grossidens*	Lyc gro	1	15 - 15	1.5	0.015	0.001
Elopidae	*Elops saurus*	Elo sau	2	27 - 32	1.5	0.030	0.010
Scombridae	*Acanthocybium solandri*	Aca sol	1		1.5	0.015	0.114
	Scomberomorus brasiliensis	Sco bra	43	24 - 91	41.8	0.642	2.216
	Scomberomorus cavalla	Sco cav	3	81 - 99.5	3.0	0.045	0.375
	Scomberomorus regalis	Sco reg	5	60 - 128	6.0	0.075	0.434
Labridae	*Bodianus rufus*	Bod ruf	1	22 - 22	1.5	0.015	0.003
	Halichoeres brasiliensis	Hal bra	2	20 - 22.5	1.5	0.030	0.003
	Halichoeres poeyi	Hal poe	4	21 - 23	1.5	0.060	0.008
Scaridae	*Sparisoma axillare*	Spa axi	3	24.5 - 28	1.5	0.045	0.009
Carangidae	*Alectis ciliaris*	Ale cil	1		1.5	0.015	0.005
	Carangoides bartholomaei	Car bar	10	16 - 56	10.4	0.149	0.284
	Carangoides crysos	Car cry	3	31 - 33	3.0	0.045	0.055
	Caranx hippos	Car hip	12	31 - 94	14.9	0.179	0.683
	Caranx latus	Car lat	2	15 - 19	1.5	0.030	0.002
	Oligoplites palometa	Oli pal	24	40 - 62	9.0	0.358	1.010
	Selene vomer	Sel vom	2	28 - 35.5	1.5	0.030	0.013
Centropomidae	*Centropomus spp*	Cen sp	1		1.5	0.015	0.003
Corphaenidae	*Coryphaena spp*	Cor sp	1		1.5	0.015	0.354
Gerreidae	*Eugerres brasilianus*	Eug bra	1		1.5	0.015	0.003
Haemulidae	*Anisotremus surinamensis*	Ani sur	4	26.5 - 38	3.0	0.060	0.043
	Haemulon aurolineatum	Hae aur	12	11 - 16	4.5	0.179	0.007
	Haemulon parra	Hae par	20	12 - 27	10.4	0.299	0.048
	Haemulon plumieri	Hae plu	34	16.5 - 37	13.4	0.507	0.144
	Haemulon squamipinna	Hae squ	4	14 - 18	3.0	0.060	0.004
	Pomadasys corvinaeformis	Pom cor	2	12.5 - 16.5	1.5	0.030	0.003
Lutjanidae	*Lutjanus analis*	Lut ana	4	34.5 - 55	4.5	0.060	0.053
	Lutjanus chrysurus	Lut chr	9	23 - 36	4.5	0.134	0.057
	Lutjanus synagris	Lut syn	252	11 - 54	55.2	3.761	1.780
Malacanthidae	*Malacanthus plumieri*	Mal plu	12	28.5 - 61.5	7.5	0.179	0.089
Rachycentridae	*Rachycentron canadum*	Rac can	1		1.5	0.015	0.025
Serranidae	*Cephalopholis fulvus*	Cep ful	67	14 - 32.5	26.9	1.000	0.022
	Epinephelus adscencionis	Epi ads	5	20.5 - 35	4.5	0.075	0.033
Sparidae	*Archosargus rhomboidalis*	Arc rho	2	20 - 20	1.5	0.030	0.003
	Calamus penna	Cal pen	3	29 - 32	4.5	0.045	0.018
Ariidae	*Bagre marinus*	Bag mar	3	22 - 31	1.5	0.045	0.023
	Netuma barba	Net bar	2	40 - 46	1.5	0.030	0.048
Balistidae	*Balistes vetula*	Bal vet	6	14 - 32	3.0	0.090	0.042
Ostraciidae	*Acanthostracion sp*	Acanthos sp	2	34 - 43	1.5	0.030	0.042

VI.III.3. Fishery dataset *versus* underwater visual census (UVC)

Considering the full assemblage of fish, a great discrepancy was observed, few species were common to both methods (Table VI.8). Great differences in densities and/or biomass between survey methods were found mainly for haemulids (Table VI.9). Haemulids followed by scarids were globally the dominant family in the UVC whereas lutjanids were the main family of the catch considering the species present in both surveys only. When considering biomass scombrids took an important place in the fishing surveys whereas serranids were not seen as important family (6^{th} family in decreasing order of importance).

Table VI.8: Common species to both surveys (catch and UVC)

Carangidae	*Alectis ciliaris*
	Carangoides bartholomaei
	Carangoides crysos
	Selene vomer
Haemulidae	*Anisotremus surinamensis*
	Haemulon aurolineatum
	Haemulon parra
	Haemulon plumieri
	Haemulon squamipinna
Holocentridae	*Holocentrus adscencionis*
Labridae	*Bodianus rufus*
	Halichoeres brasiliensis
	Halichoeres poeyi
Lutjanidae	*Lutjanus analis*
	Lutjanus chrysurus
	Lutjanus synagris
Scaridae	*Sparisoma axillare*
Scombridae	*Scomberomorus brasiliensis*
Serranidae	*Cephalopholis fulvus*
	Epinephelus adscencionis

The major part (90%) of the sampled landings originated in the studied area (common to UVC area) came from the knoll type reef structure. Fishing activity and visual census did not present any family in common on the irregular platform (IP). A single family, Carangidae, was fished on the irregular platform structure and was not observed during visual censuses. On even platform (EP), only 4 families were common to both surveys (Table VI.9).

Relative abundance in number (density) and biomass (weight) obtained between both survey (fishing *vs*. UVC) were tested and pictured for the four main families (Fig VI.7, Table VI.10). Estimates of lutjanids obtained by fishing and UVC were not found significantly different on knoll. Haemulids presented significant differences on the even platform. The remaining families estimates were different from one method to the other.

Table VI.9: Comparisons of relative density of common species grouped by family in number (a) and relative biomass in weight (b) split by geomorphological types and surveys. (K) knoll, (IP) irregular platform, (EP) even platform

(a)

	K		IP		EP		All	
	Fishing	**UVC**	**Fishing**	**UVC**	**Fishing**	**UVC**	**Fishing**	**UVC**
Carangidae	0.27	0.18	1.00			0.07	0.26	0.09
Haemulidae	1.43	45.03		20.75	0.20	6.02	1.30	23.09
Holocentridae	0.06	0.42		0.29		0.13	0.05	0.27
Labridae	0.14	4.42		3.82		2.82	0.12	3.62
Lutjanidae	4.71	6.03		0.11	2.80	0.20	4.46	2.17
Scaridae	0.06	0.45		3.57		9.51	0.05	4.91
Scombridae	0.73	0.08			1.00	0.13	0.74	0.08
Serranidae	1.16	4.97		2.86	1.40	3.42	1.16	3.81

(b)

	K		IP		EP		All	
	Fishing	**UVC**	**Fishing**	**UVC**	**Fishing**	**UVC**	**Fishing**	**UVC**
Carangidae	0.410	0.094	1.712			0.028	0.397	0.043
Haemulidae	0.321	2.779		1.067	0.008	0.466	0.288	1.409
Holocentridae	0.004	0.040		0.019		0.022	0.003	0.028
Labridae	0.018	0.669		0.458		0.402	0.016	0.508
Lutjanidae	2.251	1.015		0.049	1.456	0.056	2.141	0.383
Scaridae	0.012	0.048		0.537		1.655	0.010	0.823
Scombridae	2.471	0.105			4.050	0.209	2.566	0.121
Serranidae	0.068	0.183		0.091	0.028	0.105	0.063	0.128

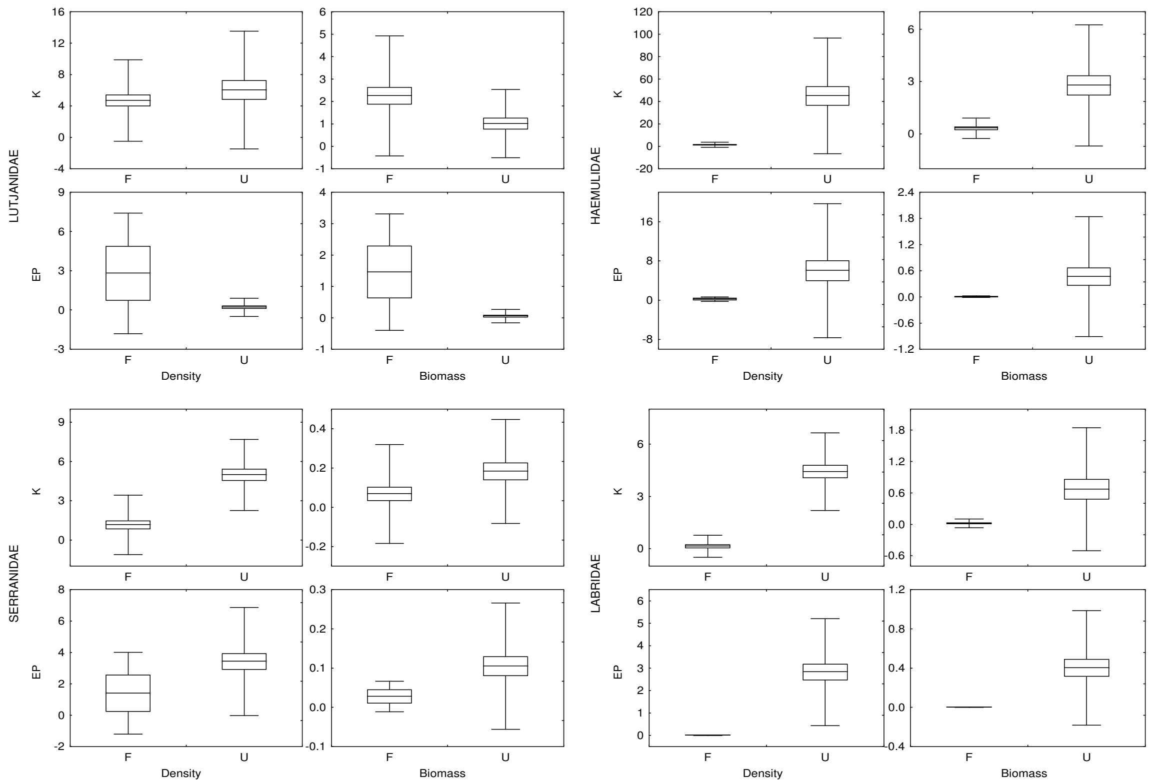
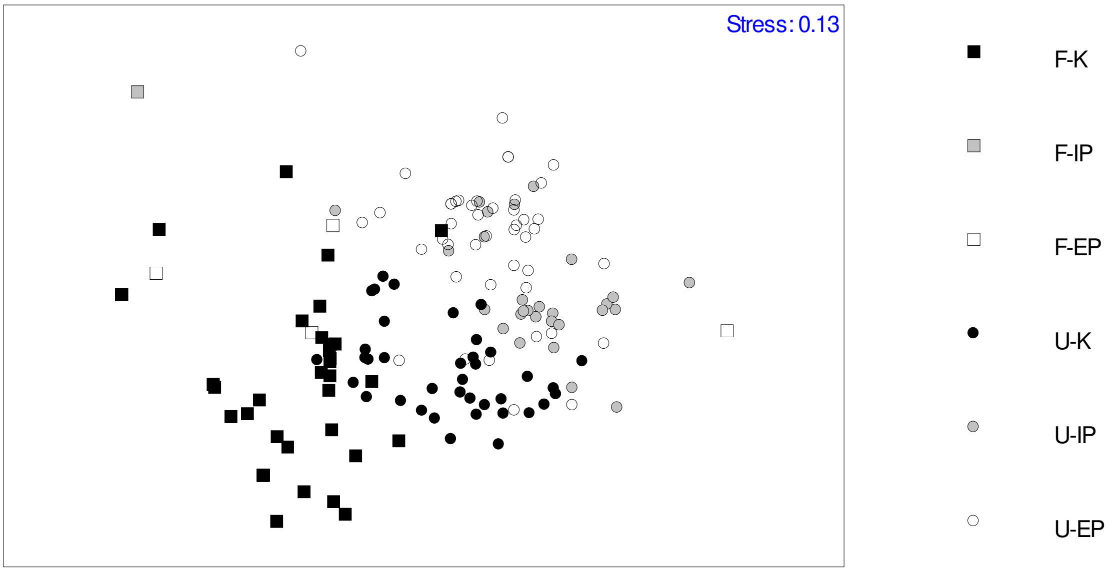


Fig. VI.7: Relative density and biomass for 4 families surveyed. (K) knoll, (EP) even platform

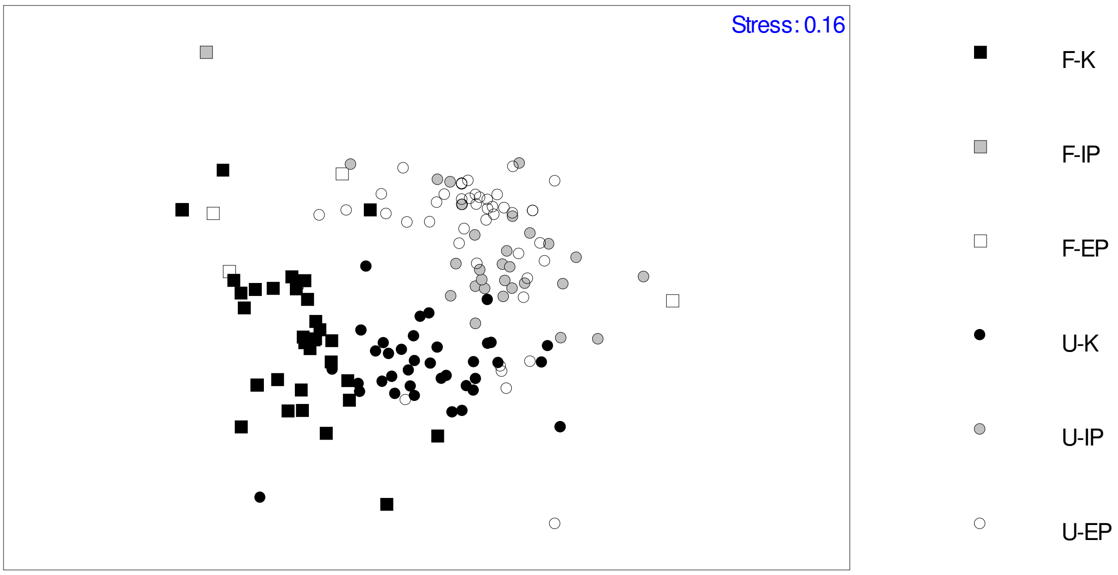
Table VI.10: Mann and Whitney U test for differences between catch and UVC on knoll (K) and even platform (EP) in number of fish (density) and CPUE in weight (biomass)

		Density		*Biomass*	
		U test	*p-level*	*U test*	*p-level*
K	Lutjanidae	895	0.530	780	0.112
	Haemulidae	211	<0.001	310	<0.001
	Serranidae	245	<0.001	378	<0.001
	Labridae	49	<0.001	92	<0.001
EP	Lutjanidae	35	<0.001	30	<0.001
	Haemulidae	68	0.120	69	0.129
	Serranidae	62	0.098	67	0.139
	Labridae	25	0.004	25	0.004

The MDS plots, based on the common species assemblage, confirmed that the relative abundance and the relative biomass of species were estimated differently by the two surveys methods (Fig VI.8). Samples of fish number and biomass were discriminated according to the geomorphological structure of the reef as well as to the data origin (UVC or catch). A two-way analysis of similarity show a stronger difference (greater R) between survey method than between geomorphological units although both were highly significant (Table VI.11), and segregated fish assemblage from each reef type seemed to be somehow linked. In the Figure VI.7, survey method discrimination occurred according to the horizontal axis, similarly reef geomorphological unit were discriminated along the vertical axis.



(a)



(b)

Fig. VI.8: MDS plot discriminating survey method and geomorphological unit. (a) relative abundance (UVC) and CPUE in number (fishing), (b) relative biomass (UVC) and CPUEs in weight. (F) landed catch survey (U) UVC survey. (K) knoll, (IP) irregular platform, (EP) even platform.

Table VI.11: Two-way ANOSIM Survey techniques (Fishing/UVC) *vs*. Geomorphological units (K) knoll, (IP) irregular platform, (EP) even platform. (a) Number of fish (b) Fish weight

(a)

Test for differences between Techniques: global R=0.588 Significance level of sample statistic: 0.1%		
Test for differences between geomorphological units global R= 0.311 Significance level of sample statistic: 0.1%		
Groups	**R Statistic**	**Significance Level %**
IP, EP	0.149	0.1
IP, K	0.444	0.1
EP, K	0.592	0.1

(b)

Test for differences between Techniques: global R=0.585 Significance level of sample statistic: 0.1%		
Test for differences between geomorphological units global R= 0.352 Significance level of sample statistic: 0.1%		
Groups	**R Statistic**	**Significance Level %**
IP, EP	0.414	0.1
IP, K	0.484	0.1
EP, K	0.125	0.3

The species that were primarily (90%) responsible for differences between UVC and CPUE methods are shown in Table VI.12. *L. synagris* and *S. axillare* were the most important species for differences between both methods.

Table VI.12: List of species that primarily (>90%) contributed to differences in estimates of relative abundance (number) (a) and relative biomass (weight) (b) between fishing survey and UVC. Contribution and cumulative contribution for the differences are shown as well as the proportional abundance of each species by method (e.g. 40.58% of all fish sampled by fishing survey were *L. synagris* by number).

(a)

Family	Species	Contribution%	Cumul%	Fishing (%)	UVC (%)
Lutjanidae	*Lutjanus synagris*	14.09	14.09	40.58	2.91
Scaridae	*Sparisoma axillare*	12.13	26.22	0.48	7.80
Serranidae	*Cephalopholis fulvus*	11.71	37.93	10.79	5.81
Scombridae	*Scomberomorus brasiliensis*	11.07	49	6.92	0.13
Haemulidae	*Haemulon aurolineatum*	10.68	59.68	1.93	26.08
Labridae	*Bodianus rufus*	7.7	67.38	0.16	3.12
Labridae	*Halichoeres brasiliensis*	7.2	74.57	0.32	2.46
Haemulidae	*Haemulon squamipinna*	5.97	80.55	0.64	6.63
Haemulidae	*Haemulon plumieri*	4.65	85.2	5.48	2.71
Haemulidae	*Haemulon parra*	2.82	88.02	3.22	0.79
Carangidae	*Carangoides bartholomaei*	2.13	90.15	1.61	0.09

(b)

Family	Species	Contribution%	Cumul%	Fishing (%)	UVC (%)
Lutjanidae	*Lutjanus synagris*	14.84	14.84	21.43	3.14
Scaridae	*Sparisoma axillare*	13.37	28.22	0.11	8.58
Scombridae	*Scomberomorus brasiliensis*	13.19	41.41	26.67	1.26
Labridae	*Bodianus rufus*	8.59	50	0.03	3.27
Haemulidae	*Haemulon aurolineatum*	8.22	58.22	0.08	7.77
Labridae	*Halichoeres brasiliensis*	7.3	65.52	0.04	1.88
Serranidae	*Cephalopholis fulvus*	6.41	71.92	0.26	0.77
Haemulidae	*Haemulon plumieri*	5.19	77.12	1.74	1.80
Haemulidae	*Haemulon squamipinna*	4.99	82.11	0.04	2.01
Haemulidae	*Haemulon parra*	2.9	85.01	0.57	0.87
Haemulidae	*Anisotremus surinamensis*	2.84	87.85	0.52	2.24
Carangidae	*Carangoides bartholomaei*	2.55	90.4	3.42	0.23

VI.IV. Discussion

Underwater visual census dataset was analysed using univariate and multivariate techniques then compared to local hand-line fishery in order to investigate whether estimates of relative species abundance index as measured by CPUE are comparable with estimates measured by UVC in a multispecies reef fish fishery.

VI.IV.1. Environmental variables and composition of fish assemblages

Although no difference in diversity (H') was detected between sites even between sites with no human activity in the last 3 years (sites 'Claros' located on the border of the marine protected area 'Costa dos Corais') multivariate techniques such as ANOSIM test presented significantly different densities. The apparent stability of Shannon diversity index even though the fish structure presenting differences may be explained by the fact that univariate techniques reduce the full set of species recorded in a sample into a single coefficient and by doing so fail in detecting species replacement, as often species richness and/or abundance remain the same.

Visual analysis based on ordination diagrams provides a direct and relatively simple mean of ecological interpretation. Exploratory analysis using MDS plot complemented by ANOSIM procedure helped us to determine what factor may influence fish distribution. In the present case, the result of the various statistical techniques applied to fish abundance were in close agreement, complemented each other, and suggested that the depth gradient remains the main factor along to the geomorphology as it is already known that morphological properties of the coral reef determine the structure of the fish assemblages (Sale, 1980). Some authors, mentioned the predation hypothesis in which predators may cause competition among their prey for refuge space (Holt, 1984). Other studies suggest that fish select the smallest possible reef structure holes to decrease predation risk (Shulman, 1984; Hixon & Beets, 1989).

The change of habitat characteristics induced significant changes in the community structure though the diversity was similar at each site. A species switch occurred instead of an increase or a domination of a particular species as it seems that complexity changes may benefits some species (Angel & Ojeda, 2001; Ferreira *et al.*, 2001; Charbonnel *et al.*, 2002; Willis & Anderson, 2003).

Differences in fish assemblage between depth strata has been commonly found in the literature as well as our study focusing on Lutjanids (chapter 3). Although the depth range was much smaller than the one considered in chapter 3, species assemblage and species abundance was mainly defined by the depth gradient. The 20 m isobath appeared to be a border line between to type of species assemblage. Considering this variable (depth strata) data considered fishery dependent and fishery independent resulted in similar patterns.

Large predators such as snapper, jacks, or groupers were poorly represented in the UVC surveys. However, they represented a large part of the total biomass of the area (see Estatpesca, 2000). The limitations of the method (UVC tends to underestimate predatory species in intensely fished areas as fish become more wary) and the location of censuses to a fixed depth range, no more than 30m deep, may have caused biases in estimating large predator species. Furthermore, the baited hook and line gear, used for the determination of the CPUE, may bias the estimate as it will select preferentially carnivorous.

Although the no-take area fish assemblage presented some significant differences, the species diversity was not higher than other sites. However, this observation may be due to the fact that the site ‘Os claros’ is close to the borderline and that part of the data was collected at beginning of the closure date, allowing not enough time for recovery and therefore a real change in the assemblage.

VI.IV.2. Comparisons of reef fish abundance using (visual census) *versus* commercial catch and effort data

Catch per unit effort (CPUE) measurement is commonly used as an index of abundance. In this study, the representation of the fish assemblage through CPUE surveys differed significantly from UVC surveys. Different selectivity of both methods lead to such conclusion. UVC surveys as well as CPUE surveys could present underestimation or over-estimation according of the species censused. Visual census present many well described biases (see for a review Harmelin-Vivien *et al.*, 1985; Jennings & Polunin, 1995a; Samoilys & Carlos, 2000). Accuracy and precision of the census may vary according to the area, time of the day, season as well as environmental factors such as topography, visibility, temperature, species richness. Also, there are two distinct fish faunas on coral reef: the diurnal and the nocturnal fish. Most species of lutjanids, holocentrids, clupeids are nocturnal (Longhurst & Pauly, 1987). This profound change that occurs at twilight will have an important effect on UVC estimates of the total fish abundance and could affect the catchability (and consequently the CPUE estimates). In this study however, this bias will not account for differences between UVC and CPUE surveys as fishing and underwater activities were carried out at daytime.

In spite of standardisation and transformation of data the two survey methods were discriminated by the multivariate analysis. However, some degrees of similarities were found when reef knolls characteristics were observed. This may be explained by the fact that the influence range both techniques and that the local structure influences the dispersion or conversely the concentration of the resource. In the case of reef knoll, fish are somewhat concentrated around the knoll which make the influence range of the baited hook is similar to the point count radius. As dispersion is stronger in the other geomorphological units difference may increase between the survey methods. Further, stronger relationship may occur for single species, or group of species that present similar ecological characteristics, and under homogeneous fishing conditions (i. e. same period). For instance, lutjanids’ estimates were similar in both surveys. Similarly, density and biomass of haemulids were not found different on even platform, although this result was mainly due to a high variance, resulting from the occasional occurrence of large schools of juveniles, within the UVC survey.

Catch and effort data, obtained from commercial data, do not come from controlled experiments therefore involve the untested assumption that the CPUE is proportional to abundance. As a result, the answers that we obtain are not clean or clear (Hilborn & Mangel, 1997). Conversely, several studies had shown that visual counts could obtain accurate estimates of abundance providing an adequate method for the group of species studied (Samoilys, 1997; Samoilys & Carlos, 2000). It has therefore been used to obtain fishery-independent stock assessment of reef fish, such as New Caledonia (Letourneur *et al.*, 2000). However both methods do have biases, although from different origins. A combination of both methods should therefore add confidence in assessment of reef fish abundance (Connell *et al.*, 1998). Best correlated estimates of CPUE and UVC may be obtained using Kulbicki's method (1988) in which CPUE obtained using experimental fishing at the same time, same place and with a large number of replicates as it would minimise error sources from spatial and temporal variations (see also Kulbicki et al. 2000). Many biases that may arise are specific to each method, and a global approach taking in account both indexes may benefit an better understanding on exploited reef environment.

Catch-per-unit-effort in fisheries science and underwater visual surveys in marine ecology are widely accepted for providing estimates of relative abundance. Both methods will bring complementary information for better knowledge on the habitat along to the fishery processes, but linking both methods needs further research before being widely used.

Main conclusions

- No spatial variation was found in term of diversity. Although catch composition varied, species switched according to the depth gradient and to geomorphological units, the species richness and diversity stayed at a similar level (species replacement).
- No large predators were found in the UVC records as censuses did not encompass their range of distribution.
- The type of geomorphological units seems to be an important factor influencing the species composition as further study should be developed to quantify such effect.
- CPUE estimates varied from UVC indexes on the overall. However, sampling performed on knolls for lutjanids were found similar. This may be explain by the fact that fish assemblage is restricted to a confined area where both survey methods present a similar operating range.
- Best results would probably be obtained with controlled fishing and UVC experiments on several identical sits.

Chapter VII. General discussion

The Brazilian effort for the development of the scientific knowledge necessary for the sustainable use of the resources within the Exclusive Economic Zone was represented by the REVIZEE program. This collective endeavour aimed the study of the ecosystem of Exclusive Economic Zone, in its physical, social, and biological characteristics. The fishery science part of the program, which collected data on species and fleet from 1996 to 2000, gave the opportunity to perform, for the first time in the Northeast region, a diagnostic of the fishing activity and its impact on fish assemblage. Regarding reef fishes, this study was an appraisal of the sustainability of the fishery, through catch analyses and stock assessment, a definition of relevant management plan as well as a critical analysis of the sampling program used (for improvement of future design).

In fisheries stock assessment, the major part of effort goes into the determination of the stock status relative to biological reference points, such as levels of fishing mortality, spawning biomass or age structure, or to obtain diagnostics that may warn manager and scientists against serious depletion or collapse. Stock assessment relies upon the estimation of many parameters and requires extensive current and historical data measured from the fishery and from independent biomass surveys (Pitcher & Preikshot, 2001). Stock assessment, although sometimes only viewed as an interpretation of commercial catch statistics to estimate potential yield and/or limitations, is far more than that. Hilborn and Walters (1992) stated that, 'first and foremost, stock assessment involves understanding the dynamics of fisheries'. Fisheries are much more than fish catch and fishermen are an important component of the dynamic system.

In this thesis, I conducted a baseline characterisation and fishery management analyses using a wide range of methods in fish stock assessment including mathematical and statistical modelling to provide a quantitative baseline assessment of the distribution and status of reef fishery resources. Four general areas have been investigated in the present study: (1) the dynamic of the commercial reef fishery in northeastern Brazil (Chapter 2); (2) the bathymetric trends of snappers through their exploitation (Chapter 3); (3) the development and applicability of traditional stock assessment models (Chapter 4) and of those which are suitable for multi-gear and multispecific fisheries (Chapters 5); and (4) the use of alternative, fishery independent, information gathered by underwater visual censuses (UVC) (Chapter 6) for a better understanding of the exploited environment as well as auxiliary information for fishery management.

Defining the reef fishery dynamic in the Northeast Brazil.

Many multivariate methods applied to fishery data have been performed in order to distinguish phenomena such as spatial pattern, fishery power, gear selectivity related to fishing trip or survey (Clarke & Warwick, 1994; Pech & Laloë, 1997; Garcia *et al.*, 1998; Legendre & Legendre, 1998; Pitcher *et al.*, 1998; Preikshot & Pauly, 1998; Pelletier & Ferraris, 2000; Rice, 2000; Pitcher & Preikshot, 2001; Stergiou *et al.*, 2002; Willis & Anderson, 2003). In fishery science, the simultaneous analysis of various components of the environment and the biomass related to the exploited populations may allow a better understanding of the environment and fishery dynamic improving the information needed for the development of a management plan (Gaertner, 1997).

Non-parametric multivariate analyses such as non-metric multi-dimensional scaling (MDS) and relatives (ANOSIM, BIO-ENV, etc) provided a way of dealing with problematic underlying distributions of abundances (Kruskall, 1964). Its weaker assumption of ordinal rather than interval information greatly increases robustness in the face of irregular distributions of abundance and high sampling variance. As a result, MDS has become a widely used technique for ecological ordinations of benthic and fish communities (Clarke, 1993; Clarke & Ainsworth, 1993). In fishery science, the incorporation of non-biological factors provided a important tool to better understand fishing dynamics (Pitcher *et al.*, 1998; Preikshot & Pauly, 1998). Such knowledge facilitated fishery researcher to focus on specific information to maximise a sampling program (money, effort and personnel). The complementarity of these techniques allow the knowledge of the structure and the dynamics of the fishing activity. Spatial segregation of fleet operation along with distribution range of species may also improve the development of future sampling and management program on a spatial aspect. In this study, such techniques helped to typify the reef fishery's components of the Northeast of Brazil (Chapter 2). Within the reef fishery in Northeast Brazil, snappers were found to be the main part of the artisanal catch. Also, while exploring the catch data, it was possible to visualise that each state showed a specific characteristic in term of fleet dynamic and therefore catch composition. This chapter was essential in understanding the fishery dynamic of the reef fishery in Northeast Brazil, hence helping the adaptation of the stock assessment models further applied within the reality of the fishery in the region (Chapters 4 and 5).

In order to better understand how the fleet dynamic is related to the snappers dynamic, the primary group of species driving the fishery, their distribution and relationship with the fishery dynamic was studied The ontogenetic depth distribution of snappers as well as the fleet operating distribution were described for management purpose. Implication of the fleet dynamic and consequently fishing effect on lutjanid population was discussed.

Fish stock assessment and fishery management in Northeast Brazil

Fisheries in both developed and developing countries are often reported to be in crisis. Fishery systems are complex, inherently variable and incompletely understood. The combination of these factors creates considerable uncertainty, which must be respected both in fisheries evaluation and in implementation of management regimes. Wherever there is uncertainty, there is risk, and this must be considered (Buckworth, 1998). In the fishing industry, the range of risk is enormous, because it deals with environmental factors and volatile markets, changes in harvesting management strategy, socio-economic considerations, political 'imperatives' and economic reality (Lucena, 2000). Uncertainties need to be identified and uncertainty reduced to encourage the taking of risk (in terms of management option) (Penhorn, 1999). A feature of 'controllable' uncertainties can only be managed successfully, i.e. risk be reduced, if they form the basis of an integrated comprehensive fishery management that embraces socio-economic considerations and harvest strategies.

The uncertainty and a poor knowledge of the resources are major setbacks for the development of a suitable assessment and management of fish stocks in developing countries (Lucena, 2000). Thus model with few data need were preferred. In the present case, simple catch-at-age models incorporating characteristics of the multi-fleet exploitation and biology of the species were developed (Chapters 4 and 5).

Once the dynamic of the reef fishery and the part of ecology of the species were characterised, the next logical step was to explore stock assessment model that would be used to evaluate the current status of the exploited stock as well as to allow simulated scenario for management purposes. Additionally, one should also better assess biological / ecological characteristics of the exploited species (i.e. reproduction, size at first maturity, etc). Traditional models were employed (Chapter 4) and the advantages and limitations of the techniques were discussed. Non-equilibrium models, such as real cohort VPA, provided coherent results. Model extensions that deal with the multifleet and multispecies aspect of the reef fishery were used in the Chapter 5. It was evident that different fleets played distinctive roles on the life history of the snappers. Fleets with different operation capacities will affect stocks on different ways and this is mainly related to the fleet power, which is related to fleet category. 'Jangadas' and 'paquetes' had a major effect on stock of *L. synagris* since they operate in shallower waters whereas *L. analis* and *L. jocu* were more affected by 'boats' (BOM and BOV). For each species, the multifleet aspects of the reef fishery was also evident, *L. jocu*, for example, had all stages of its life history exploited but, distinctively for each fleet in agreement with the combined effect of fish distribution and fleet operating position, 'paquete' mainly exploits the young individuals and 'boat' exploitation relies on larger individuals (Chapter 3).

When fishery dependent data has the potential to be biased by many factor (such for instance, under-reporting, lack of cooperation, gear selectivity), fishery independent data can provide measure on reef fish abundance and community composition. As a result, quantitative multispecies stock assessment methods as an integrated assessment should help for management decisions regarding fish stocks at broader levels.

Fishery independent information were used to get a picture of an ecological 'hot spot', where management attempts are set up, and to assess the relationship between catch-per-unit-of-effort (CPUE) through comparisons of abundance estimates obtained by underwater visual censuses (UVC) and by inshore fishery survey (Chapter 6). Fish composition varied accordingly to the habitat type. CPUE estimates varied from UVC indexes on the overall. However, sampling performed on knolls for lutjanids were found similar. This may be explained by the fact that lutjanid assemblage is restricted to a confined area where both survey methods present a similar operating range. Although at this point no clear conclusion can be made about the relationship between UVC and CPUE method, it was shown that a non destructive fishery independent method should bring a valuable source of information (Kulbicki *et al.*, 2000; Letourneur *et al.*, 2000). This would become even more important when spatial management strategies such as marine protected areas or 'no-take' areas are implemented because these methods are able to address estimation of mortality rates within and outside the closed area without reliance of fishery catch data and does so in a non-destructive way (Ault *et al.*, 2001).

Survey design. Gathering more and better information

Differences may occur between research survey data and commercial data as fishers focus on their activity on target species and particular zone according to their experience and to the economic market interest, whereas scientific surveys fishes without optimising the catch nor target fishing activity on some species of commercial interest. However, additional information from research survey that may be standardised and may determine precise estimates of CPUE as well as spatial structure will greatly improve our view of the stock in terms of abundance and distribution.

This study also presents the quantitative bases required for future preparation of an optimal sampling design analysis that produces precise statistics required for future implementation of a fishery management plan for the Northeast of Brazil. Results of this study will help to subsequent development of an efficient monitoring design that could optimise, in a cost-effective way, the precision of estimates for key management system efficacy. Chapters 4 and 5 draws attention to the fact that putting a large piece of effort in collecting 'basic' data does not completely fill our expectation for a satisfactory management action. Time-series with catch estimates at specific level are needed in order to carry out any type of model. For instance, catch-at-age model has best performances when at least the entire cohort is taken into account (in the snappers case, at least 19 years).

Furthermore, a broad sampling design should be conducted to gather auxiliary information that would help to define a holistic picture of the exploited ecosystem, namely mapping of fishing effort in a greater detail and precision, identification of fishing ground (localisation, identification of species caught by site), increase of the resolution and precision of base 'habitat' maps for key environment variables (reef complexity, bathymetry, reef mapping), best knowledge of fishers behaviour, technological characteristics (gears, boat) gathered by routine census at landings sites. Such information may not be too difficult to collect depending on the capacity of the socio-economic pattern and fishery scientist to cooperate. In this study, although the sample design of did not totally fulfil our expectations, management recommendations can emerge despite the complexity of the fishery.

Recommendations for the management plan of the reef fishery in Northeast Brazil.

Management actions can be divided into catch controls, effort controls, and technical measures (Jennings *et al.*, 2001). Catch controls limit the catches of fishers or the fleet as a whole, effort controls limit the numbers of fishers in the fishery and what they can do, while technical measures control the catch that they can be made for a given effort (OECD, 1997).

Catch control are amongst the most widely used management regulations. A catch quota or catch-limitation system as a straight measure may be efficient if supported by an effective monitoring and surveillance scheme (Nagasaki & Chikuni, 1989) and accepted on a social basis. However, it is true that catch limitation is generally impractical and hardly applicable in the Northeast of Brazil. Reef fishing activity is mainly performed by poor people and the characteristic of the activity that present highly spread landing sites make controls difficult.

Also, there are some disadvantages from a biological and social point of view. The expectation of a reduction of a specific catch may not be always fulfilled and the process involved in the reduction of a catch is generally a vague one (Nagasaki & Chikuni, 1989). Furthermore, the recovery of depleted resources may require a long time, particularly for long-living species such as the lutjanids studied. In a technical point of view, catch quotas management tends to encourage a race to fish amongst fishers in order to maximise their share of the quota (the fishery is closed when the aggregated catch equals total allowable catch). This would encourage the 'overcapacity' as larger and more powerful vessel will compete more efficiently.

Effort controls aims to reduce the fishing mortality by limiting the fishing power through the restriction of the number of fishers, boats in activity, amount, size and type of gear and/or vessel they use. Effort control can be implemented through licences. Licences restrict the number of boat or fishers in the fishery. Technical measures restrict the size and sex of fished species that are caught or landed, the gear used and the times when, or areas where, fishing is allowed. Restrictions occur with the area and/or period closed to fishing. Efficiency of size control, as for catch control, will depend on effective monitoring and surveillance capacity. In Brazil, such control would only be efficient on motorised boat as they are the easiest fleet to control efficiently. From the various management options available, few are really applicable in the Northeast of Brazil. One of them that is being implemented in the Northern Brazil, is the a local initiative started by 'Projeto Recifes Costeiros' (www.recifescosteiros.org.br) within the protected area 'APA dos Corais' that make use of fishing right licences. Fishing licence is only available to the local community which in return shall help to enforce regulation as it is of its own interest to make the fishing exploitation sustainable.

Throughout this thesis the technical diversity of the fishery, the selection and application of assessment methods and how fishing affects species was described. Thus, how fishery science can inform the management process and what can be achieved through management? One of the main findings of this thesis was that the spatial component (through the distribution of snapper, fleet allocation and fishing ground position) was the major factor acting on the reef fishery dynamic. Also, it was reported for most fish species a status of fully or over-exploitation. In this situation, regulation will only be adopted when fish stocks and the fishing industry will become so depressed that the need for action is truly compelling (Rettig, 1987).

Others measures such as establishment of smaller no take zones (3-4 km²) inside the APA, the moratorium on exploitation of vulnerable species at risk (namely the lord-of-the-rocks *Epinephelus itajara* and the nurse shark *Ginglymostoma cirratum*), closed seasons during reproduction (shrimp and lobster), and minimum allowed size (red snapper *Lutjanus purpureus* and lobster) were already implemented.

To improve the management in the northeastern of Brazil, two additional propositions are suggested based on the findings of this study : (1) technical measure restringing the fishing area and (2) the effort restriction by control on fleet's 'fishing power'.

In regard to the implementation of a restricted area, in a tropical multispecific framework, which is in most cases not well studied fisheries, management will have to be implemented without good scientific knowledge. As such, closed area may provide a means of doing this. The use of restricted area for fishing, specially in tropical region, already evidenced an increase of diversity, biomass, mean size and fecundity (Russ, 1991). In the Northeast Brazil, the protected area 'APA marinha costa dos corais' established a clear rise of diversity and biomass within a 'no-take area' established in 1999 (Ferreira *et al.*, 2000). Snappers are relatively sedentary fishes (by opposition to migratory fishes) after recruitment to the reef and, a closed area, would help to reduce fishing mortality on part of the population. As due to the fish distribution as seen in the Chapter 3 only part of the of the life cycle is contained within the protected area. Thus, in such context, protected area might be most efficient if set towards the off-shore in an attempt to protect the entire range of fish distribution and consequently the entire life cycle of the species. If the implementation of such wide area would not be possible, then a network of closed areas would provide the best alternative to protect various phases of the life cycle of target species and thus to be a guard against fishery collapse (Bohnsack, 1998).Such network should encompass a full range of marine and coastal ecosystems following four principles (SCBD, 2004): (1) Representativeness, all biogeographic regions should be represented and within each region, all major habitats should be represented (2) replication, all the habitats should be replicated within the network (3) viability, the network should be ecologically viable avoiding isolation (4) precautionary design, a precautionary approach should be taken whenever there is uncertainty. The aim of the MPA network should be to create a coherent entity and not only a collection of individual MPA. A critical issue is the proportion of marine space protected followed by the connectivity between closed areas as the viability of one area may depend on what happens elsewhere. The biodiversity commission recommendation (SCBD, 2004) is that protected area should cover at least 30% of the total area to have an effective protection and that connectivity between MPA takes into account the following: (1) allow species to continue to access their required range of food sources (2) allow species to continue to access their required range of habitat during their life cycle and (3) maintain metapopulation complex.

Alternatively, in the case of social pressure against permanent closed area and/or enforcement difficulties temporary closed areas could be used to implement rotational harvesting strategies (Jennings *et al.*, 2001). Traditional management before modern fishery managers often chose to harvest on a rotational basis. In Brazilian reef fishery this concept is often used as fishers go to some ground for a while and leave it when catch reduce to an unsustainable level, then they return after a period of time (Ferreira, pers com).

Although, results showed that motorised boats have the main effect on the yield, restriction on the fishing power of such fleet would be a political and social decision that is most likely impossible to take in the current economical context of Brazil and hardly applicable. However, a licence scheme, like already established within the protected area after a decree by IBAMA in march 2002 and implemented by the 'Projeto Recife Costeiros', would be an efficient alternative that promote the local fishers over fishers from other regions. In this way, local fishers will be part of the enforcement of the regulations. Regarding the results of this study, however, it seems that licences should be applied not only on fishermen but also on powered boats, not only because they were pointed out having a major effect on yield but also based on the fact that the remaining fishery partners would hardly be controllable (there are many unregistered 'paquete' and 'jangada').

Such recommendation go against the ultimate fishing policies elaborated by the Brazilian government entity (*Secretaria Especial de Aqüicultura e Pesca*, SEAP). Indeed, political decisions which is currently towards giving incentives to develop national fisheries. In the light of our findings, this initiative should be not encouraged for the reef fishery in Northeast Brazil. However, initiatives such as management strategy using protected area involving the local communities are being developed. Economical alternatives that reduce the fishing impact as well as educative action for local population will also help the implementation of such management plan.

References

Acosta, A. and Appeldoorn, R.S. (1992) Estimation of Growth Mortality and Yield Per Recruit For *Lutjanus Synagris* (Linnaeus) in Puerto Rico. *Bull. Mar. Sci.*, **50:** (2) 282-291.

Allen, G.R. (1985) *Snappers of the world. An annotated and illustrated catalogue of Lutjanid species known to date.* FAO, Roma, 208 pp.

Anderson, L.G. (1986) *The economics of fisheries management.* The Johns Hopkins University Press, London, 296 pp.

Angel, A. and Ojeda, F.P. (2001) Structure and trophic organization of subtidal fish assemblages on the northern Chilean coast: the effect of habitat complexity. *Mar. Ecol. Prog. Ser.*, **217:** (1) 81 - 91.

Anon (2002) Avaliação e ações prioritárias para a conservação da biodiversidade das zonas costeira e marinha. Ministério do Meio Ambiente,Workshop.

Appeldoorn, R.S. (1996) Model and Method in reef fishery assessment. *In Reef fisheries.* N.a.R. Polunin, CM, ed. Fish and fisheries Chapman & Hall, London, 219-248.

Araújo, M.E. and Feitosa, V.C. (*in press*) Análise de agrupamento da ictiofauna recifal do Brasil com base em dados secundários: uma avaliação crítica. *Trop. Oceano.*

Araujo, T.M.F. (1984) Morfologia, composição, sedimentologia e história evolutiva do recife de coral da ilha de Itaparica, Bahia. M.Sc., Universidade Federal de Bahia, 92 pp.

Ault, J.S., Bohnsack, J.A. and Meester, G.A. (1998) A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fish. Bull.*, **96:** (3) 395-414.

Ault, J.S., Luo, J.G., Smith, S.G., Serafy, J.E., Wang, J.D., Humston, R. and Diaz, G.A. (1999) A spatial dynamic multistock production model. *Can. J. Fish. Aquat. Sci.*, **56:** (1) 4-25.

Ault, J.S., Smith, S.G., Meester, G.A., Luo, J. and Bohnsack, J.A. (2001) Site characterization for Biscayne National Park: Assessment of fisheries resources and habitats. NOAA, Southeast Fisheries Science Center, Technical Memorandum, 186 pp.

Ault, J.S., Smith, S.G., Meester, G.A., Luo, J., Bohnsack, J.A. and Miller, S.L. (2002) Baseline multispecies coral reef fish stock assessment for the Dry Tartarugas. NOAA, Southeast Fisheries Science Center, Technical Memorandum, 117 pp.

Baranov, F.I. (1918) On the question of the biological basis of fisheries. *Nauchnye Issledovaniya Ikhtiologicheskii Inatituta Izvestiya*, **1:** (1) 81-128.

Beverton, R.J.H. and Holt, S.J. (1956) A Review of Methods for Estimating Mortality Rates in Exploited Fish Populations, with Special Reference to Sources of Bias in Catch Sampling. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, **140:** (1) 67 - 83.

Beverton, R.J.H. and Holt, S.J. (1957) On the dynamics of exploited fish populations. Fishery investigation of Ministry of Agriculture , fisheries and food, 19, 533 pp.

Biseau, A. and Gondeaux, E. (1988) Methods of Data-Analysis in Typological Studies of Fishery Fleets. *J. Cons. int. Explor. Mer*, **44:** (3) 286-296.

Bohnsack, J.A. (1998) Application of marine reserves to reef fisheries management. *Austr. J. Ecol.*, **23:** (1) 298-304.

Bohnsack, J.A. and Bannerot, S.P. (1986) A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA, Technical report NMFS, 41, 1-15 pp.

Brugge, W.J. and Holden, M.J. (1991) Multispecies management: a manager's point of view. *ICES mar. Sci. Symp.*, **193:** (1) 353-358.

Buckworth, R.C. (1998) World fisheries are in crisis? We must respond! *In Reinventing fisheries management.* T.J. Pitcher, Hart, P.J.B. & Pauly, D., ed. Kluwer Academic Publishers, Netherlands, 3-14.

Burton, M.L. (2001) Age, growth, and mortality of gray snapper, *Lutjanus griseus,* from the east coast of Florida. *Fish. Res.*, **99:** (1) 254-265.

Burton, M.L. (2002) Age, growth and mortality of mutton snapper, *Lutjanus analis,* from the east coast of Florida, with a brief discussion of management implications. *Fish. Res.*, **59:** (1) 31-41.

Caddy, J.F. and Mahon, R. (1995) Reference points for fisheries management. FAO, Fisheries Technical Paper, 347, 83 pp.

Cadima, E.L. (2000) Manual de avaliação de recursos pesqueiros. FAO,FAO Documento Técnico sobre as Pescas, 393, 162 pp.

Cappo, M., Eden, P., Newman, S.J. and Robertson, S. (2000) A new approach to validation of periodicity and timing of opaque zone formation in the otoliths of eleven species of Lutjanus from the central Great Barrier Reef. *Fish. Bull.*, **98:** (3) 474-488.

Carrasson, M. and Matallanas, J. (2001) Feeding ecology of the Mediterranean spiderfish, *Bathypterois mediterraneus* (Pisces: Chlorophthalmidae), on the western Mediterranean slope. *Fish. Bull.*, **99:** (2) 266-274.

Castro, C.B. and Pires, D.O. (2001) Brazilian coral reefs: what we already know and what is still missing. *Bull. Mar. Sci.*, **69:** (2) 357-371.

Cergole, M.C. (1993) Avaliação do estoque da sardinha verdadeira, Sardinella brasiliensis da costa sudeste do Brasil, período 1977-1990. D. Sc., USP, 245 pp.

Cervigón, F., Cipriani, R., Fischer, W., Garibaldi, L., Hendrickx, M., Lemus, A.J., Márquez, R., Poutiers, J.M., Robaina, G. and Rodriguez, B. (1992) *Fichas FAO de identificación de especies para los fines de la pesca. Guía de campo de las especies comerciales marinas y de aquas salobres de la costa septentrional de Sur América.* FAO, Roma, 513 pp.

Charbonnel, E., Serre, C., Ruitton, S., Harmelin, J.-G. and Jensen, A. (2002) Effects of increased habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast). *ICES J. Mar. Sci.*, **59:** (1) 208 - 213.

Charles, A.T. (1998) Living with uncertainty in fisheries: analytical methods, management priority and the Canadian groundfishery experience. *Fish. Res.*, **37:** (1) 37-50.

Charles, A.T. and Reed, W.J. (1985) A bioeconomic analysis of sequential fisheries - competition, coexistence, and optimal harvest allocation between inshore and offshore fleets. *Can. J. Fish. Aquat. Sci.*, **42:** (5) 952-962.

Choat, J.H. and Axe, L.M. (1996) Growth and longevity in acanthurid fishes; an analysis of otolith increments. *Mar. Ecol. Prog. Ser.*, **134:** (1) 15-26.

Choat, J.H., Axe, L.M. and Lou, D.C. (1996) Growth and longevity in fishes of the family Scaridae. *Mar. Ecol. Prog. Ser.*, **145:** (1) 33-41.

Clarke, K.R. (1993) Non-parametric multivariate analyses of changes in community structure. *Austr. J. Ecol.*, **18:** (1) 117-143.

Clarke, K.R. and Ainsworth, M. (1993) A method linking multivariate community structure to environmental variables. *Mar. Ecol. Prog. Ser.*, **92:** (1) 205-219.

Clarke, K.R. and Gorley, R.N. (2001) Primer v5: User Manual/Tutorial. PRIMER-E Ltd, 91 pp.

Clarke, K.R. and Warwick, R.M. (1994) *Change in marine communities: an approach to statistical analysis and interpretation.* Plymouth Marine Laboratory, Plymouth, UK, 144 pp.

Coleman, F.C., Koenig, C.C., Huntsman, G.R., Musick, J.A., Eklund, A.M., McGovern, J.C., Chapman, R.W., Sedberry, G.R. and Grimes, C.B. (2000) Long-lived reef fishes: The grouper-snapper complex. *Fisheries*, **25:** (3) 14-21.

Connell, S.D., Samoilys, M.A., Smith, M.P.L. and Leqata, J. (1998) Comparisons of abundance of coral-reef fish: Catch and effort surveys *vs* visual census. *Australian Journal of Ecology*, **23:** (6) 579-586.

da Silveira, I.C.A., Miranda, L.B. and Brown, W.S. (1994) On the origins of the North Brazil Current. *J. Geophys. Res.*, **99:** (1) 22501-22512.

Dann, N. (1987) Multispecies *versus* single-species assessment of North Sea fish stocks. *Can. J. Fish. Aquat. Sci.*, **44:** (1) 360-370.

Darwin, C.R. (1841) On the remarkable bar of sandstone off Pernambuco on the coast of Brazil. *Edinburg and Dublin Phil. Magazine and Journal Science*, **19:** (3) 2.

Darwin, C.R. (1851) *Geological observations on coral reefs, volcanic islands and South America.* Smith, Elder, and Company, London.

Davis, T.L.O. and West, G.J. (1992) Growth and Mortality of *Lutjanus Vittus* (Quoy and Gaimard) From the North-West Shelf of Australia. *Fish. Bull.*, **90:** (2) 395-404.

Deriso, R.B., Quinn II, T.J. and Neal, P.R. (1985) Catch-at-age analysis with auxiliary information. *Can. J. Fish. Aquat. Sci.*, **42:** (1) 815-824.

Derzhazin, A.N. (1922) The stellate sturgeon (*Acipenser stellatus*, Pallas), a biological sketch. *Byulleten´Bakinskoi Ikhtiologicheskoi Stantsii*, **1:** (1) 1-393.

Diedhiou, M. (2000) Aspectos biologicos da guaiuba, *Lutjanus chrysurus* Bloch, 1791 (Perciformes: Lutjanidae na costa nordeste do Brasil: Idade crescimento, reprodução, morformetria e pesca. M.Sc., UFPE, 77 pp.

Diedhiou, M., Ferreira, B.P. and Rezende, S.M. (2003) Idade e Crescimento da guaiúba *Lutjanus chrysurus* (Bloch 1791), na Costa Nordeste do Brasil. *Arquiv. ciênc. Mar*, in press.

Duarte, L.O. and Garcia, C.B. (1999) Diet of the mutton snapper *Lutjanus analis* (Cuvier) from the Gulf of Salamanca, Colombia, Caribbean Sea. *Bull. Mar. Sci.*, **65:** (2) 453-465.

Dufrêne, M. and Legendre, P. (1997) Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecol. Monogr.*, **67:** (3) 345-366.

Dupont, W.D. (1983) A stochastic catch-effort method for estimating animal abundance. *Biometrics*, **39:** (1) 1021-1033.

Eide, A. and Flaaten, O. (1998) Bioeconomic multispecies models of the Barent Sea fisheries. *In Models for multispecies management.* T. Rodseth, ed. Springer-Velag, Heidelberg, 141-172.

Ekau, W. (1999) Topographical and hydrographical impacts on macrozooplankton community structure in the Abrolhos Bank region, East Brazil. *Arch. Fish. Mar. Res.*, **47:** (2-3) 307-320.

Estatpesca (2000) Boletim estatistico da pesca maritima do nordeste do Brasil. IBAMA, 139 pp.

Ferreira, B.P. (2000) Reef fishes and fisheries in Brazil's coral coast MPA: management perspectives. Proc.*9th International Coral Reef Symposium. World coral reefs in the millenium: bridging research and management for sustainable development*, Bali, 162.

Ferreira, B.P. and Cava, F. (2001) Ictiofauna marinha da APA Costa do Corais: lista de espécies através de levantamento da pesca e observações subaquáticas.

Ferreira, B.P., Cava, F.C. and Ferraz, A.N. (1998) Relações Morfométricas em Peixes Recifais na Zona Econômica Exclusiva. *Bol. Téc. Cient. CEPENE*, **6:** (1) 61-76.

Ferreira, B.P. and Maida, M. (2001) Fishing and the future of Brazil´s northeastern reefs. *InterCoast*, **38:** (1) 22-23.

Ferreira, B.P., Maida, M. and Cava, F.C. (1999) Levantamento da Pesca Artesanal de Subsistência na Area de Proteção Ambiental Costa dos Corais (Pe-Al): Fase Piloto. Proc. *Resumos do XIII Encontro Brasileiro de Ictiologia*, São Carlos, SP, 568.

Ferreira, B.P., Maida, M. and Cava, F.C. (2000) Características e perspectivas para o manejo da pesca na APA Marinha Costa dos Corais. Proc.*II Congresso Brasileiro de unidades de Conservação*, Campo Grande, MS, 50-58.

Ferreira, B.P., Rezende, S.M., Teixeira, S.F. and Frédou, T. (2004a) Sinopse Idade, Crescimento, Mortalidade, Reprodução e Avaliação de Estoques de *Lutjanus analis*. *In Relatório Final do REVIZEE/ SCORE-NE: Parte II- Análise das principais pescarias comerciais do nordeste do Brasil- Dinâmica das populações marinhas e avaliação de estoques.* Brasilia

Ferreira, B.P., Rezende, S.M., Teixeira, S.F. and Frédou, T. (2004b) Sinopse Idade, Crescimento, Mortalidade, Reprodução e Avaliação de Estoques de *Lutjanus chrysurus*. *In Relatório Final do REVIZEE/ SCORE-NE: Parte II- Análise das principais pescarias comerciais do nordeste do Brasil- Dinâmica das populações marinhas e avaliação de estoques.* Brasilia

Ferreira, B.P., Rezende, S.M., Teixeira, S.F. and Frédou, T. (2004c) Sinopse Idade, Crescimento, Mortalidade, Reprodução e Avaliação de Estoques de *Lutjanus jocu*. *In Relatório Final do REVIZEE/ SCORE-NE: Parte II- Análise das principais pescarias comerciais do nordeste do Brasil- Dinâmica das populações marinhas e avaliação de estoques.* Brasilia

Ferreira, B.P., Rezende, S.M., Teixeira, S.F. and Frédou, T. (2004d) Sinopse Idade, Crescimento, Mortalidade, Reprodução e Avaliação de Estoques de *Lutjanus synagris*. *In Relatório Final do REVIZEE/ SCORE-NE: Parte II- Análise das principais pescarias comerciais do nordeste do Brasil- Dinâmica das populações marinhas e avaliação de estoques.* Brasilia

Ferreira, C.E.L., Goncalves, J.E.A. and Coutinho, R. (2001) Community structure of fishes and habitat complexity on a tropical rocky shore. *Env. Biol. Fishes*, **61:** (4) 353 - 369.

Floeter, S.R. and Gasparini, J.L. (2000) The southern Atlantic reef fish fauna: composition and zoogeographic patterns. *J. Fish Biol.*, **56:** (1) 1099-1114.

Floeter, S.R. and Gasparini, J.L. (2001) The Brazilian endemic reef fishes. *Coral Reefs*, **19:** (1) 292.

Floeter, S.R., Guimarães, R.Z.P., Rocha, L.A., Ferreira, C.E.L., Rangel, C.A. and Gasparini, J.L. (2001) Geographic variation in reef-fish assemblages along the Brazilian coast. *Glob. Ecol. Biogeogr.*, **10:** (1) 423-431.

Ford, E. (1933) An account of the herring investigations conducted at Plymouth during the years from 1924 to 1933. *J. Mar. Biol. Ass. UK*, **19:** (1) 305-384.

Fournier, D.A. (1996) An introduction to AD model builder for use in nonlinear modelling and statistics. Otter Research Ltd, User Manual.

Fournier, D.A. and Archibald, C. (1982) A general theory for analysing catch-at-age data. *Can. J. Fish. Aquat. Sci.*, **39:** (1) 1195-1207.

Fournier, D.A., Sibert, J.R., Majkowski, J. and Hampton, J. (1990) MULTIFAN a likelihood based method for estimating growth parameters and age composition form multiple length frequency data sets illustrated by using data for southern bluefin tuna (*Thunnus maccoyii*). *Can. J. Fish. Aquat. Sci.*, **45:** (1) 301-317.

Francis, R.I.C.C. (1990) Back-calculation of fish length: a critical review. *J. Fish Biol.*, **3:** (1) 883-902.

Gaertner, J.-C. (1997) Organisation des Assemblages démersaux dans le golfe du Lion: structures spatiales et stabilité temporelle. Ph.D., Université de la Méditerranée, 139 pp.

Gaeta, S.A., Lorenzetti, J.A., Miranda, L.B., Susini-Ribeiro, S.M.M., Pompeu, M. and De Araujo, C.E.S. (1999) The Victoria Eddy and its relation to the phytoplankton biomass and primary productivity during the austral fall of 1995. *Arch. Fish. Mar. Res.*, **47:** (2-3) 253-270.

Garcia, C.B., Duarte, L.O. and von Schiller, D. (1998) Demersal fish assemblages of the Gulf of Salamanca, Colombia (southern Caribbean Sea). *Mar. Ecol. Prog. Ser.*, **174:** (1) 13-25.

Gaston, K.J., Blackburn, T.M. and Lawton, J.H. (1993) Comparing animals and automobiles: a vehicle for understanding body size and abundance relationships in species assemblages? *Oikos*, **66:** (1) 172-179.

Gayanilo Jr., F.C., Sparre, P. and Pauly, D. (1996) *FAO-ICLARM Stock Assesment Tools FISAT User's Guide.*FAO, Roma, 126 pp.

Gobert, B. (1994) Size structures of demersal catches in a multispecies multigear tropical fishery. *Fish. Res.*, **19:** (1) 87-104.

Goevender, A. (1995) Mortality and biological reference points for the king mackerel (*Scomberomorus commerson*) fishery off Natal, South Africa (based on a per-recruit assessment). *Fish. Res.*, **23:** (1) 195-208.

Grimes, C.B. (1987) Reproductive biology of the Lutjanidae: a review. *In Tropical snappers and groupers: biology and fisheries management.* J.J. Polovina & S. Ralston, eds., Westview press, Boulder, USA, 271-294.

Grutter, A.S. (2000) Ontogenetic variation in the diet of the cleaner fish *Labroides dimidiatus* and its ecological consequences. *Mar. Ecol. Prog. Ser.*, **197:** (1) 241-246.

Gulland, J.A. (1965) Estimation of mortality rates. Annex to Arctic fisheries working group report. ICES,C.M. Doc. 3

Gulland, J.A. (1969) Manual of methods for fish stock assessment. Part 1: Fish population analysis. FAO,FAO Man. Fish. Sci., 4, 154 pp.

Gulland, J.A. (1989) Natural mortality and size. *Mar. Ecol. Prog. Ser.*, **39:** (1) 197 - 199.

Gulland, J.A. (1991) Under what conditions will multispecies models lead to better fisheries management? *ICES mar. Sci. Symp.*, **193:** (1) 348-352.

Gulland, J.A. and Boerema, L.K. (1973) Scientific advice on catch levels. *Fish. Bull.*, **71:** (2) 325-335.

Harmelin-Vivien, M.L., Harmelin, J.G., Chauvet, C., Duval, C., Galzin, R., Lajeune, P., Barnabé, G., Blanc, F., Chevalier, L., Duclerc, J. and Lasserre, G. (1985) Evaluation visuelle des peuplements et populations de poissons: méthodes et problèmes. *Rev. Ecol. Terre & Vie*, **40:** (1) 467-539.

He, X., Bigelow, K.A. and Boggs, C.H. (1997) Cluster analysis of longline sets and fishing strategies within the Hawaii-based fishery. *Fish. Res.*, **31:** (1) 147-158.

Hilborn, R. (1985) Fleet dynamics and individual variation: why some people catch more fish than others. *Can. J. Fish. Aquat. Sci.*, **42:** (1) 2-13.

Hilborn, R. and Mangel, M. (1997) *The ecological detective : confronting models with data.* Princeton University Press, Princeton, NJ, 315 pp.

Hilborn, R. and Walters, C.J. (1992) *Quantitative fisheries stock assessment: choice, dynamics and uncertainty.* Chapman and Hall, New York, 570 pp.

Hixon, M.A. and Beets, J.P. (1989) Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs. *Bull. Mar. Sci.*, **44:** (1) 666-680.

Hodd, P.B. and Johnson, A.K. (1999) Age, growth, mortality, and reproduction of vermilion snapper, R*homboplites autorubens*, from the eastern Gulf of Mexico. *Fish. Bull.*, **97:** (4) 828-841.

Hoening, J.M. (1983) Empirical use of longevity data to estimate mortality rates. *Fish. Bull.*, **81:** (4) 898-903.

Hollowed, A.B., Bax, N., Richard Beamish, Collie, J., Fogarty, M., Livingston, P., Pope, J. and Rice, J.C. (2000) Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? *ICES J. Mar. Sci.*, **57:** (1) 707-719.

Holt, R.D. (1984) Spatial heterogeneity, indirect interactions, and the coexistence of prey species. *Am. Nat.*, **124:** (1) 377-406.

Hood, P.B. and Johnson, A.K. (2000) Age, growth, mortality, and reproduction of red porgy, *Pagrus pagrus*, from the eastern Gulf of Mexico. *Fish. Bull.*, **98:** (4) 723-735.

IBAMA/FUNATURA (1991) Plano de manejo do parque nacional marinho dos Abrolhos. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis/Fundação Pró-Natureza, 96 pp.

Ihaka, R. and Gentleman, R. (1996) R: a language for data analysis and graphics. *Jour. Comp. Graph. Stat.*, **5:** 299-314.

Jennings, S., Kaiser, M.J. and Reynolds, J.D. (2001) *Marine fisheries ecology.* Blackwell Science Ltd, Oxford, 417 pp.

Jennings, S. and Polunin, N.V.C. (1995a) Biased underwater visual census biomass estimates for target species in tropical reef fisheries. *J. Fish Biol.*, **47:** (4) 733-736.

Jennings, S. and Polunin, N.V.C. (1995b) Comparative size and composition of yield from 6 Fijian reef fisheries. *J. Fish Biol.*, **46:** (1) 28-46.

Jones, R. (1984) Assessing the effects of changes in exploitation pattern using length composition data (With notes on VPA and cohort analysis). F.A.O, Fishery Technical Report, 256 pp.

Jones, R. (1987) An investigation of length composition analysis using simulated length composition. Proc. *Length-based methods in fisheries research*, Sofat, Kowait, ICLARM & Kowait institute for scientific research, 217-238.

Jones, R. (1990) Length-cohort analysis: The importance of choosing the correct growth parameters. *J. Cons. int. Explor. Mer*, **46:** (1) 133-139.

Joyeux, J.-C., Floeter, S.R., Ferreira, C.E.L. and Gasparini, J.L. (2001) Biogeography of tropical reef fishes: the South Atlantic puzzle. *J. Biogeogr.*, **28:** (1) 831-841.

Kempf, M., Coutinho, P.N. and Morais, J.O. (1970) Plataforma continental do norte e nordeste do Brasil. Nota preliminar sobre a natureza do fundo. *Trab. Oceanogr. UFPE*, **9-11:** (1) 9-26.

Kendall, M.G. and Gibbons, J.D. (1990) *Rank correlation methods.*E. Arnold, London, UK, .

Koslow, J.A., Aiken, K., Auil, S. and Clementson, A. (1994) Catch and effort analysis of the reef fisheries of Jamaica and Belize. *Fish. Bull.*, (92) 737-747.

Koslow, J.A., Hanley, F. and Wicklund, R. (1988) Effects of fishing on reef communities at Pedro Bank and Port Royal Cays, Jamaica. *Mar. Ecol. Prog. Ser.*, **43:** (1) 201-212.

Kramer, D.L. and Chapman, M.R. (1999) Implication of fish home range size and relocation for marine reserve function. *Env. Biol. Fishes*, **55:** (1) 65-79.

Kruskall, J.B. (1964) Multi-dimensional scaling by optimizing goodness of fit to a non-parametric hypothesis. *Psychometrica*, **29:** (1) 1-27.

Kulbicki, M. (1988) Correlation between catch data from bottom longlines and fish censuses in the SW lagoon of new Caledonia. Proc. *6th International Coral Reef Symposium*, **2**, 305-312.

Kulbicki, M. (1998) How the acquired behaviour of commercial reef fishes may influence the results obtained from visual censuses. *J. Exp. Mar. Biol. Ecol.*, **222:** (1-2) 11-30.

Kulbicki, M., Labrosse, P. and Letourneur, Y. (2000) Fish stock assessment of the northern New Caledonian lagoons: 2 - Stocks of lagoon bottom and reef-associated fishes. *Aquat. Living. Resour.*, **13:** (2) 77-90.

Laborel, J.M. (1967) Les peuplements de Madréporaires des côtes tropicales du Brésil. Ph. D., Aix-Marseille.

Laborel, J.M. and Kempf, M. (1967) Formação de vermetos e algas calcareas nas costas do Brasil. *Trab. Oceanogr. UFPE*, **7-8:** (1) 33-50.

Labrosse, P., Letourneur, Y., Kulbicki, M. and Paddon, J.R. (2000) Fish stock assessment of the northern New Caledonian lagoons: 3 - Fishing pressure, potential yields and impact on management options. *Aquat. Living. Resour.*, **13:** (2) 91-98.

Leão, Z.M.A.N. (1986) Guia de identificação dos corais e hidrocorais do Brasil. Instituto de Geosciências, Universidade Federal de Pernambuco,Programa de pesquisa e pós-graduação em geofisica, 57 pp.

Leão, Z.M.A.N., Kikuchi, R.K.P. and Testa, V. (2003) Corals and coral reefs of Brazil. *In Latin American coral reefs.* J. Cortés, ed. Elservier Science B.V., 9-52.

Legendre, P. and Legendre, L. (1998) *Numerical Ecology.* Elsvier, Amsterdam, 853 pp.

Letourneur, Y., Kulbicki, M. and Labrosse, P. (2000) Fish stock assessment of the northern New Caledonian lagoons: 1 - Structure and stocks of coral reef fish communities. *Aquat. Living. Resour.*, **13:** (2) 65-76.

Levinton, J.S. (2001) *Marine biology. Function, biodiversity, ecology.* Oxford University Press, Oxford, 515 pp.

Lieske, E. and Myers, R. (1994) *Coral reef fishes. Indo-Pacific & Caribbean including the Red Sea.* Haper Collins Publishers, 400 pp.

Longhurst, A. and Pauly, D. (1987) *Ecology of tropical oceans.* Academic Press, San Diego, California, 407 pp.

Lucena, F.M. (2000) Species interaction in fish stock assessment and management in southern Brazil: a bio-economic approach. Ph.D., University of East Anglia, 235 pp.

Lucena, F.M., O'Brien, C.M. and Reis, E.G. (2002) Effect of exploitation of the bluefish *Pomatamus saltatrix* by two competing fleets in southern Brazil: An application of a catch-at-age model. *Mar. Freshwater Res.*, **53:** (5) 1-13.

Luckhurst, B.E., Dean, J.M. and Reichert, M. (2000) Age, growth and reproduction of the lane snapper Lutjanus synagris (Pisces : Lutjanidae) at Bermuda. *Mar. Ecol. Prog. Ser.*, **203:** (1) 255-261.

Lukens, R.R. (1981) Observations of deep-reef ichthyofauna from the Bahamas and Cayman Islands, with notes on relative abundance and depth distribution. *Gulf Res. Rep.*, **7:** (1) 79-81.

Mabesoone, J.M. and Coutinho, P.N. (1970) Littoral and shallow marine geology of northern and northeastern Brazil. *Trab. Oceanogr. UFPE*, **12:** (1) 1-224.

Machias, A., Somarakis, S. and Tsimenides, N. (1998) Bathymetric distribution and movements of red mullet *Mullus surmuletus*. *Mar. Ecol. Prog. Ser.*, **166:** 247-257.

MacPherson, E. (1998) Ontogenetic shifts in habitat use and aggregation in juvenile sparid fishes. *J. Exp. Mar. Biol. Ecol.*, **220:** (1) 127-150.

MacPherson, E. and Duarte, C.M. (1991) Bathymetric trends in demersal fish size - Is there a general relationship? *Mar. Ecol. Prog. Ser.*, **71:** (2) 103-112.

Magnusson, K.G. (1995) An overview of multispecies VPA - theory and applications. *Rev. Fish. Biol. Fish.*, **5:** (1) 195-212.

Maida, M. and Ferreira, B.P. (1997) Coral Reefs of Brazil: Overview and Field Guide. Proc.8^{th} *International Coral Reef Symposium*, Panama, 263-274.

Manickchanddass, S. (1987) Reproduction, Age and Growth of the Lane Snapper, *Lutjanus synagris* (Linnaeus), in Trinidad, West-Indies. *Bull. Mar. Sci.*, **40:** (1) 22-28.

Manooch, C.S. (1987) Age and growth of snappers and groupers. *In Tropical snappers and groupers: biology and fisheries management.* J.J. Polovina & S. Ralston, eds., Westview press, Boulder, USA, 329-406.

Margalef, R. (1958) Information theory in ecology. *Gen. Syst.*, **3:** 36-71.

McClanahan, T.R. (1995) A coral reef ecosystem-fisheries model: impacts of fishing intensity and catch selection on reef structure and processes. *Ecol. Model.*, **80:** (1) 1-19.

McGeoch, M.A. and Chown, S.L. (1998) Scaling up the value of bioindicators. *Trends Ecol. Evol.*, **13:** (1) 46-47.

Megrey, B.A. (1989) Review and comparison of age-structured stock assessment models form theoretical and applied points of view. Proc. *American Fishery Society Symposium*, **6**: (1) 8-48.

Mendoza, J.J. and Larez, A. (2003) A biomass dynamics assessment of the southeastern Caribbean snapper–grouper fishery. *Fish. Res.*, **66:** (2-3) 129-144.

Milton, D.A., Short, S.A., Oneill, M.F. and Blaber, S.J.M. (1995) Aging of 3 Species of Tropical Snapper (Lutjanidae) From the Gulf of Carpentaria, Australia, Using Radiometry and Otolith Ring Counts. *Fish. Bull.*, **93:** (1) 103-115.

Moura, R.L., Gasparini, J.L. and Sazima, I. (1999) New records and range extensions of reef fishes in the Western South Atlantic, with comments on reef fish distribution along the Brazilian coast. *Rev. Bras. Zool.*, **16:** (2) 513-530.

Murawski, S.A. (1984) Mixed-species yield per recruitment analyses accounting for technological interactions. *Can. J. Fish. Aquat. Sci.*, **41:** (1) 897-916.

Murawski, S.A., Lange, A.M., Sissenwine, M.P. and Mayo, R.K. (1983) Definition and Analysis of Multispecies Otter-Trawl Fisheries Off the Northeast Coast of the United-States. *J. Cons. int. Explor. Mer*, **41:** (1) 13-27.

Murphy, G.I. (1965) A solution of the catch equation. *J. Fish. Res. Bd. Can.*, **22:** 191-202.

Nagasaki, F. and Chikuni, S. (1989) Management of multispecies resources and multi-gear fisheries. Experience in coastal waters around Japan. FAO,FAO Fisheries Technical Paper, 305, 68 pp.

Nagelkerken, I., van der Velde, G., Gorissen, M.W., Meijer, G.J., van't Hof, T. and den Hartog, C. (2000) Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuar. Coast. Shelf Sci.*, **51:** (1) 31-44.

Newman, S.J. (2001) Growth rate, age determination, natural mortality and production potential of the scarlet seaperch, *Lutjanus malabaricus* Scheider 1801, off the Pilara coast of north-western Australia. *Fish. Res.*, **58:** (1) 215-225.

Newman, S.J., Cappo, M. and Williams, D.M. (2000) Age, growth, mortality rates and corresponding yield estimates using otoliths of the tropical red snappers, *Lutjanus erythropterus*, *L. malabaricus* and *L. sebae*, from the central Great Barrier Reef. *Fish. Res.*, **48:** (1) 1-14.

Newman, S.J. and Dunk, I.J. (2002) Growth, Age Validation, Mortality, and other Population Characteristics of the Red Emperor Snapper, *Lutjanus sebae* (Cuvier, 1828), off the Kimberley Coast of North-Western Australia. *Estuar. Coast. Shelf Sci.*, **55:** (1) 67-80.

Newman, S.J. and Williams, D.M. (1996) Variation in reef associated assemblages of the Lutjanidae and Lethrinidae at different distances offshore in the central Great Barrier Reef. *Env. Biol. Fishes*, **46:** (2) 123-138.

OECD (1997) Towards sustainable fisheries: economic aspects of the management of living marine resources. Organisation for economic co-operation and development,

Oliveira, V.S. (2000) Distribuição e abundancia relativa de peixes dermersais capturados com espinhel de fundo na plataforma externa e talude continental da costa nordeste do Brasil. MSc Thesis, Universidade Federal de Pernambuco, 86 pp.

Ould Dedah, S., Condrey, R.E. and Shaw, R.F. (1999) Conservative fit of the Schaeffer model for a multispecies fishery. *Fish. Res.*, **41:** (1) 155-168.

Paloheimo, J.E. (1980) Estimation of mortality rates in fish population. *Trans. Am. Fish. Soc.*, **109:** (1) 378-386.

Pascoe, S. (2000) Single species conservation in a multispecies fishery: the case if the Australian eastern gemfish. *Ecol. Econom.*, **32:** (1) 125-136.

Pascoe, S., Tamiz, M. and Jones, D. (1997) Multi-objective modelling of the UK fisheries of the English Channel. Proc. *IXth Conference of the European Association of Fisheries Economists*, France, 150-166.

Patterson III, W.F., Cowan Jr, J.H., Wilson, C.A. and Shipp, R.L. (2001) Age and growth of red snapper, *Lutjanus campechanus,* from an artificial reef area off Alabama in the norhtern Gulf of Mexico. *Fish. Bull.*, **99:** (1) 617-627.

Pauly, D. (1980a) On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 stocks. *J. Cons. int. Explor. Mer*, **39:** (1) 175-192.

Pauly, D. (1980b) *A selection of simple methods for the assessment of tropical fish stocks.* Food and Agriculture Organization of the United Nations, Rome, VII, 54 pp.

Pech, N. and Laloë, F. (1997) Use of Principal Component Analysis with Instrumental Variables (PCAIV) to analyse fisheries catch data. *ICES J. Mar. Sci.*, **54:** (1) 32-47.

Pech, N., Samba, A., Drapeau, L., Sabatier, R. and Laloë, F. (2001) Fitting a model of flexible multifleet–multispecies fisheries to Senegalese artisanal fishery data. *Aquat. Living. Resour.*, **14:** (1) 81-98.

Pella, J.J. and Tomlinson, P.K. (1969) A generalized stock production model. *Bull. Inter-Am. Trop. Tuna Comm.*, (13) 419-496.

Pelletier, D. and Ferraris, J. (2000) A multivariate approach for defining fishing tactics from commercial catch and effort data. *Can. J. Fish. Aquat. Sci.*, **57:** (1) 51-65.

Penhorn, L.J. (1999) View point: a demersal fishing industry management perspective of risk. *ICES J. Mar. Sci.*, **56:** (1) 1070-1072.

Pikitch, E.K. (1988) Objectives for biologically and technically interrelated fisheries. *In Fisheries science and management: Objectives and limitations.* W.S. Wooster, ed. New York, 28, 107-136.

Pitcher, T., Mackinson, S., Vasconcellos, M., Nøttestad, L. and Preikshot, D. (1998) Rapid appraisal of the status of fisheries for small pelagics using multivariate, multidisciplinarity ordination. Proc. *Fishery Stock assessment models*, 759-782.

Pitcher, T.J. and Preikshot, D. (2001) RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. *Fish. Res.*, **49:** (3) 255-270.

Polovina, J.J. and Ralston, S. (1987) *Tropical snappers and groupers: biology and fisheries management.* Westview press, Boulder, USA, 659 pp.

Polunin, N.V.C. and Roberts, C.M. (1996) *Reef fisheries.* Chapman and Hall, London, 477 pp.

Pope, J.G. (1972) An investigation of the accuracy of virtual population analysis using cohort analysis. *Res. Bull. ICNAF*, **9:** 65-74.

Prager, M.H. (2003) Reply to the Letter to the Editor by Maunder. *Fish. Res.*, **61:** (1) 151-154.

Preikshot, D. and Pauly, D. (1998) Multivariate interdisciplinary assessment of small-scale tropical fisheries. Proc. *Fishery stock assessment models*, 803-814.

Ralston, S. and Polovina, J.J. (1982) A multispecies analysis of the commercial deep-sea hand-line fishery in Hawaii. *Fish. Bull.*, **80:** (3) 435-448.

Reis, E.G. (1992) An assessment of the exploitation of the white croaker *Micropogonias furnieri* (Pisces, Scianidae) by the artisanal and industrial fisheries in coastal waters of southern Brazil. Ph. D., University of East Anglia.

Restrepo, V.R., Powers, J.E. and Turner., S.C. (1990) Incorporating uncertainty in VPA via simulation. ICCAT, SCRS/90/28, 355-361 pp.

Rettig, R.B. (1987) Bioeconomic models: do they really help fishery managers? *Trans. Am. Fish. Soc.*, **116:** (1) 405-411.

Rex, M.A. and Etter, R.J. (1998) Bathymetric patterns of body size: implications for deep-sea biodiversity. *Deep-Sea Research Part II -Topical Studies in Oceanography*, **45:** (1-3) 103-127.

Rezende, S.M. (1999) Idade e crescimento do dentão, *Lutjanus jocu* (Bloch & Schneider 1801) (Pisces Teleostei: Lutjanidae) na costa nordeste do Brasil. MSc Thesis, Universidade Federal de Pernambuco, 104 pp.

Rezende, S.M. and Ferreira, B.P. (*in press*) Age, growth and mortality of dog snapper *Lutjanus jocu* (Bloch & Schneider 1801) in the northeast coast of Brazil. *Braz. Jour. Oceanogr.*

Rezende, S.M., Ferreira, B.P. and Frédou, T. (2003) A pesca de lutjanídeos no nordeste do Brasil: histórico das pescarias, características das espécies e relevância para o manejo. *Bol. Téc. Cient. CEPENE*, **11:** (1) 1-17.

RFSAP - Reef Fish Stock Assessment Panel- (1999) September 1999 Report of the Reef Fish Stock Assessment Panel. NOAA, Gulf of Mexico Fishery Management Council, 29 pp.

Rice, J.C. (2000) Evaluating fishery impacts using metrics of community structure. *ICES J. Mar. Sci.*, **57:** (3) 682-688.

Ricker, W.E. (1975) Stock and recruitment. *J. Fish. Res. Bd. Can.*, **191**

Rikhter, V.A. and Evanov, V.N. (1976) On one of the approaches to estimation of natural mortality of fish population. ICNAF, Res. Doc., 76/VI/8, 12 pp.

Roberts, C.M. (1996) Settlement and beyond: population regulation and community structure of reef fishes. *In Reef fisheries.* N.V.C. Polunin & C.M. Roberts, eds., Chapman and Hall, London, 20, 85-112.

Rocha, L.A. (2003) Patterns of distribution and processes of speciation in Brazilian reef fishes. *J. Biogeogr.*, **30:** (1) 1161-1171.

Rocha-Olivares, A. (1998) Age, growth, mortality, and population characteristics of the Pacific red snapper, *Lutjanus peru*, off the southeast coast of Baja California, Mexico. *Fish. Bull.*, **96:** (3) 562-574.

Romesburg, H.C. (1984) *Cluster analysis for researchers.* R. E. Krieger Publishing Company, Malabar, Florida, 334 pp.

Rooker, J.R. (1995) Feeding ecology of the schoolmaster snapper, *Lutjanus apodus* (Walbaum), from southwestern Puerto Rico. *Bull. Mar. Sci.*, **56:** (3) 881-894.

Russ, G.R. (1991) Coral reef fisheries: effects and yields. *In The Ecology of Fishes on Coral reefs.* P.F. Sale, ed. Academic Press, San Diego, 601-635.

Sadovy, Y.J. (1996) Reproduction of reef fishery species. *In Reef fisheries.* N.V.C. Polunin and C.M. Roberts, eds. Fish and fisheries, Chapman & Hall, London, 15-59.

Sale, P.F. (1980) The ecology of fishes on coral reefs. *Oceanogr. Mar. Biol. Ann. Rev.*, **18:** (1) 367-421.

Samoilys, M.A. and Carlos, G. (2000) Determining methods of underwater visual census for estimating the abundance of coral reef fishes. *Env. Biol. Fishes*, (57) 289-304.

Santa Maria, A. and Chavez, E.A. (1999) Fishery evaluation: *Lutjanus peru* (Pisces : Lutjanidae) from Guerrero, Mexico. *Rev. Biol. Trop.*, **47:** (3) 571-580.

Santos, S. (2001) Caracteristicas da pesca no nordeste, utilizando analise multivariada. MSc Thesis, Universidade Federal Rural Pernambuco, 77 pp.

SCBD (2004) Technical advice on the establishment and management of a national system of marine and coastal protected areas, Montreal, Canada, 40pp.

Schaefer, M.B. (1954) Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bull. Inter-Am. Trop. Tuna Comm.*, (2) 247-285.

Schmid, C., Schäfer, H., Podestá, G. and Zenk, W. (1995) The Vitória Eddy and its relation to the Brazil Current. *J. Phys. Oceanogr.*, **25:** (11) 2532-2546.

Shulman, M.J. (1984) Resource limitation and recruitment patterns in a coral reef fish assemblage. *J. Exp. Mar. Biol. Ecol.*, **74:** 85-109.

Smith, C.L. (1997) *National Audubon Society field guide to tropical marine fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda.* Alfred A. Knopf, New York, 720 pp.

Sokal, R.R. and Rohlf, F.J. (1995) *Biometry.* Freeman and Co., New York, 850 pp.

Sparre, P. and Venema, S.C. (1998) Introduction to tropical fish stock assessment Part I: Manual. FAO,FAO Fisheries Technical Paper, 306.1 Rev. 2, 407 pp.

Spix, J.B.v. and Martius, C.F.P. (1828) Reise in Brasilien. *In Gedruckt bei M. Lindauer.* Municha, Book II, 795-799.

Stergiou, K.I., Moutopoulos, D.K. and Erzini, K. (2002) Gill net and longlines fisheries in Cyclades waters (Aegean Sea): species composition and gear competition. *Fish. Res.*, **57:** (1) 25-37.

St-John, J. (1999) Ontogenetic changes in the diet of the coral reef grouper *Plectropomus leopardus* (Serranidae): patterns in taxa, size and habitat of prey. *Mar. Ecol. Prog. Ser.*, **180:** (1) 233-246.

Stramma, L. (1991) Geostrophic transport of the South Equatorial Current in the Atlantic. *Mar. Res.*, **49:** (1) 281-294.

Stuhr, A. (1996) Phytoplankton production measurements. *In Sedimentation processes and productivity in the continental shelf waters off east and Northeast Brazil. Cruise report and first results of the Brazilian German project JOPS-II (Joint Oceanographic Projects).* W.E.B.A. Knoppers, ed. Center for Tropical Marine Ecology, Bremen, 83-85.

Teixeira, S.F. (1998) Aspectos da Pesca e Reprodução do sirigado Mycteroperca bonaci Poey 1860 (Serranidae: Epinephelinae) no Nordeste do Brasil. M.Sc., Universidade Federal de Pernambuco,

Thompson, W.F. and Bell, F.H. (1934) Biological statistics of the Pacific halibut fishery. Effect of changes in intensity upon total yield and yield per unit of gear. Rep. Int. Fish. (Pacific halibut) Comm., 8, 49 pp.

Uiblein, F. (1991) Ontogenic shifts in resource use and shoaling tendency related to body size in Red Sea goatfish (*Parupeneus forsskali*, Mullidae). *Mar. Ecol. Pubbl. Stn. Zool. Napoli*, **12:** (2) 153-161.

Ulrich, C., Gascuel, D., Dunn, M.R., Le Gallic, B. and Dintheer, C. (2001) Estimation of technical interaction due to competition for resource in a mixed-species fishery, and the typology of fleets and métiers in the English Channel. *Aquat. Living. Resour.*, **14:** (1) 267-281.

Ulrich, C., Le Gallic, B., Dunn, M.R. and Gascuel, D. (2002) A multi-species multi-fleet bioeconomic simulation model for the English Channel artisanal fisheries. *Fish. Res.*, **58:** (1) 379-401.

von Bertalanffy, L. (1938) A quantitative theory of organic growth. In quires on growth laws. *Hum. Biol.*, **10:** (1) 181-213.

Walford, L.A. (1946) A new graphic method of describing the growth of animals. *Biol. Bull. Mar. Biol. Lab. Woods Hole*, **90:** (1) 141-147.

Walters, C.J. and Hilborn, R. (1976) Adaptative control of fishing systems. *J. Fish. Res. Bd. Can.*, (33) 145-159.

Willis, T.J. and Anderson, M.J. (2003) Structure of cryptic reef fish assemblages: relationships with habitat characteristics and predator density. *Mar. Ecol. Prog. Ser.*, **257:** (1) 209 - 221.

Wilson, C.A. and Nieland, D.L. (2001) Age and growth of red snapper, *Lutjanus campechanus,* from the northern Gulf of Mexico off Louisiana. *Fish. Bull.*, **99:** (1) 653-664.

Appendix

Appendix 1 : Publications derived from this study

Bathymetric trends of Northeastern Brazilian snappers (Pisces, Lutjanidae): Implications for the reef fishery dynamic

Thierry Frédou [1,2,3], Beatrice Padovani Ferreira[1]
[1]*Departamento de Oceanografia, Universidade Federal de Pernambuco, Recife, Pernambuco 50739-540 Brazil.*
[2]*Université de la Méditerranée, Centre d'Océanologie de Marseille, UMR CNRS 6540, 13288 Marseille cedex 9, France.*
[2]*Present address: Centro de Geociências, Universidade Federal do Pará, Campus Universitário do Guamá, Belém, Pará 66075-110 Brazil*

ABSTRACT
The investigation of bathymetric distribution of five snappers caught along the Brazilian Northeastern coast by artisanal fleets through the analysis of the catch composition and relative abundance (CPUE) showed that, on the overall, fished mean size increased along depth and that particular species dominated the catch according to the depth strata. Mutton snapper, L. analis*, yellowtail snapper,* L. chrysurus*, and dog snapper,* L. jocu *were mainly caught at intermediate depth (20-80m) whereas lane snapper,* L. synagris*, and silk snapper,* L. vivanus*, inhabit respectively shallow (<20m) and deep (>80 m) waters. Each fleet category, exploit preferentially a particular combination of species and their size range. The fleet dynamic of the Northeast Brazil is technologically heterogeneous and determines the catch composition. Geographical distribution of the fishery and technical interaction between fleets and gears should be considered by the management of these species in order to maintain the sustainability of the stock and to guarantee the continuance of the resource.*
Keywords: Fish distribution, technological interaction, artisanal fishery, Lutjanids, reefs

INTRODUCTION

The abundance of marine species fluctuates in space and time. Such fluctuations may be due to physical (currents, temperature, etc.), or biological processes (as growth and mortality) as well as behavioural processes (migration, habitat use) (Jennings *et al.*, 2001). Various studies have been conducted on spatial and/or temporal distribution of reef fish communities, as size dependent processes have long been recognised as important for the community structure and resources (Sale, 1980; Gobert, 1994).

Fishes are an important component of reef environment as they influence the structure of the communities through predation, competition, and territoriality processes (Sale, 1980). The complexity of the interaction on the reef ecosystem turns study on fishing effect rather difficult (Jennings & Polunin, 1995; Polunin & Roberts, 1996). In Brazil, various species are exploited by fishermen mostly using hook and line, gill nets and traps. Reef fisheries, which operate mainly in the northeastern, have an important role in the socio-economic life of the region (Ferreira & Maida, 2001). However, very little is known on the fisheries dynamics operating in this area and their effects on reef fish communities.

It is rather common to observe size distribution according to depth for reef fishes (MacPherson & Duarte, 1991; Hilborn & Walters, 1992). Considering the fishery activity, a common pattern observed for target species is the increase of the number of large specimens in the catches with increasing depth (Roberts, 1996). This pattern has been attributed to two main natural processes: ontogenetic migrations from coastal reefs to the external part of the shelf or depth related growth and mortality rates. While migration may be related to availability of suitable prey for juvenile fish or predation avoidance (Roberts, 1996), differential growth and mortality may be related to environmental factors. Temperature variation according to the depth gradient leads to variation in basal metabolism rates and therefore may alter the growth rate (Longhurst & Pauly, 1987). Determining the natural pattern of distribution is specially important for species that are targeted by fisheries, as the effects of fishing in a population may also be extended to population parameters.

Coral reef formations in Brazil extend for approximately 3000 km along the Northeastern

Corresponding author: Thierry Frédou E-mail: tfredou@no-log.org

coast (Maida & Ferreira, 1997). They are constituted by organic substrates built with coral, algae and mollusc skeletons. The continental shelf varies from 45 to 60 km wide in Ceará and Rio Grande do Norte, then becomes relatively narrow in Pernambuco coasts, to wide again in the south of Bahia, reaching 200 km (Maida & Ferreira, 1997). Brazilian reef fishes are intensively exploited by artisanal fisheries that concentrate on the reef formations distributed along the continental shelf up to the continental slope and over oceanic banks (Ferreira *et al.*, 1998; Ferreira & Maida, 2001).

In the Northeast Brazil, reef fishes represent 46 % (of which lutjanids represent 20%) of the total catch of the main target species in weight (total catch: 26171 tonnes). The 54% remaining is constituted by the pelagic and the deep-sea demersal fauna (Estatpesca, 2000). During the end of the 60's, the 70's, 80's, 90's and the beginning of 2000's, lutjanids' catches in the Northeast Brazil ranged between 34%, 11341 tonnes during the 60's, and 43%, 77422 tonnes during the 80's. During the 60´s and 70´s, the most valuable and most frequently caught species in Northeast Brazil were the red snapper, *Lutjanus purpureus (Poey 1866)*, and in minor proportions, *L. analis*. From 1978 with the collapse of the red snapper fishery, others species as *L. jocu*, *L. chrysurus*, and more recently, *L. synagris*, constitute the major part of the lutjanids catch in Northeast Brazil (65%) (SUDEPE, 1967-1979; IBGE, 1980-1989; IBAMA, 190-2001)[1].

According to Ferreira *et al.* (2001), fisheries in Brazilian reefs may be divided into two types. First, the activity of recreational and artisanal scale fishermen occurs nearby the coast in shallow waters and reefs formations. Fishing point may be reached by swimming or using rowing or sailing canoes. Secondly, the medium scale commercial fisheries that operates by the coastal part of the shelf, using sailing or motorised boats that reach deeper waters as far as the shelf break. Only motorised boats, that may operate also on the banks far from the coast, have storing capacity (Ferreira & Maida, 2001). Along the Northeastern coast, snappers represent one of the main resources in terms of abundance and fishermen´s income (Santos, 2001). Generally demersal, the snappers are tropical and sub tropical fishes that are distributed on reefs down to depths about 450 m (Allen, 1985; Polovina & Ralston, 1987). Top predators, they consume a broad range of prey generally dominated by fish. They show low growth and natural mortality rates (Manooch, 1987). Snappers produce eggs with pelagic dispersion (Grimes, 1987).

Our study focused on five species of *Lutjanus*, which inhabit coastal to deep demersal waters. The main species caught by the artisanal fishery in Northeast of Brazil were looked at: the mutton snapper *L. analis* (Cuvier, 1828), the yellowtail snapper *L. chrysurus* (Bloch, 1791), the dog snapper *L. jocu* (Bloch and Schneider, 1801), the lane snapper *L. synagris* (Linnaeus, 1758) and the silk snapper *L. vivanus* (Cuvier, 1828). The distribution and relative abundance of these species along a depth gradient, across the Northeast Brazil continental shelf and upper slope was described. The effects of the reef fishery on distribution, size of fish and CPUE of snappers considering the relationship between the species distribution and the dynamics of the fleets (gear used, fleet category and operating area) were also discussed.

MATERIAL AND METHODS

Study site and data collection

Most of the data for this study was collected as part of a national programme called REVIZEE (Evaluation of the Potential of the Live Resources from Brazilian Exclusive Economic Zone), which was established in 1996 in order to provide information on the biology and fishery of its main resources. Another programme "Projeto Recifes Costeiros" complemented the dataset available on the artisanal fishery in Pernambuco. A comparative analysis was applied to the reef fisheries distributed over 2000 km of coast encompassing five Brazilian states (Ceará, Rio Grande do Norte, Pernambuco, Alagoas and Bahia) through a five-year sampling programme. It was gathered information regarding the fishing tactics (fishing area, gear used, target groups, etc) and catch composition of fleet operating in the region.

Data were collected from August 1996 to March 2000. Species were identified and

[1] Brazilian fisheries statistic: Superintendência do Desenvolvimento da Pesca (SUDEPE), 1967-1979; Instituto Brasileiro de Geografia e Estatística (IBGE), 1980-1989; Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis IBAMA, 1990-2001.

measured *in situ* (fork length FL). The landings sites were chosen in order to get a representative picture of the catch composition in the region. Sites were localised over the five states cited above. In addition, some data were collected from research vessels that operated on the banks and oceanic islands (Atol das Rocas and Arquipélago de São Pedro e São Paulo) off the Rio Grande do Norte coast.

Fishermen were interviewed and information regarding the operation within the fishery and catch were collected. Within the REVIZEE framework, more than 69 000 records of fishes supplied by 2400 trips were gathered. For this study, nearly 22 000 fishes, which had information on depth, were considered amongst the 5 species of *Lutjanus* (Table 1).

Table 1: Number of four lutjanid species sampled from august 1996 to March 2000 with information on depth by states.

Species	*Ceará*	*Rio Grande do Norte*	*Pernambuco*	*Alagoas*	*Bahia*	**Total**
L. analis	392	178	977	103	1320	2970
L. chrysurus	2578	400	1092	93	5618	9781
L. jocu	750	79	394	142	989	2354
L. synagris	2271	534	1770	13	489	5077
L. vivanus	130	252	183	42	1090	1697
Total	6121	1443	4416	393	9506	21879

Information on specific landings and effort (number of boats) by fleet category were collected for the studied period by the program 'ESTATPESCA' held by the Brazilian Environmental Agency for official statistics (IBAMA, *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renovaveis*). The reef fishery can be distributed into five categories of fleets classified as following, from the most rudimental to the most technically advanced fleet: "Paquete" (PQT), "Jangada" (JAN), "Bote a vela" (BOV), "Bote" (BOT), "Bote motorizado" (BOM) (see table 2 for details). In addition, historical landings were compiled for the period from 1967 to 2001 by various governmental organisations: the Brazilian Institute for Geography and Statistics (IBGE, *Instituto Brasileiro de Geografia e Estatística*), the Research Centre for Northeastern Fisheries (CEPENE, *Centro de Pesquisa e Extensão Pesqueira do Nordeste*), and the Superintendence for the Fishing Development (SUDEPE, *Superintendência para o Desenvolvimento da Pesca*).

Data analysis

The relationship between depth and fish size was assessed by correlation and regression analyses. The correlation analysis was used to test the statistical significance of the relationship for each species. The correlation between depth and size was determined for all species using non-parametric Spearman's rank correlation coefficient. The regression analysis was performed using the Kendall's robust line-fit method (1995). Kendall's rank correlation was used in order to test whether the slope (β) for each species was different from zero.

Catches were analysed by gear, which were arranged amongst the following categories: line, net and trap. Minimum, maximum and average values of fish size were analysed by gear in order to describe the gear effects on the life history of the species. For each species, catches were also analysed by sampled year and fleet category. Catch-per-unit-effort (CPUE) was used as an index of relative abundance. The catch was defined in two different ways: (1) by using total weight (kg) caught by species and (2) by using number of individuals caught. Furthermore, in order to standardise the effort between gears, the time (days) spent at sea for each trip was chosen as the best estimate. In spite of the roughness of the unit of effort, catch and effort for each species were positively correlated (Spearman's correlation $r = 0.5$, $p < 0.001$). The CPUE analysis was carried out by species considering the following depth strata: < 20m (inner shelf), 20 to 80m (outer shelf), and >80m (slope) (Mabesoone & Coutinho, 1970). The Kruskal and Wallis non-parametric test was used to test the differences of the CPUE index between depth strata as well as differences between fleet category. We also looked at CPUE versus depth strata relationship using Spearman's rank correlation analysis.

Table 2: Fleet category description.

Fleet type	*Code*	*Depth range (m)* *25% - median - 75%*	*Description*
Paquete	PQT	8 - 12 - 24	Sail, wood-made, flat shell without keel nor cabin Size<6m, no storing capacity
Jangada	JAN	14 - 30 - 42	Sail, wood-made, flat shell without keel nor cabin storing capacity (isotherm box)
Bote à vela	BOV	43 - 73.5 - 96	Sail, cabin, storing capacity size<15m storing capacity, ice
Bote motorizado	BOM	41 - 52.5 - 93	Motorised, cabin, storing capacity size<15m storing capacity, ice
Bote	BOT	82 - 93 - 115	Sail and motor facilities, cabin, storing capacity size<15m storing capacity, ice

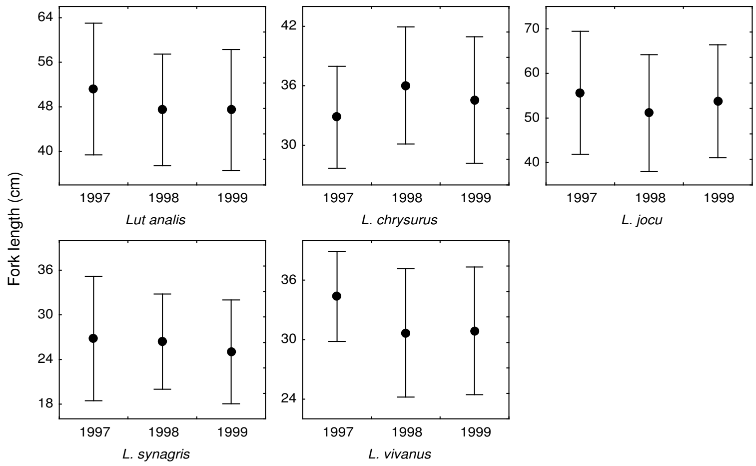


Figure 1: Mean size (cm) of each species exploited along the Northeastern coast during the studied period. Bars indicate standard errors of means.

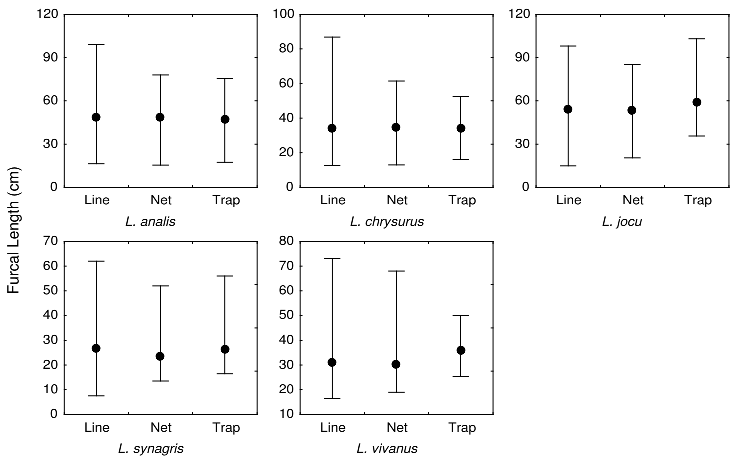


Figure 2: Mean size (cm) of the five main snapper species caught by the three main gear categories (Line, Net and Trap). Bars indicate full range.

RESULTS

Catch composition of Lutjanus species by year, gear and depth

Depth versus body size relationships was assessed for five Lutjanids: *L. analis*, *L. chrysurus, L. jocu*, *L. synagris*, *and L. vivanus*. The relationship between depth and fish size for the five species was assessed using Spearman's rank correlation and Kendall's robust line-fit. All five species showed a positive and significant correlation between the fork length and the depth (Table 3).

Considering all gears pooled together, the fish size caught ranged for snappers from 7.5 to 103.0 cm FL. Mean fork length showed a decreasing trend for *L. synagris L. analis, L. vivanus* ($p<0.05$) and for *L. jocu* (although non significant), conversely *L. chrysurus* showed a significant ($p<0.05$) increasing trend (Fig 1).

Line fishery caught snappers from 7.5 to 99 cm FL, while nets caught individuals from 13 to 85 cm FL and traps caught individuals from 16 to 103 cm FL. Analysing the catch composition by species, every gear affected almost the entire size range of the snapper populations, however traps were found the most selective for *L. chrysurus* and *L. vivanus* (Fig 2). The fork length of snappers caught by all the three gears increased according to depth until a maximum at 60 m (Table 4). The operating depth range was deeper for line and shallower for net and traps (Table 5a). Paired gear groups were tested using the Mann-Whitney U procedure. Line depth operation was significantly different from Net and Trap ($p<0.001$), while no difference could be distinguished between Net and traps. Lines, nets and traps caught, in average, individuals of similar size range for all species. Fishermen using hook and line operated preferentially between 40 and 60 m. Users of net occurred rather equally through the depth gradient with a peak between 0 and 20 m and, traps were set up preferentially within the 20-40 m (5b). Largest specimens of each species were caught at deeper limits of the species range. As a general pattern, small individuals were exclusive to shallow waters and larger ones to deeper waters; an intermediate zone presented a mixed sized fishes (Fig 3).

Catch per unit of effort (CPUE) versus depth relationship

Although snappers have a wide range of distribution, differences between species were detected. The maximum relative abundance (numerical and biomass CPUE) of the *Lutjanus* species varied according to depth. *L. synagris* and *L. vivanus* were more abundant at the extremes of the snappers distribution range: shallower and deeper waters respectively. The three other species (*L. analis*, *L. chrysurus*, and *L. jocu*) showed a smoother distribution with a maximum abundance reported in the 20 – 80 m depth strata - outer shelf part (Table 6a and 6b). The relationship between the numerical CPUE (individuals caught per day at sea) and the depth was negatively correlated for *L. synagris, L. jocu, L. chrysurus, and L. analis*. *L. vivanus* presented a non-significant positive relationship (Table 7a), while the relationship between the depth and the CPUE in kg per day at sea was negative for *L. synagris*, positive for *L. analis* and *L. vivanus*, and non significant for *L. chrysurus* and *L. jocu* (table 7b).

Fleets mostly operated between 40 and 60 m (25% of the total number of trips)(Table 8), where the major part of Lutjanids stocks are located, affecting mainly the adults of *L. analis* and *L. jocu* (> 30 cm FL) and, both juveniles (< 23 cm FL) and adults of *L. chrysurus* (Fig 3). The depth stratum 20-40 m concentrated 20% of trips, which influenced young adults (> 30 cm) of *L. jocu*, and both juveniles and young adults of *L. synagris* and *L. chrysurus*.

Table 3: Spearman's rank correlation coefficients (r) and slope (β) between depth and fish size. **Note**: n is the number of specimen measured for each species, n1 is the total number of two point slopes, n2 is the number of slope randomly sampled used to estimate β (median of the β's of each two points slope). See robust line-fit for method (Sokal and Rohlf, 1995).

Species	*r*	*p-levels*	*n*	*β*	*p-levels*	*n1*	*n2*
L. analis	0.40	p<0.001	3526	0.217	p<0.001	6214575	7515
L. chrysurus	0.29	p<0.001	9957	0.071	p<0.001	49565946	7354
L. jocu	0.18	p<0.001	2521	0.089	p<0.001	3176460	7540
L. synagris	0.35	p<0.001	5136	0.138	p<0.001	13186680	7723
L. vivanus	0.13	p<0.001	1719	0.023	p<0.001	1476621	6993

Table 4: Mean fork length of the five snappers (*L. analis, L. chrysurus, L. jocu, L. synagris, L. vivanus*) by gear and depth layer.

Depth (m)	*Line*	*Net*	*Trap*	*All*
0-20	23.4	22.1	27.3	23.1
20-40	32.2	30.7	30.9	31.9
40-60	40.2	37.6	45.4	39.8
60-80	39.2	42.0	40.7	39.5
>80	39.8	37.8	38.2	39.3

Table 5: (5a) Median and quartile of depth of operation for each gear. (5b) Proportion of gear used by depth layers.

(5a)

Gear	*Median*	*Quartile 25%*	*Quartile 75%*
Line	43.5	27	63
Net	34	12.6	52.5
Trap	36	27	44.3

(5b)

Depth (m)	*Line*	*Net*	*Trap*	*All*
0-20	25.1%	40.3%	24.6%	28.1%
20-40	21.1%	20.7%	35.4%	21.7%
40-60	25.3%	21.0%	23.1%	24.4%
60-80	6.7%	3.9%	1.5%	5.9%
>80	21.8%	14.1%	15.4%	19.9%
Total	100%	100%	100%	100%

Table 6: (6a) Mean biomass CPUE (kg/time at sea) by species and depth strata. (6b) Mean numerical CPUE (Number of individuals/time at sea) by species and depth strata.

(6a)

Depth	*All*	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*
<20	6.0	1.6	3.5	1.2	**6.5**	--
20-80	**10.8**	**2.1**	**8.5**	**2.1**	5.3	2.8
>80	6.9	1.2	8.0	1.1	1.7	**3.9**

(6b)

Depth	*All*	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*
<20	1.7	1.0	0.5	0.3	**1.8**	--
20-80	**12.6**	**9.6**	**4.8**	**5.2**	1.4	1.4
>80	8.6	4.6	5.1	3.6	0.5	**2.2**

Table 7: Spearman's rank correlation coefficients, probability and sample size (n) of the relationship between depth and CPUE (bold and underlined coefficients are significant at 5%). (7a) numerical CPUE, (7b) biomass CPUE.

(7a)

Species	*r*	*p-level*	*n*
All	**-0.06**	0.029	1227
L. analis	**-0.19**	<0.001	597
L. chrysurus	**-0.16**	<0.001	567
L. jocu	**-0.27**	<0.001	518
L. synagris	**-0.27**	<0.001	614
L. vivanus	0.13	0.153	132

(7b)

Species	*r*	*p-level*	*n*
All	**0.45**	<0.001	1224
L. analis	**0.09**	0.025	594
L. chrysurus	0.03	0.467	567
L. jocu	-0.05	0.284	518
L. synagris	**-0.12**	0.003	614
L. vivanus	**0.21**	0.018	132

Table 8: Effort allocation in number of trips by depth layer by fleet category. PQT: 'paquete', JAN: 'jangada', BOV: 'sailing boat', BOT: 'mixed propulsion', BOM: 'motorised boat' Total n: 1767 trips.

Depth	*PQT*	*JAN*	*BOV*	*BOT*	*BOM*	**Total**
0-20	13.5%	11.7%	0.1%	0.1%	1.8%	27.2%
20-40	1.8%	8.1%	0.6%	--	9.8%	20.4%
40-60	0.3%	5.8%	0.5%	0.1%	18.4%	25.1%
60-80	0.2%	1.7%	0.7%	0.2%	3.1%	5.8%
>80	--	0.7%	1.5%	1.4%	17.9%	21.6%
Total	15.79%	28.07%	3.40%	1.75%	50.99%	100%

Table 9: Proportion of the main fleet categories that exploit the five lutjanids species studied.

Species	*BOM*	*BOT*	*BOV*	*JAN*	*PQT*	**Total**
L. analis	88.5%	3.8%	2.2%	4.1%	1.4%	100%
L. chrysurus	91.4%	0.3%	1.1%	6.7%	0.5%	100%
L. jocu	81.7%	1.9%	0.6%	15.5%	0.3%	100%
L. synagris	49.0%	0.2%	8.2%	27.8%	14.8%	100%
L. vivanus	89.5%	1.4%	6.5%	0.8%	1.9%	100%
Total	84.2%	1.1%	2.5%	9.6%	2.6%	100%

Table 10: Kruskal-Wallis ANOVA by ranks between relative abundances by fleet category. (ns):non significant

	Biomass CPUE (kg/time at		Numerical CPUE (nb/time at sea)
Species	*n*	*p*	*p*
L. analis	594	<0.001	<0.001
L. chrysurus	567	<0.001	0.384(ns)
L. jocu	518	<0.001	0.005
L. synagris	615	0.007	<0.001
L. vivanus	132	0.024	0.279(ns)
All	1224	<0.001	<0.001

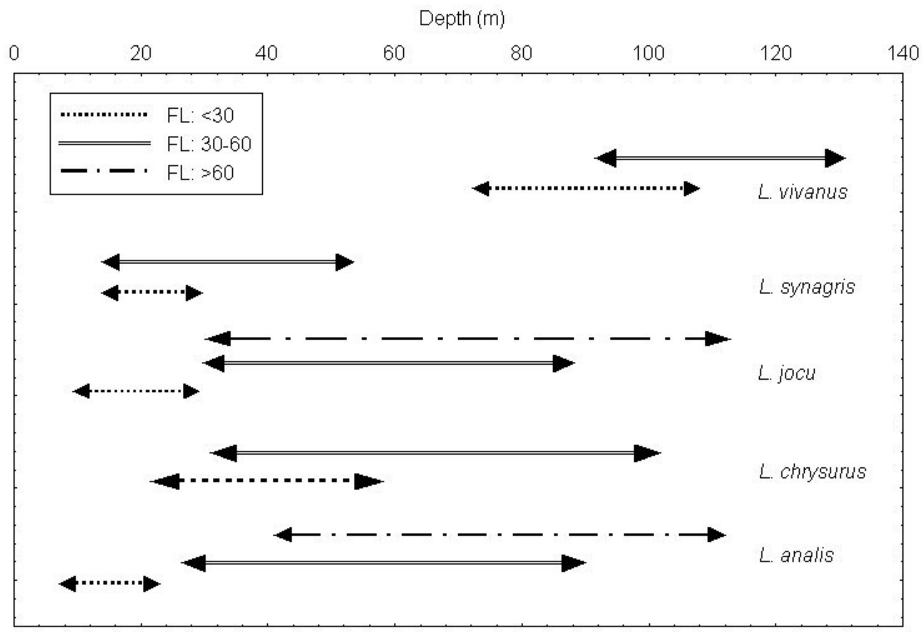


Figure 3: Size distribution (cm) of the five *Lutjanus* species (FL= fork length) according to the depth in the studied area.

Fleet interactions and catch composition of Lutjanus species by fleet

Motorised boats "Botes Motorizados" (BOM) and wind motioned "jangadas" (JAN) were the most important fleet categories with respectively 28% and 51% of the total number of trips during the studied period along the northeastern coast (Table 8). Motorised boats operated mostly from 20 m towards offshore (over 80 m deep) whilst "jangadas" fished from the coast up to 60 m deep. Sailing boats (BOV) and mixed boats (BOT) represented 5% of the total number of trips with an operation range mostly above 80 m. "Paquetes" represented 15% of the total number of trips and operated mainly from the coast up to 20 m deep.

The snappers' catch composition (Table 9) shows that motorised boats (BOM) fished on the five studied species. However, *L. synagris*, that inhabits shallower waters, was less affected by motorised boats but it was the main target of the wind propelled "paquetes" and "jangadas". Conversely, *L. vivanus,* which inhabits deeper waters, was targeted almost exclusively by motorised boats. The remaining species were caught by all categories. As fishing activity was greater at shallow (<20 m) and intermediate depth (40 to 60 m), where rudimental fleet and more advanced technologically fleets overlap, fishery in Northeast of Brazil affects mainly species that inhabits preferably this depth layer (*L. analis*, *L. jocu* and *L. chrysurus*).

Differences between relative abundance and fleet category were significant for all species when the biomass CPUE was considered and for three species *L. analis, L. jocu and L. synagris* when numerical CPUE was analysed (Table 10).

The "jangadas" (JAN) fleet category was the most numerous fleet in activity along the northeastern coast, from Ceará to Alagoas (53% of total operating boats) (Table 11), followed by the motorised boats category (BOM) with 22.4% of the total fleet. However, although motorised boats were less numerous, their fishing power was greater than "jangada's" ones and, landings of motorised boats (BOM) and "jangadas" equally represented 27% of the *Lutjanus* catches recorded by the Brazilian official statistics during the period from 1997 to 2001 (estatpesca). Motorised boats (BOM) and sailing boats (BOV) showed the greater yield considering the biomass, CPUE and the numerical CPUE. BOM yielded 13.7 and BOV 9.6 kg / days spent at sea whilst "jangadas" yielded 6.1 kg/ days (Table 12a and 12b).

Trip duration, days spent at sea, was different amongst fleet categories and states (Table 13). While small fleets, "paquetes" and "jangadas", spent at sea no more than two days, more sophisticated fleets trip duration (BOM, BOV) could reach 12 days at sea. However it is recorded differences between states. "Jangadas" from Ceará and Rio Grande do Norte spent, in average, 2 days at sea whilst, in Pernambuco, trip was restricted to a day. Motorised boats (BOM) time at sea ranged from 1 - 2 days in Bahia to 4 - 5 days in Pernambuco, Alagoas and Rio Grande do Norte. In Ceará trips of Motorised boats (BOM) may last up to 13 days .

Table 11: Boats in activity, registered by the national fishery statistic program by state along the Northeastern coast during the studied period. Averaged total number of boats in activity along the studied period:17000 boats.

Fleet	*Ceará*	*Rio Grande do Norte*	*Pernambuco*	*Alagoas*	*Bahia*	**Total**
PQT	11.2%	4%	--	--	0.8%	16%
JAN	10.6%	12.6%	10.9%	11.8%	6.8%	52.7%
BOV	2.7%	4.8%	--	1%	0.3%	8.9%
BOM	5%	6.1%	5%	3%	3.3%	22.4%
Total	29.5%	27.5%	15.9%	15.8%	11.2%	100%

Table 12: Relative abundance, catch per unit of effort ((10a) numerical CPUE, (10b) biomass CPUE), by fleet category for the five Lutjanids species.

(11a)

Fleet	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*	*All*
PQT	1.4	4.1	1.1	5.7	--	5.2
JAN	1.3	3.8	1.8	4.4	1.7	6.4
BOV	0.9	7.6	1.7	2.1	2.4	7.3
BOT	0.9	--	0.9	--	--	4.1
BOM	2.2	11.3	1.9	8	3.3	11.9

(11b)

Fleet	*L. analis*	*L. chrysurus*	*L. jocu*	*L. synagris*	*L. vivanus*	*All*
PQT	1.7	1.6	1.1	1.5	--	1.8
JAN	7.0	1.6	4.6	1.3	1.4	6.1
BOV	2.4	5.5	6.3	1.6	1.9	9.6
BOT	2.2	--	3.5	--	--	4.8
BOM	8.9	6.8	4.8	2.0	1.7	13.7

Table 13: Averaged time spent at sea (days/trips) by state and fleet category.

Fleet	Ceará	Rio Grande do Norte	Pernambuco	Alagoas	Bahia
PQT	1.3	1.8	1	--	--
JAN	2.2	2.3	1	--	--
BOV	11	1.8	--	--	--
BOT	--	2.9	--	--	--
BOM	12.7	3	4.5	4	1.7

DISCUSSION

Patterns of the relationship between body size and abundance in natural assemblage have been documented for a number of animal taxa (Gaston *et al.*, 1993). Also, in a fishery context, an increase of the number of large specimen with increasing depth is commonly observed (Roberts, 1996). Our results indicated that significant body size versus depth relationship has been observed for each species. Bathymetric distribution according to demersal fish size has been already reported (Lukens, 1981; MacPherson & Duarte, 1991). The relationships, examined in our study, showed a general trend going towards a greater size with increasing depth, such a result was also reported in various studies (Rooker, 1995; Machias *et al.*, 1998; Rex & Etter, 1998). However, the depth- body size relationship is weaker at intermediate depths due to a spatial overlap. Indeed, when small individuals are exclusive to shallow waters and only large ones are caught in deep waters, mixed catch of medium and large fishes is reported at intermediate depths. This movement may be related to feeding, and reproductive habits (Uiblein, 1991; MacPherson, 1998; St-John, 1999; Grutter, 2000; Carrasson & Matallanas, 2001).

Oliveira (2000) reported that maximum relative abundance (CPUE) of teleosts species on the external part of the shelf and the slope was observed within the depth strata of 100 – 150 m. In this study, the maximum abundance of four *Lutjanus* species (*L. vivanus* did not present a significant pattern) was negatively correlated with the increasing depth, when numerical CPUE was considered. However, the relationship changed when the biomass CPUE was considered. Individuals were caught in greater number in shallow waters but as most of them were small sized fishes, the relationship between CPUE index, considering weight, and depth showed a mixed pattern. Negative relationship of numerical CPUE was counterbalanced by the bathymetric distribution of lutjanids caught. Mean maximum relative abundance varied, for each species, from the shallow water layers with *L. synagris* to the deep water layers with *L. vivanus*. Several explanations have been offered to describe this pattern, including differential mortality or growth with depth or migration to deeper water with increasing size (Roberts, 1996). Ecological characteristics of shallow and deep waters may be responsible for such distribution. Shallow waters feature shelters for younger fish, they, generally, have a higher productivity and are inhabited by small preys that are also targeted by young, small sized fish. Alternatively, fishes that inhabit deep cool waters have their losses of energy reduced (Longhurst & Pauly, 1987), which allows them to store more energy so they are less susceptible to fluctuations in food supply (scarcer in deep waters) (Sogard, 1997). The maximum length reported for the *Lutjanus* species (*L. analis*: 94 cm FL, *L. chrysurus*: 87 cm FL, *L. jocu*: 128 cm FL, *L. synagris*: 60 cm FL, *L. vivanus*: 83 cm FL) (Allen, 1985) is similar to the maximum length registered for the Northeast Brazilian catches. For all species, juveniles were also caught. Hence, the three main operating fishing gears (traps, lines and gill nets) affect almost the entire range of the life history of the *Lutjanus* species. However, gears caught fishes of similar size for all species.

In a multispecific perspective, the fleet/gear comes into contact with stocks of different species, and a mixed catch result due to the exploitation of technologically interdependent species (Anderson, 1986). In such a context, the technological interactions is not only related to the selection of part of the stock but also with the selection of the species caught. Considering the species' distribution and the multispecific nature of the reef fishery in Northeast Brazil, fleet operation may vary from shallow to deep waters depending, amongst others factors (environmental conditions, motorised or wind motioned boats, shelf width, trade winds, etc), on the availability of a typical coastal species (as *L. synagris*) or a typical deeper-water species (as *L. vivanus*). Considering such stratified distribution, fleets with different operation capacities will affect stocks on different ways.

These differences may not necessarily related to gear (a boat in tropical fishery may carry more than one gear) but also to the fleet power, which is related to fleet category, and also to the state, due to its environmental characteristics. Fishing grounds, i.e. shallow or deep waters, will be reached according to fleet power. Factors as engine power, carrying capacity, presence or absence of ice are related to the distance to the shore and hence, the time at sea. Additionally, environmental conditions such as wind, rain, currents, or the continental shelf width may influence the access to shallow or deep fishing grounds.

Our results highlighted the fact that technological interactions, will affect the catch composition and therefore the fishing impact on snappers. All fleets categories mostly operated within the 40-60 m depth zone, what consequently affected mostly *L. analis*, *L. jocu* and *L. chrysurus.* Motorised boats (BOM) affected mainly *L. vivanus* because of its deeper waters fleet operation. “Jangadas” and “paquetes” had as their main target *L. synagris* since they operate in shallower waters.

Also, climatic, oceanographic or geographic characteristics as winds, currents or geomorphology of the shelf may influence the fleet operation and catch composition. For example, wind powered boats, “paquetes”, “jangadas”, sailing boats (BOV), in Ceará had a greater operating range, and therefore affect a greater number of species, due to the dominant winds (Trade winds) that allow the vessel to reach deeper waters.

Fleets are likely to exploit different stages of the life cycle of a fish community while operating in different geographical areas, in simultaneous or sequential harvesting (Charles & Reed, 1985). Fisheries of the same fish community are linked through their exploitation. To maintain the sustainability of the stock and to guarantee the continuance of the resource, the optimal fleet mix and catch allocation should be carefully considered (Kulbicki *et al.*, 2000; Labrosse *et al.*, 2000; Letourneur *et al.*, 2000; Lucena *et al.*, 2002).

The multifleet and multispecies nature of the northeastern Brazilian fisheries has various consequences in terms of resources management and ecological issues. In the study area, few marine protected areas (MPA) have been created along the coast as a part of a new management alternative of reef ecosystems (Ferreira, 2000). Some marine protected areas have been set parallel nearby the coast, mainly because of logistical reasons, i.e. zone easily accessible and that can be watched from the shore. This setting would only preserve part of the life cycle of some species, excluding other species. Due to the within and between fish species spatial structure, the MPA design will have consequences on its efficiency (Kramer & Chapman, 1999). In small reserves near the shore, snappers’ home range will exceed the MPA limits. Considering the reef fishery in Northeast Brazil, the MPA might be most efficient if set in direction to the off-shore in a attempt to protect the entire range of fish distribution and consequently the entire life cycle of the species. This could also offer some protection of various kind of habitats used by different stage of the life-cycle of each species.

Although we are aware that a dataset originated from commercial fisheries may only partially represent the fish community because of gear selectivity and fishing tactics, we may consider that variations in the effort and/or gear fishing power represent the actual trend in the fish distribution (fishermen go where the fish is). More attention should be given on technological interactions and multispecies aspects of the reef fishery in Northeast Brazil as stock assessment models for the management of single species fished by one type of gear (or fleet) may be inadequate to apply to the northeastern Brazilian fisheries and to predict changes at the assemblage level (Pikitch, 1988; Hilborn & Walters, 1992). The inter and intra-specific bathymetric distribution and the multifleet character of the Northeastern Brazilian reef fishery demonstrate that considering only one category of a fleet will likely bias our assessment on the real impact of fishing activities.

ACKNOWLEDGEMENT - This research is part of the ‘Programa Nacional de Avaliação do Potencial Sustentável dos Recursos vivos da Zona Econômica Exclusiva- REVIZEE’ funded by the Ministério do Meio Ambiente – MMA and the Secretaria da Comissão Interministerial para os Recursos do Mar – SECIRM. We thank André Vasconcelos, Kenia Cunha, Elton Nunes, Kátia Freire, Denis Hellebrandt, Marcelo Nóbrega, Moustapha Diedhiou, Roberto Kobayashi, Sergio

Rezende (DTI/CNPq), Simone Teixeira and several students involved in data collection. We particularly thank Yves Letourneur and Flávia Lucena for their helpful comments on earlier drafts.

RESUMO

A distribuição batimétrica de cinco espécies de peixes do Nordeste Brasileiro foi examinada através da análise da composição da captura e e abundância relativa (CPUE) mostrou que, de uma maneira geral, o comprimento furcal aumentou com a profundidade e que algumas espécies dominaram a captura de acordo com a faixa de profundidade. A cioba, L. analis*, a guaiúba,* L. chrysurus*, e o dentão,* L. jocu *foram principalmente pescados na zona intermediaria (20-80 m) enquanto ariocó,* L. synagris *e o pargo olho-de-vidro* L. vivanus *ocorreram respectivamente nas águas rasas e nas águas profundas. Cada tipo de embarcação do Nordeste do Brasil explota preferencialmente uma combinação particular de espécies e uma determinada amplitude de tamanho. A dinâmica da frota do nordeste do Brasil é tecnologicamente heterogênea e determina a composição da captura. A distribuição geográfica da pesca e a interação técnica entre as frotas e as artes de pesca devem ser consideradas pelo manejo destas espécies visando a manutenção dos estoques em bases sustentáveis e a garantia de continuidade do recurso.*

REFERENCES

Allen, G.R. (1985) *Snappers of the world. An annotated and illustrated catalogue of Lutjanid species known to date.* FAO, Roma, 208 pp.

Anderson, L.G. (1986) *The economics of fisheries management.* The Johns Hopkins University Press, London, 296 pp.

Carrasson, M. and Matallanas, J. (2001) Feeding ecology of the Mediterranean spiderfish, *Bathypterois mediterraneus* (Pisces: Chlorophthalmidae), on the western Mediterranean slope. *Fish. Bull.*, **99:** (2) 266-274.

Charles, A.T. and Reed, W.J. (1985) A bioeconomic analysis of sequential fisheries - competition, coexistence, and optimal harvest allocation between inshore and offshore fleets. *Can. J. Fish. Aquat. Sci.*, **42:** (5) 952-962.

Estatpesca (2000) Boletim estatistico da pesca maritima do nordeste do Brasil. 139 pp.

Ferreira, B.P. (2000) Reef fishes and fisheries in Brazil's coral coast MPA: management perspectives. Proc.9^{th} *International Coral Reef Symposium. World coral reefs in the millenium: bridging research and management for sustainable development*, Bali, 162.

Ferreira, B.P., Cava, F.C. and Ferraz, A.N. (1998) Relações Morfométricas em Peixes Recifais na Zona Econômica Exclusiva. *Bol. Téc. Cient. CEPENE*, **6:** (1) 61-76.

Ferreira, B.P. and Maida, M. (2001) Fishing and the future of Brazil´s northeastern reefs. *InterCoast*, **38:** 22-23.

Ferreira, B.P., Maida, M. and Cava, F.C. (2001) Características e perspectivas para o manejo da pesca na APA Marinha Costa dos Corais. Proc.*II Congresso Brasileiro de unidades de Conservação*, Campo Grande, MS, 50-58.

Gaston, K.J., Blackburn, T.M. and Lawton, J.H. (1993) Comparing animals and automobiles: a vehicle for understanding body size and abundance relationships in species assemblages? *Oikos*, **66:** (1) 172-179.

Gobert, B. (1994) Size structures of demersal catches in a multispecies multigear tropical fishery. *Fish. Res.*, **19:** 87-104.

Grimes, C.B. (1987) Reproductive biology of the Lutjanidae: a review. *In Tropical snappers and groupers: biology and fisheries management.* J.J. Polovina & S. Ralston (eds.), Westview press, Boulder, USA, 271-294.

Grutter, A.S. (2000) Ontogenetic variation in the diet of the cleaner fish *Labroides dimidiatus* and its ecological consequences. *Mar. Ecol. Prog. Ser.*, **197:** 241-246.

Hilborn, R. and Walters, C.J. (1992) *Quantitative fisheries stock assessment: choice, dynamics and uncertainty.* Chapman and Hall, New York, 570 pp.

Jennings, S., Kaiser, M.J. and Reynolds, J.D. (2001) *Marine fisheries ecology.* Blackwell Science Ltd, Oxford, 417 pp.

Jennings, S. and Polunin, N.V.C. (1995) Comparative size and composition of yield from 6 Fijian reef fisheries. *J. Fish Biol.*, **46:** (1) 28-46.

Kramer, D.L. and Chapman, M.R. (1999) Implication of fish home range size and relocation for marine reserve function. *Env. Biol. Fishes*, **55:** 65-79.

Kulbicki, M., Labrosse, P. and Letourneur, Y. (2000) Fish stock assessment of the northern New Caledonian lagoons: 2 - Stocks of lagoon bottom and reef-associated fishes. *Aquat. Living. Res.*, **13:** (2) 77-90.

Labrosse, P., Letourneur, Y., Kulbicki, M. and Paddon, J.R. (2000) Fish stock assessment of the northern New Caledonian lagoons: 3 - Fishing pressure, potential yields and impact on management options. *Aquat. Living. Res.*, **13:** (2) 91-98.

Letourneur, Y., Kulbicki, M. and Labrosse, P. (2000) Fish stock assessment of the northern New Caledonian lagoons: 1 - Structure and stocks of coral reef fish communities. *Aquat. Living. Res.*, **13:** (2) 65-76.

Longhurst, A. and Pauly, D. (1987) *Ecology of tropical oceans.* Academic Press, San Diego, California, 407 pp.

Lucena, F.M., O'Brien, C.M. and Reis, E.G. (2002) Effect of exploitation of the bluefish *Pomatamus saltatrix* by two competing fleets in southern Brazil: An application of a catch-at-age model. *Mar. Freshwater Res.*, **53:** (5) 1-13.

Lukens, R.R. (1981) Observations of deep-reef ichthyofauna from the Bahamas and Cayman Islands, with notes on relative abundance and depth distribution. *Gulf Res. Rep.*, **7:** (1) 79-81.

Mabesoone, J.M. and Coutinho, P.N. (1970) Littoral and shallow marine geology of northern and northeastern Brazil. *Trab. Oceanogr. UFPE*, **12:** 1-224.

Machias, A., Somarakis, S. and Tsimenides, N. (1998) Bathymetric distribution and movements of red mullet *Mullus surmuletus*. *Mar. Ecol. Prog. Ser.*, **166:** 247-257.

MacPherson, E. (1998) Ontogenetic shifts in habitat use and aggregation in juvenile sparid fishes. *J. Exp. Mar. Biol. Ecol.*, **220:** (1) 127-150.

MacPherson, E. and Duarte, C.M. (1991) Bathymetric trends in demersal fish size - Is there a general relationship? *Mar. Ecol. Prog. Ser.*, **71:** (2) 103-112.

Maida, M. and Ferreira, B.P. (1997) Coral Reefs of Brazil: Overview and Field Guide. Proc.*8th International Coral Reef Symposium*, Panama, 263-274.

Manooch, C.S. (1987) Age and growth of snappers and groupers. *In Tropical snappers and groupers: biology and fisheries management.* J.J. Polovina & S. Ralston, eds., Westview press, Boulder, USA, 329-406.

Oliveira, V.S. (2000) Distribuição e abundancia relativa de peixes dermersais capturados com espinhel de fundo na plataforma externa e talude continental da costa nordeste do Brasil. MSc Thesis, Universidade Federal de Pernambuco, 86 pp.

Pikitch, E.K. (1988) Objectives for biologically and technically interrelated fisheries. *In Fisheries science and management: Objectives and limitations.* W.S. Wooster (ed.) New York, 28, 107-136.

Polovina, J.J. and Ralston, S. (1987) *Tropical snappers and groupers: biology and fisheries management.* Westview press, Boulder, USA, 659 pp.

Polunin, N.V.C. and Roberts, C.M. (1996) *Reef fisheries.* Chapman and Hall, London, 477 pp.

Rex, M.A. and Etter, R.J. (1998) Bathymetric patterns of body size: implications for deep-sea biodiversity. *Deep-Sea Research Part II -Topical Studies in Oceanography*, **45:** (1-3) 103-127.

Roberts, C.M. (1996) Settlement and beyond: population regulation and community structure of reef fishes. *In Reef fisheries.* N.V.C. Polunin & C.M. Roberts (eds.), Chapman and Hall, London, 20, 85-112.

Rooker, J.R. (1995) Feeding ecology of the schoolmaster snapper, *Lutjanus apodus* (Walbaum), from southwestern Puerto Rico. *Bull. Mar. Sci.*, **56:** (3) 881-894.

Sale, P.F. (1980) The ecology of fishes on coral reefs. *Oceanogr. Mar. Biol. Ann. Rev.*, **18:** 367-421.

Santos, S. (2001) Caracteristicas da pesca no nordeste, utilizando analise multivariada. MSc Thesis, Universidade Federal Rural Pernambuco, 77 pp.

Sogard, S.M. (1997) Size selective mortality in the juvenile stages of teleosts fishes: a review. *Bull. Mar. Sci.*, **37:** 1129-1157.

Sokal, R.R. and Rohlf, F.J. (1995) *Biometry.* Freeman and Co., New York, 850 pp.

St-John, J. (1999) Ontogenetic changes in the diet of the coral reef grouper *Plectropomus leopardus* (Serranidae): patterns in taxa, size and habitat of prey. *Mar. Ecol. Prog. Ser.*, **180:** 233-246.

Uiblein, F. (1991) Ontogenic shifts in resource use and shoaling tendency related to body size in Red Sea goatfish (*Parupeneus forsskali*, Mullidae). *Mar. Ecol. Pubbl. Stn. Zool. Napoli*, **12:** (2) 153-161.

A PESCA DE LUTJANÍDEOS NO NORDESTE DO BRASIL: HISTÓRICO DAS PESCARIAS, CARACTERÍSTICAS DAS ESPÉCIES E RELEVÂNCIA PARA O MANEJO⋆

Sérgio Magalhães Rezende [1]
Beatrice Padovani Ferreira[1]
Fredou Thierry[1]

RESUMO

A estatística oficial da captura de recursos pesqueiros demersais no Nordeste do Brasil foi realizada no período de 1967 a 2000 por três instituições governamentais, a saber: Superintendência de Desenvolvimento da Pesca - SUDEPE, Instituto Brasileiro de Geografia e Estatística – IBGE e Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis - IBAMA. Os dados apresentados por estas instituições mostram um cenário em que durante a década de 60 a pesca das espécies da família Lutjanidae é dominada pelo pargo, *Lutjanus purpureus* Poey, espécie mais importante dentre os peixes demersais capturados. A situação atual indica que 12 espécies do gênero *Lutjanus* são exploradas pela pesca na costa nordeste. Os desembarques de Lutjanídeos são registrados nas estatísticas oficiais nas categorias multi-específicas a exemplo da categoria “pargo” que agrega cinco espécies. À exceção do estado da Bahia (BA), onde o “pargo” nunca foi um recurso significativo, esta categoria dominou as capturas de peixes nos estados do Ceará (CE), Rio Grande do Norte (RN) e Pernambuco (PE) até a década de 70. Em Pernambuco a “cioba”, *Lutjanus analis* (Cuvier) passou a ser a principal espécie capturada na década de 80, seguida pela “guaiúba”, *L. chrysurus* (Bloch), “dentão”, *L. jocu,* (Bloch & Schneider) e

---

⋆ Trabalho apoiado pelo Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, Comissão Interministerial para os Recursos do Mar – CIRM e Ministério do Meio Ambiente e da Amozônia Legal – MMA.

[1] Pesquisadores do Departamento de Oceanografia, Universidade Federal de Pernambuco.

“ariacó”, *L. synagris* (Linnaeus). No Rio Grande do Norte a “guaiúba” passou a aumentar sua participação nas capturas também na década de 80 e, atualmente, estas quatro espécies (*L. chrysurus*, *L. jocu, L. synagris*”, *L. analis)* ocorrem na mesma proporção. No Ceará, onde as capturas de “pargo” se mantiveram como as mais importantes por um período mais longo que nos demais estados, se tem observado na última década a crescente participação da guaiúba e do ariacó. De acordo com resultados obtidos como parte do programa REVIZEE/NE os parâmetros de idade e crescimento para estas espécies indicam crescimento lento **(K<0,2)** e longevidade média a alta (20 a 30 anos). Estas características tornam estas espécies altamente vulneráveis a sobrepesca, o que indica a necessidade de criação de programas de manejo voltados para o grupo.
Palavras-chave: Pesca, Lutjanídeos, Nordeste.

____

ABSTRACT

From 1967 to 2000 records of landings of demersal fisheries were recorded by three governmental agencies:: Superintendência de Desenvolvimento da Pesca - SUDEPE, Instituto Brasileiro de Geografia e Estatística – IBGE and Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis - IBAMA. Catches of snappers (Lutjanidae) were dominated by the pargo *Lutjanus purpureus* Poey, during the 60´s. Nowadays, 12 species of the genera *Lutjanus* are exploited by demersal fisheries in the North-eastern coast. Landing records aggregate species in multiespecific categories, as with the “pargo” category, composed by five different species. Until the 70´s, this category was the most important for most states, with the exception of Bahia state. In Pernambuco state the mutton snapper or “cioba”, *Lutjanus analis* (Cuvier) became the most representative species in the 80´s, followed by the yellowtail snapper or “guaiúba”, *L. chrysurus* (Bloch), the dog snapper or “dentão”, *L. jocu,* (Blocch & Schneider) and the lane snapper or “ariacó”, *L. synagris* (Linnaeus). In the Rio Grande do Norte state “guaiúba” landings increased in the 80´s and nowadays the four species (*L. chrysurus*, *L. jocu, L. synagris*”, *L. analis)* are equally represented. In Ceará state, where pargo

landings remained higher for a longer period, “guaiúba” and “ariacó” landings have also increased in the last decades. According with the results of the REVIZEE/NE program, the age and growth parameters for these species indicate slow growth and **(K<0,2)** and medium to high longevity (20 to 30 years). These characteristics make these species vulnerable to over fishing, what indicates the need to develop fisheries management programs for the group.
Key words: Fisheries, Lutjanids, North-eastern Brazilian Coast.

INTRODUÇÃO

A família Lutjanidae, pertence à ordem Perciforme, a mais diversificada entre todas as ordens de peixes e também a ordem com maior número de espécies entre os vertebrados (Nelson, 1997). Esta família é considerada como importante recurso pesqueiro em toda sua área de ocorrência (Fischer, 1978; Ralston & Myamotu 1983; Polovina & Ralston, 1987; Ralston & Williams 1989; Morales-Nin & Ralston, 1990; Haitght *et al.*, 1993; Roberts & Polunin, 1996).

A exploração comercial dos Lutjanídeos na costa ocidental do oceano Atlântico teve início em 1800 na América Central (insular e continental) e sul dos EUA. Somente um século mais tarde se iniciava a exploração recreacional deste grupo na América Central, que é tradicionalmente capturado com linha e anzol de fundo (Polovina & Ralston, 1987).

Espécies de peixes demersais da familia Lutjanidae vêm sendo exploradas pela pesca comercial na costa norte/nordeste do Brasil desde a introdução das linhas pargueiras pelos portugueses durante os anos 50 e 60, com o propósito de diversificar as pescarias de atum e lagosta que já se encontravam em declínio. No início dos anos 60 foram realizados com sucesso algumas pescarias na costa dos estados do Maranhão, Piauí e Ceará e, também nos bancos oceânicos do Ceará, Caiçaras e Atol das Rocas (Fonteles-Filho, 1969). O ano de 1961 pode ser considerado como o ano em que teve início efetivamente a pesca comercial dos estoques da família Lutjanidae, que passou por períodos de elevada produção com tendência de declínio a partir do final dos anos 80 (Ivo & Sousa, 1988; Ximenes & Fonteles-Filho, 1988).

Atualmente, a pesca de pargo evoluiu para a estratificação e diversificação ao longo de toda a costa norte e nordeste, se estendendo até o sul da Bahia, contribuindo significativamente nos desembarques controlados destas regiões (Ferreira *et al.*, 2001; IBAMA-ESTATPESCA 2001).

Nos dias de hoje, manejar e projetar os rendimentos destas diferentes pescarias é o desafio mais relevante na preservação da diversidade dos estoques e, sobretudo, da atividade pesqueira que além de sua relevância cultural representa o principal sustento de muitas populações costeiras nas regiões onde os peixes demersais ocorrem.

O presente trabalho analisa, sob esta perspectiva, a evolução da pesca de Lutjanídeos na região nordeste do Brasil e a importância da existência de dados oficiais de qualidade como ferramenta para o desenvolvimento de estratégias de manejo dos recursos pesqueiros.

METODOLOGIA

Dados oficiais das capturas de recursos pesqueiros na região Nordeste do Brasil foram publicados, nas últimas quatro décadas, por três diferentes instituições governamentais federais, a saber: Superintendência de Desenvolvimento da Pesca - SUDEPE, Instituto Brasileiro de Geografia e Estatística – IBGE e Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis - IBAMA. Para as análises as espécies capturadas foram agrupadas em categorias, com registro da produção em toneladas.

Ao longo de sete anos, de agosto de 1996 a junho de 2003, o projeto "Biologia e Dinâmica Populacional de Peixes Recifais" foi executado como parte integrante do Programa de Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva - Região Nordeste (REVIZEE/NE). O mencionado projeto teve como objetivo estudar a dinâmica das populações de peixes recifais da família Lutjanidae na costa nordeste do Brasil, tendo em vista fornecer subsídios para o manejo da pesca de espécies desta família.

Os dados aqui utilizados para análise da composição específica da captura foram provenientes de amostragens biométricas realizadas pelo Programa REVIZEE/NE durante os desembarques da frota artesanal e comercial nos estados de Ceará, Rio Grande do Norte, Pernambuco e Bahia, entre os anos de 1997 e 2000. No total foram amostrados 33.824 peixes pertencentes a 12 espécies da família Lutjanidae. Destes peixes amostrados foram obtidos os comprimentos totais, furcais e padrões, além de pesos eviscerados. Peso total e determinação do sexo foram obtidos somente quando os exemplares encontravam-se não eviscerados.

A partir das categorias de pescado denominadas pelo Programa IBAMA-ESTAPESCA (pargo, cioba, guaiúba, ariocó, dentão) e seus equivalentes nomes científicos identificados pelo Programa REVIZEE/NE, foi calculada a biomassa tanto para as categorias de pescado como também por espécie separadamente, através dos pesos obtidos nas amostragens, e da transformação do comprimento em peso através da relação de peso e comprimentos calculados para cada uma das espécies.

A percentagem relativa para cada uma das espécies foi obtida a partir da biomassa total amostrada para cada espécie.

RESULTADOS E DISCUSSÃO

Atualmente, os Lutjanídeos, vulgarmente conhecidos como vermelhos, continuam sendo capturados desde águas costeiras até a plataforma externa, bancos e ilhas oceânicas do Nordeste (Ferreira *et al.*, 1997), contribuindo com 12,5% dos desembarques totais controlados nos estados do Ceará, Pernambuco e Rio Grande do Norte (IBAMA-ESTATPESCA, 2001).

As espécies do grupo estão entre as categorias de pescado mais valiosas no mercado, sendo consideradas como peixe de primeira qualidade em todos os estados.

A estatística oficial dos desembarques controlados no Nordeste registra as capturas de Lutjanídeos, e também mostra a alta diversidade da comunidade de peixes demersais tropicais, a exemplo da categoria “pargo” que nos estados do

Ceará, Rio Grande do Norte e pernambuco é composta de cinco espécies. As tabelas 1 e 2 apresentam a correspondência entre as categorias e nomes científicos das espécies contidas em cada uma para os estados do Nordeste. O gênero *Lutjanus* participa com oito categorias que correspondem a 12 espécies nas capturas controladas dos estados nordestinos Devido a variações nas denominações regionais, somente Ceará, Pernambuco e Rio Grande do Norte apresentam a mesma correspondência entre categorias de pescado e espécies.

Tabela 1 - Correspondência entre os nomes vulgar e nome científico para as categorias de pescado do gênero *Lutjanus*.

Nome vulgar	Nome científico
Ariacó	*Lutjanus synagris*
Carapitanga	*Lutjanus apodus*
Baúna	*Lutjnaus griseus*
Caranha	*Lutjanus cyanopterus*
Cioba	*Lutjanus analis*
Dentão	*Lutjanus jocu*
Guaiúba	*Lutjanus chrysurus*
Pargo verdadeiro	*Lutjanus purpureus*
Pargo olho de vidro	*Lutjanus vivanus*
Pargo boca negra	*Lutjanus bucanella*
Pargo mariquita	*Etelis oculatus*
Pargo piranga	*Rhomboplites aurorubens*

Tabela 2 - Correspondência entre as categorias de pescado e nome científico de suas respectivas espécies em estados da região Nordeste do Brasil.

Estado	Categoria de pescado	Nome científico
Alagoas	Vermelhos	*Etelis oculatus* *Lutjanus analis* *L. bucanella* *L. chrysurus* *L. jocu* *L. purpureus* *L. vivanus* *L. synagris* *Rhomboplites aurorubens*
Ceará	Pargo	*L. purpureus*, *L vivanus*, *L. bucanella*, *E. oculatus* e *R. aurorubens*
	Ariacó	*L. synagris*
	Cioba	*L analis*
	Dentão	*L. jocu*
	Guaiúba	*L. chrysurus*
	Vermelhos	Outras espécies de Lutjanideos e Serranideos
Pernambuco e Rio Grande do Norte	Pargo	*L. purpureus*, *L vivanus*, *L. bucanella*, *E. oculatus* e *R. aurorubens*
	Cioba	*L. analis*
	Dentão	*L. jocu*
	Guaiúba	*L. chrysurus*
	Ariacó	*L. synagris*

Análises das estatísticas oficiais mostram que as capturas de Lutjanídeos entre 1967 e 1969 não foram expressivas. Após 1973, no entanto, com aumento do esforço pesqueiro sobre estes estoques as capturas cresceram significativamente até 1976 (Ivo & Hanson, 1982). No caso específico do pargo, a produção começou a declinar a partir de 1979 e em 1982 já mostrava indícios de sobrepesca, com diminuição do comprimento médio e aumento da participação do estoque jovem nas capturas (Ivo & Hanson, 1982; Ximenes & Fonteles-Filho 1988).

No Ceará e Rio Grande do Norte a categoria “pargo” mostrou-se sempre como um o recurso pesqueiro importante ao longo de todo o período analisado, com altas produções até 1990. A partir deste ano as capturas passaram a decrescer até o ano de 1990 (Figura 1).

No caso do Ceará, a pesca do pargo mostrou aumento contínuo da produção desde a década de 70 até 1981, quando atingiu 6.617 t. A partir de 1977 pode-se observar a participação de outras espécies nas capturas como o dentão, *Lutjnaus jocu*, a guaiúba, *L. chrysurus*, a cioba, *L analis* e o ariacó, *L. synagris*. A partir de 1981 se observa uma mudança na composição dos desembarques no estado do Ceará; e, ao mesmo tempo em que ocorre uma redução nos índices de produtividade do “pargo”, as demais espécies adquirem maior importância nos desembarques. As espécies mais representativas nas capturas de 2001, no estado do Ceará, foram guaiúba, com 1.346 t, pargo, com 926 t, ariacó, com 618 t, cioba, com 118 t, e dentão, com 79,4 t (Figura 1).

O pargo continua como o segundo recurso mais importante no estado do Ceará, mas as estatísticas provavelmente incluem capturas desta espécie efetuadas pela frota nordestina que se concentra e opera na região Norte, na plataforma continental dos estados do Pará e Amapá (Souza, 2000).

No estado do Rio Grande do Norte, durante o período de 1967 a 1979, a categoria “pargo” foi dominante nas capturas, embora não tenha apresentado um padrão de aumento continuado como no caso do Ceará. A maior captura registrada foi no ano de 1977, com 701 t. A partir deste ano até 1989 as capturas de pargo foram reduzidas e não ultrapassaram 100 t nos últimos sete anos, com a categoria pargo contribuindo com 65,.5 t em 2001 (Figura 1).

No período entre 1967 e 1977, as capturas de cioba foram tão expressivas no estado do Rio Grande do Norte quanto às do pargo, embora tenham apresentado oscilações para maior nos anos de 1972, 1974 e 1975. Em 1976, apenas a cioba apareceu nas estatísticas, com 552 t, mas no ano seguinte, as capturas tanto de pargo (701 t) como de cioba (384 t) foram expressivas. A partir de 1978 a guaiúba passa a ser registrada nas capturas do estado do Rio Grande do Norte e desde então tem sido a espécie com maior produção. Nos últimos sete anos tem sido registradas as capturas da cioba, do ariacó e do dentão, cujas produções para o ano de 2001 foram, respectivamente, 300,1 t, 163,7 t, 176,0 t e 32,3 t (Figura 1).

O volume de captura anual do "pargo" no estado de Pernambuco nos últimos 30 anos não chegou a ultrapassar 1.000 t, como ocorreu nos anos de 1967 e 1968, quando a categoria "pargo" contribuiu isoladamente com 1.500 e 3.500 t, respectivamente. Ao contrário, o desembarque desse grupo atingiu penas 4,0 t em 2001. Entre 1972 e 1978 ainda ocorreram capturas de pargo como grupo dominante, mas não ultrapassando as 500 t, o que representa apenas 50% do valor obtido quando da introdução da pesca de linha de fundo no Brasil (Figura 1).

A partir da década de 80 a categoria pargo, no estado de Pernambuco, já estava comercialmente extinta. A participação dos outros estoques nas capturas começou em 1978; quando foram registradas as seguintes produções por categoria: "ariacó (149,0 t), "cioba" (110,7 t), "guaiúba" (37.1 t) e "dentão" (9,5 t).

O estado da Bahia, por outro lado, mostra um aumento continuado das capturas de Lutjanídeos ao longo desta série histórica, sendo que a categoria mais importante de 1969 a 1977 foi a "cioba" que, neste último ano alcançou 780 t. De 1978 em diante "guaiúba" tem sido a principal categoria nas capturas, partindo de 200 t em 1978 e chegando a 1.350 t em 1997. Segue-se a "cioba" o "ariacó" e o "dentão", que ainda participam nas capturas, mas com baixa representatividade (Figura 1).

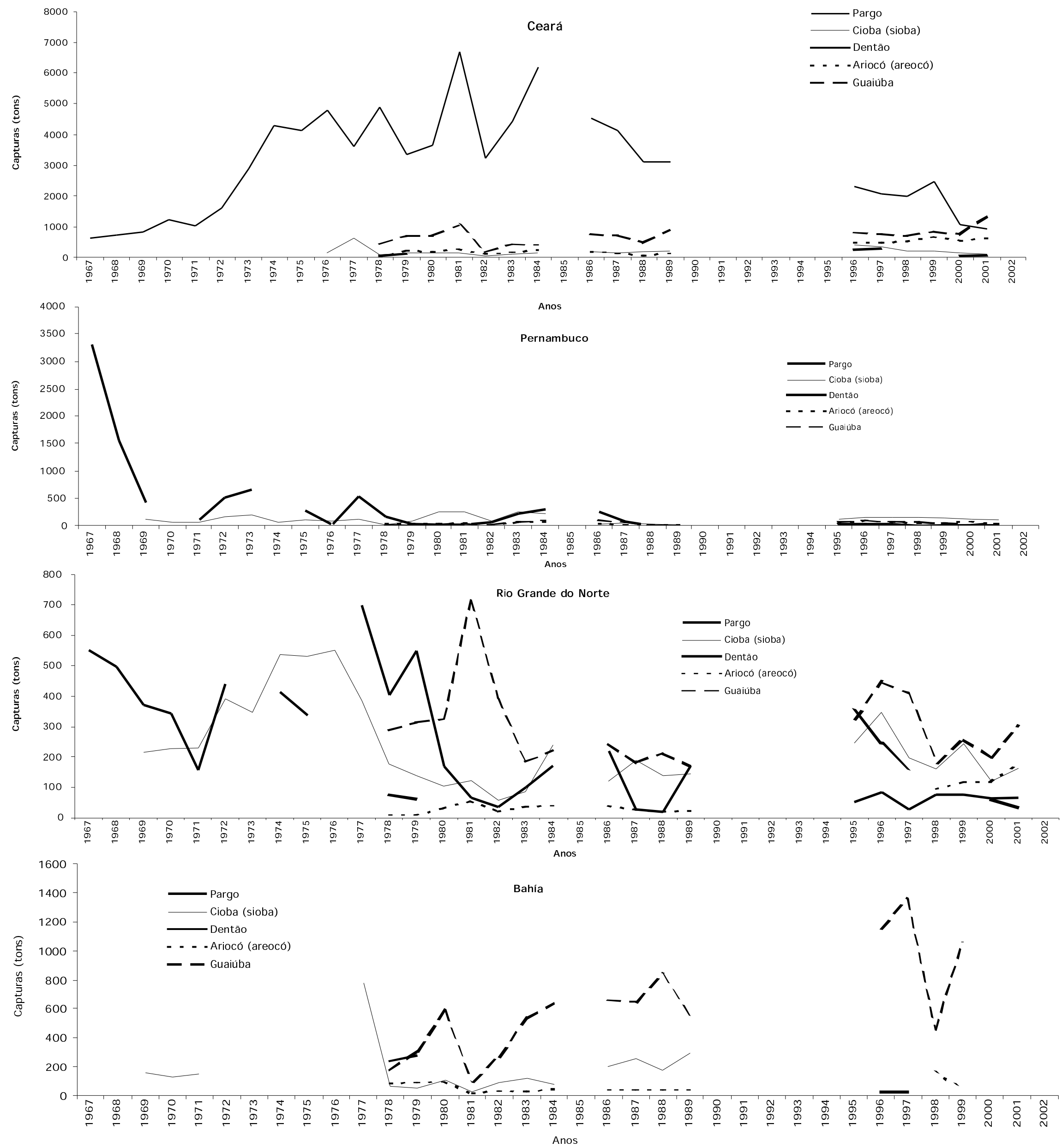


Figura 1: Produção pesqueira (tons) dos estados de CE, PE, RN e BA para as categorias de pescado pargo, cioba, dentão, guaiúba e ariacó repectivamente, entre o período de 1967 a 2001.

De acordo com dados do programa REVIZE/NE (Tabela 3), os valores da participação das cinco espécies que compõem a categoria "pargo" (2,7 t, 33.824 indivíduos amostrados) na biomassa amostrada são os seguintes; *Lutjanus vivanus,* a mais representativa da categoria, com 50,7% (1,37 t, 2.505 indivíduos amostrados), *Rhomboplites aurorubens*, como a segunda espécie em importância dentro da categoria, com 16,9% (0,457 t, 1.296 indivíduos amostrados); *Lutjanus purpureus* com 16,67% (0,447 t, 470 indivíduos amostrados).

Tabela 3: Correspondência entre os dados das capturas oficiais (tons) pelo Programa IBAMA-ESTATPESCA e biomassa amostrada (tons) pelo programa REVIZEE/NE.

*Categoria de pescado (IBAMA)	*Captura total (tons*ano^{-1}) por estado IBAMA 2001	*Captura total (tons*ano^{-1}) por categoria IBAMA 2001	**Espécies de Lutjanídeos amostrados no REVIZEE/NE	**Biomassa total (tons) amostrada por espécie pelo REVIZE/NE	Biomassa amostrada pelo REVIZE/NE por categoria de pescado (tons)	**Porcentagem relativa da biomassa total (tons) amostrada por espécie
Pargo	**CE- 926.1** **PE- 4.0** **RN- 65.5**	995.6	***L. purpureus***	0.447	2.7	16.67%
			L vivanus	1.374		50.7%
			L. bucanella	0.197		7.3%
			E. oculatus	0.214		7.9%
			R. aurorubens	0.457		16.9%
Cioba	**CE- 118.8** **PE- 110.7** **RN- 163.7**	393.2	***L. analis***	9.24	9.24	100%
Dentão	**CE- 79.4** **PE- 9.5** **RN- 32.3**	121.2	***L. jocu***	9.13	9.13	100%
Guaiúba	**CE- 1346.0** **PE- 37.1** **RN- 300.1**	1683.2	***L. chrysurus***	7.97	7.97	100%
Ariocó	**CE- 618.4** **PE- 149.0** **RN- 176.2**	943.6	***L. synagris***	1.27	1.27	100%

*Dados obtidos das estatísticas pesqueiras do Programa IBAMA-ESTATPESCA 2001.

**Dados obtidos das amostragens de biometria do Programa REVIZEE/NE.

Em pescarias multi-específicas, como a com linha de fundo que ocorre no Nordeste Brasil, existe a tendência de que espécies menos produtivas, ou que necessitam de tempo considerável para serem recompostas, tenham suas populações gradativamente reduzidas e sejam substituídas nas capturas por espécies mais produtivas, e que apresentam maior capacidade de recompor as populações (Larkin, 1977). É provável, no entanto, que a evolução da composição específica das capturas de Lutjanideos no Nordeste se deva ao deslocamento da frota para novas áreas de pesca. O declínio da pesca do pargo nos bancos oceânicos levou a frota a se deslocar para áreas de plataforma e talude continental no final da década de 70 e hoje a frota atua em duas áreas de pesca diferentes ao largo da costa dos estados do Pará e Amapá, com uma ampla variedade de artes de pesca como linha pargueira com bicicleta, caíque, covo, espinhel "long-line" e rede. Dois estoques pertencentes a uma mesma população são explorados, sendo que um destes apresenta poucos indivíduos em estágio final de maturação, indicando a existência de áreas de desova diferentes das áreas de pesca (Souza, 2000; Salles, 2000). Desde então, outras espécies que não ocorrem nos bancos e ilhas oceânicas, como *Lutjanus analis*, *L. chrysurus* e *L synagris* passaram a ser registradas pelas estatísticas oficiais, mas provavelmente já eram exploradas anteriormente por uma frota essencialmente artesanal. Segundo Silva (1970), na composição específica dos desembarques da frota de jangadas amostrada em seu estudo, na localidade do Pina em Recife-PE, os Lutjanídeos foram agrupados na categoria denominada Cioba e afins.

Aparentemente, estoques de pargo *L. purpureus* concentram-se em áreas específicas, como bancos oceânicos e pontos de quebra da plataforma continental (Fonteles-Filho & Ferreira 1987), sustentando assim maiores capturas porém por um intervalo de tempo menor. Estoques concentrados em feições topográficas restritas, como em montanhas oceânicas, tendem ao colapso rápido, geralmente após 10 anos de pescarias (Koslow *et al*., 2000).

O cenário da pesca dos Lutjanídeos para os estados do Nordeste indica uma tendência decrescente, mas as atuais análises são limitadas pela qualidade e confiabilidade das estatísticas oficiais consideradas.

Os principais problemas que a estatística pesqueira nacional tem sofrido, e com ela os pesquisadores da pesca, são: (a) descontinuidade da coleta de dados confiáveis; (b) falta de padronização e correspondência entre os estados quanto aos nomes das categorias de pescado e espécies equivalentes; (c) falta de padronização na metodologia de cálculo entre os estados; (d) tratamento dos dados de forma multi-específica para as categorias de pescado. Além disso, a publicação de dados repetidos nos anos de 1990 a 1995 e a diferenças na metodologia aplicada pela BAHIAPESCA e o ESTATPESCA interromperam a seqüência histórica além de impossibilitar comparações entre regiões ou estados. Outro problema é o fato de que os dados são relativos apenas à produção, o que limita as observações das tendências da pesca que devem ter incorporado variações significativas do esforço de pesca no período analisado (Rezende & Ferreira, 2000).

Em praticamente todo o período analisado, o estado do Ceará foi o que apresentou as maiores capturas de Lutjanídeos. Nos estados de Pernambuco e Rio Grande do Norte esses recursos pesqueiros encontram-se praticamente comercialmente extintos, o que passa a exigir a tomada de um elenco de ações corretivas. O estado que apresenta uma situação aparentemente otimista é a Bahia, embora as capturas se concentrem na guaiúba e ariacó.

Entre os diferentes recursos pesqueiros discriminados pelas estatísticas pesqueiras para a região Nordeste, no período analisado, apenas as lagostas e pargo têm sido inseridos em Grupos Permanentes de Estudo (GPE), gerando desta forma informações mais detalhadas sobre produção, esforço de pesca e captura por unidade de esforço (CPUE). Adotado desde a década de 70, o GPE do pargo tem-se dedicado a definir e executar o regulamento da pesca desta espécie através do estabelecimento de um tamanho mínimo de captura em função da maturidade sexual.

Indícios de sobrepesca sobre o comprimento médio populacional e sobre o tamanho de primeira reprodução já foram relatados para o "pargo".

A participação de cinco espécies diferentes nas capturas da categoria "pargo", sem o registro oficial para estas espécies separadamente, impossibilita quaisquer avaliações de estoque mais confiáveis. Bons programas de obtenção de dados estatísticos pesqueiros das capturas e oficialmente publicados são de grande valia para a aplicação com sucesso de modelos de produção e rendimento pesqueiro, dando segurança para a tomada de decisões de manejo sustentável das pescarias.

Recentemente, a American Fisheries Society reconheceu que os Lutjanídeos devem ser submetidos a um sistema gerencial preventivo de modo a se evitar situações de sobrepesca e colapso dos estoques (Coleman *et al*., 2000). Esta recomendação se baseou na constatação de que as espécies dos gêneros *Etelis, Lutjanus* e *Rhomboplites* são reconhecidas como de grande longevidade e crescimento lento (Polovina & Ralston 1987) e, portanto, seus estoques não suportam níveis de mortalidade por pesca muito mais elevados que os níveis da mortalidade natural. Resultados de estudos sobre idade, crescimento e mortalidade das cinco espécies de Lutjanídeos mais importantes na Zona Econômica Exclusiva da costa nordeste do Brasil confirmam as características citadas para as espécies destes gêneros (Programa REVIZEE/NE, 2003).

Concluindo, a criação de um grupo específico de estudos e uma política de obtenção de estatísticas pesqueiras de qualidade são medidas altamente recomendáveis como forma de garantir o uso sustentável dos recursos pesqueiros da região Nordeste do Brasil.

BIBLIOGRAFIA CONSULTADA

ALEGRIA Jr., C.; Menezes, M.F. Edad y crecimiento del ariacó, *Lutjanus synagris* (Linnaeus), en el Nordeste del Brasil. **Arq. Ciên. Mar**, Fortaleza, v. 10, n, 1, p. 65-68, 1970.

CAVA, F.C.; FERRAZ, A.N.A.; TEIXEIRA S.F., RODRIGUES, M.C. Dinâmica populacional de peixes recifais na Zona Econômica Exclusiva brasileira, região Nordeste, com ênfase na família Lutjanidae. Parte II. **Resumos do II Workshop REVIZEE/ NORDESTE**, Genipabu, p. 49, 1998.

COLEMAM, F.C.; KOENIG, C.C.; HUNTSMAN, G.A.; MUSICK, J.A.; EKLUND, A. M; MCGOVERN, J.C.; CHAPMAN, R.W.; SEDBERRY, G.R.; GRIMES, C.B**.** **Long-lived reef fishes: the grouper-snapper complex**, 2000.

DUARTE, Y.F.; CAVA, FC.; FERRAZ, A.N.A.; TEIXEIRA, S.F.; REZENDE, S.M. 1998. Dinâmica populacional de peixes recifais na Zona Econômica Exclusiva brasileira, região Nordeste, com ênfase na família Lutjanidae. Parte **I. Resumos do II Workshop REVIZEE/ NE,** Genipabu, p. 48, 1998.

FISHER, W. FAO Species Identification Sheets for Fishery Purposes. Western Central Atlantic (Fishing Area 31). **FAO Fisheries Department,** Rome 1978**.**

FERREIRA, B.P.; REZENDE, S.M.; TEIXEIRA, S.F.; FERRAZ, A.N.A.; CAVA, F.C.; 1997. Peixes recifais na Zona Econômica Exclusiva brasileira, região Nordeste. **Resumos VII COLACMAR**, 305 p., Santos, 1997.

FONTELES-FILHO, A.A. Estudo preliminar sobre a pesca do pargo, *Lutjanus purpureus* Poey, no Nordeste brasileiro. **Arq. Ciên. Mar**, Fortaleza, v. 9, n.1, p. 83-88, 1969.

FONTELES-FILHO, A.A.; FERREIRA, F.T.P. Distribuição geográfica das capturas do pargo, *Lutjanus purpureus* Poey, e sua relação com fatores oceanográficos nas regiões Norte e Nordeste do Brasil. **Bol. Ciên. Mar**, Fortaleza, n.45, p.1-23, 1987.

HAIGHT, W.R.; PARRISH, J.D.; HAYES, T.A. Feeding ecology of deepwater lutjanid snappers at Penguin Bank, Hawaii. **Trans. Amer. Fish. Soc**., v. 122, p.328-347, 1993.

IBAMA-ESTATPESCA 2002

IVO C.T.C.; HANSON, A.J. Aspectos da biologia e dinâmica populacional do pargo, *Lutjanus purpureus* Poey, no Norte e Nordeste do Brasil**. Arq. Ciên. Mar**, Fortaleza, v. 22, p.1-14, 1982. .

IVO, C.T.C.; SOUSA, M.J.B. Sinopse de informações sobre o pargo, **Lutjanus purpureus** Poey (Piesces:Lutjanidae), no Norte e Nordeste do Brasil. **Arq. Ciên. Mar**, Fortaleza, v. 27, p. 57-67, 1988

KOSLOW, J.A., 2000. Fish stocks and benthos of seamounts, *in*. Thiel H.; Koslow J. A. (eds.), Managing risks to biodiversity and the environment on the high sea, including tools such as marine protected areas – scientific requirements and jegal aspects. **Proceedings of the Expert Workshop**, Isle of Vilm, 216 p., 2000.

LARKIN, P.A., 1977. An epitaph for the concept of maximum sustainable yield. **Trans. Amer. Fish. Soc.**, v.106, n.1, p.1-11, 1977.

LIMA, F.R. Crescimento do pargo (*Lutjanus aya* Bloch 1765): aspectos quantitativos. **Bol. Est. Pesca**, Recife, v.5, n.2, p.33-42, 1965.

MENEZES, M.F.; GESTEIRA, T.C.V. Idade e crescimento do pargo, *Lutjanus purpureus* Poey, do Norte e Nordeste **Brasileiros**. **Arq. Ciên. Mar**, Fortaleza, v.14, n.2, p.81-85, 1974.

MORALES-NIN, B.; RALSTON, S. Age and growth of *Lutjanus kasmira* (Forskål) in Hawiian waters. **J. Fish. Biol**., v.36, p.191-203, 1990.

NELSON, J., 1994. **Fishes of the world**. A Wiley-Interscience Publication. John Wiley & Sons, 523 p., New York, 1994.

POLOVINA, J.J.; RALSTON, S. **Tropical snappers and groupers: biology and fisheries management**. Westview Press, Oceans Resources and Marine Policy Series, 659 p., 1987

POLUNIN, N.V.C.; ROBERTS, C.M. **Reef fisheries**. Chapman & Hall, Fish and Fisheries Series 20, 477 p., 1996.

RALSTON, S.; MYAMOTU, G.T., 1983. Analyzing the width of daily otolith increments to age on the Hawaiian snapper, *Pristipomoides filamentosus*. **Fish. Bull**., v. 81, n. 3, p. 523-533, 1983.

RALSTON, S.; WILLIAMS, H.A. Numerical integration of daily growth increments: an efficient means of aging tropical fishes for stock assessement. **Fish. Bull.**, v.87, p.1-16, 1988.

REVIZEE/NE. Projeto Biologia e Dinâmica Populacional de Lutjanídeos na Zona Econômica Exclusiva, Região Nordeste. Resultados Finais, 2003.

REZENDE, S.M.; FERREIRA, B.P. 2000. Informe sobre a Pesca do pargo e Espécies afins no Estado de Pernambuco. Relatório da Reunião Técnica sobre o estado da Arte da Pesca de Pargo no Norte e Nordeste do Brasil. **GPE do Pargo IBAMA**, 2000.

SALLES R. M., 2000. Identificação dos Estoques de Pargo *Lutjanus purpureus* Poey nsa Regiões Nordeste e Norte do Brasil. Relatório da Reunião Técnica sobre o estado da Arte da Pesca de Pargo no Norte e Nordeste do Brasil. **GPE do Pargo IBAMA**.

SILVA, O.C., 1970. Estudos das pescarias dos botes à vela da praia do Pina (Recife, Brasil). Trab. Oceangr. UFPE 9/11: 305- 316. XIMENES M.O.C., Fonteles-Filho A.A., 1988. Estudo da Idade e Crescimento do Pargo, *Lutjanus purpureus* Poey (Pisces: LUTJANIDAE), no Norte e Nordesto do Brasil. **Arq. Ciên. Mar**., Fortaleza. 27: 69-81

SOUZA R F. C. 2000.. Relatório da Reunião Técnica sobre o estado da Arte da Pesca de Pargo no Norte e Nordeste do Brasil. **GPE do Pargo IBAMA**.

TEIXEIRA S. F., 1998. Aspectos Reprodutivos do sirigado *Mycteroperca bonaci* (Poey 1860) (Serranidae-Epinephelinae) do Nordeste do Brasil. Dissertação (Mestrado)-**Universidade Federal de Pernambuco**. CTG. Departamento de Oceanografia. 117Pp.

XIMENES M.O.C., FONTELES-FILHO A.A., 1988. Estudo da Idade e Crescimento do Pargo, *Lutjanus purpureus* Poey (Pisces: LUTJANIDAE), no Norte e Nordesto do Brasil. **Arq. Ciên. Mar**., Fortaleza. 27: 69-81.

Appendix 2 : Fleet categories of reef fisheries from Northeastern Brazil

From top to bottom ‘paquete’ (source : Projeto Recifes Costeiros), ‘jangada’ (source : Alexandre Ferraz), ‘Bote a vela’ (source : Alexandre Ferraz), ‘Bote motorizado’ (source Sergio Rezende)